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OFF-HIGHWAY GASOLINE CONSUMPTION ESTIMATION MODELS USED IN THE FEDERAL HIGHWAY ADMINISTRATION ATTRIBUTION AND PROCESS

2008 Updates

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LIST OF ACRONYMS

ATV	All Terrain Vehicle
CTA	Center for Transportation Analysis
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
GAO	Government Accounting Office
GSA	General Services Administration
HTF	Highway Trust Fund
IRS	Internal Revenue Service
LPG	Liquefied Petroleum Gases
MPG	Miles per Gallon
NASS	National Agricultural Statistics Services
NMMA	National Marine Manufacturers Association
ORNL	Oak Ridge National Laboratory
PSR	Power Systems Research
SCM	State, County, and Municipal
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle Miles Traveled

ABSTRACT

This report is designed to document the analysis process and estimation models currently used by the Federal Highway Administration (FHWA) to estimate the off-highway gasoline consumption and public sector fuel consumption. An overview of the entire FHWA attribution process is provided along with specifics related to the latest update (2008) on the Off-Highway Gasoline Use Model and the Public Use of Gasoline Model.

The Off-Highway Gasoline Use Model is made up of five individual modules, one for each of the off-highway categories: agricultural, industrial and commercial, construction, aviation, and marine. This 2008 update of the off-highway models was the second major update (the first model update was conducted during 2002-2003) after they were originally developed in mid-1990. The agricultural model methodology, specifically, underwent a significant revision because of changes in data availability since 2003. Some revision to the model was necessary due to removal of certain data elements used in the original estimation method. The revised agricultural model also made use of some newly available information, published by the data source agency in recent years.

The other model methodologies were not drastically changed, though many data elements were updated to improve the accuracy of these models. Note that components in the Public Use of Gasoline Model were not updated in 2008. A major challenge in updating estimation methods applied by the public-use model is that they would have to rely on significant new data collection efforts. In addition, due to resource limitation, several components of the models (both off-highway and public-us models) that utilized regression modeling approaches were not recalibrated under the 2008 study.

An investigation of the Environmental Protection Agency's NONROAD2005 model was also carried out under the 2008 model update. Results generated from the NONROAD2005 model were analyzed, examined, and compared, to the extent that is possible on the overall totals, to the current FHWA estimates. Because NONROAD2005 model was designed for emission estimation purposes (i.e., not for measuring fuel consumption), it covers different equipment populations from those the FHWA models were based on. Thus, a direct comparison generally was not possible in most sectors. As a result, NONROAD2005 data were not used in the 2008 update of the FHWA off-highway models.

The quality of fuel use estimates directly affect the data quality in many tables published in the *Highway Statistics*. Although updates have been made to the Off-Highway Gasoline Use Model and the Public Use Gasoline Model, some challenges remain due to aging model equations and discontinuation of data sources.

1. INTRODUCTION

1.1 BACKGROUND

The August 2005 *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* funds more than $14 billion annually to the states. The allocations to states are based on state-reported motor-fuel data and the results of a U.S. Department of Transportation (DOT) Federal Highway Administration (FHWA) Highway Trust Fund (HTF) attribution process. During the annual attribution process, the FHWA determines a state's share of the overall on-highway motor-fuel consumption and estimates amounts of the HTF receipts to be attributed to highway users in each state. This information is then used to distribute funds through the apportionment process for several major highway programs.

As a part of the attribution process (see Figure 1.1), the FHWA utilizes models to estimate portions of motor fuel use data. Specifically, estimation models are used in producing state-level consumption estimates for (1) off-highway use of gasoline; (2) federal, state, county, and municipal governments (i.e., public sector) use of gasoline; and (3) on-highway use of gasohol. These models, which were built using mathematical/statistical formulas and supplemental information from other information sources, are used to aid FHWA program analysts during the complicated and frequently lengthy attribution process. Because state-submitted data are not sufficient for the FHWA to accurately distribute HTF funds to the states, and to achieve uniformity and accuracy across the states in certain motor-fuel uses (e.g., off-highway gasoline uses) where states historically have been unable to provide actual and reliable data, the use of models is necessary.

The Center for Transportation Analysis (CTA) at the Oak Ridge National Laboratory (ORNL) developed models for the FHWA in the 1990's to estimate off-highway fuel consumption. A non-technical report[1] describing the methodologies and data sources of all these models was summarized by ORNL in early 2002. To further support the FHWA in its effort to better inform states on the attribution process, ORNL assisted the FHWA in conducting a Motor-Fuel Modeling Workshop in Alexandria, Virginia, in March 2002. The purposes of that Workshop were to provide state and FHWA field staff with an understanding of the various models that impacted state's data and HTF attribution and to obtain state inputs on these models and potential alternative data sources. As a result of that Workshop, the models used to estimate off-highway gasoline consumption were streamlined and updated by ORNL during 2002. The updated models were later built into an integrated system in September 2002 by ORNL. This system has been used by the FHWA in the attribution process since then.

[1] *Estimation Procedures in FHWA Attribution Process: A Sketch of the Current Models*, Ho-Ling Hwang, Center for Transportation Analysis, Oak Ridge National Laboratory, January 2002. This report is available under FHWA Highway Community Exchange "Community of Practice" (CoP) website (http://knowledge.fhwa.dot.gov/cops/hcx.nsf/home).

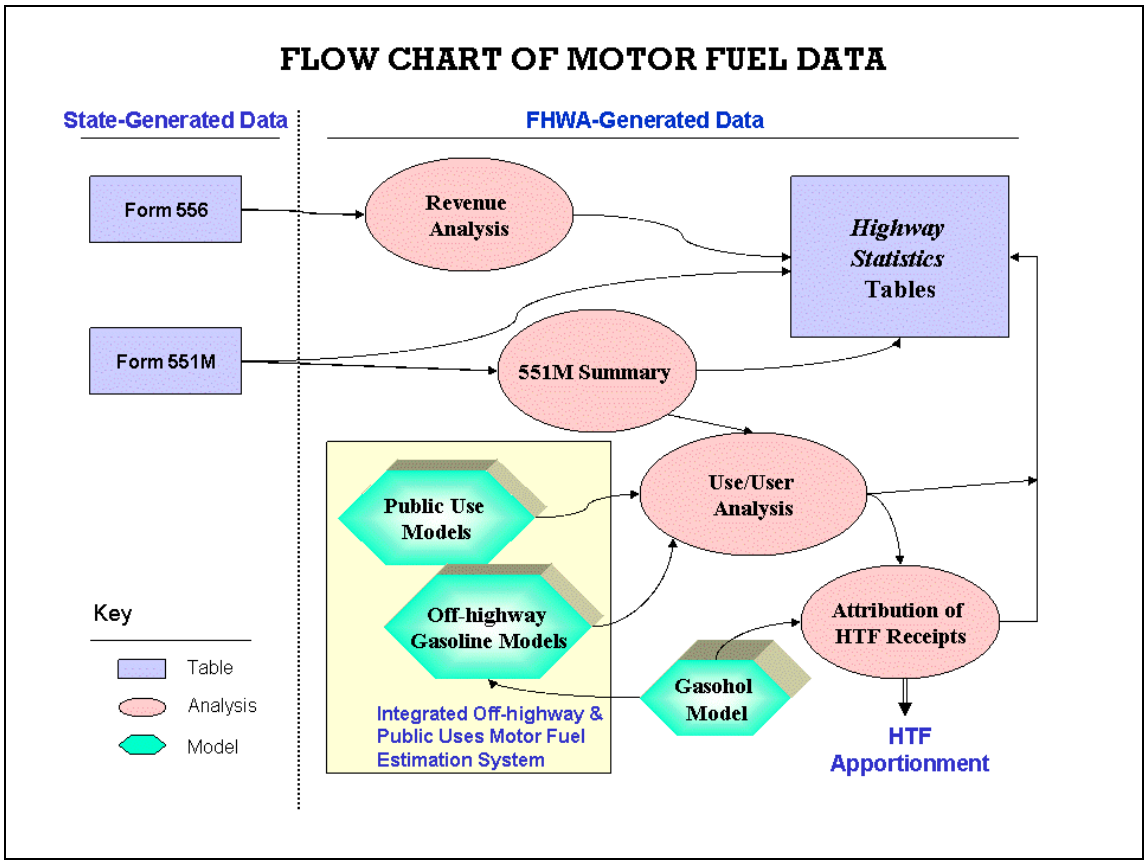

Figure 1.1 Flows of motor fuel data in the FHWA attribution process.

Due to the significant amount of gasohol involved (approximately 10% of total fuel) in the motor-fuel program and the differences in federal fuel tax structure for gasohol and gasoline during the period of time, as well as the fact that most states have difficulties in tracking gasohol separately from gasoline, a reliable gasohol model was critically needed by the analysts within the FHWA. A major update of the gasohol model was, therefore, conducted by ORNL for the FHWA in 2003. This gasohol model has provided FHWA with the ability to (1) obtain state-level gasohol consumption estimates in three blends (i.e., 10%, 7.7 to under 10%, and 5.7 to under 7.7%), and (2) to estimate total ethanol needed in the gasohol. In 2005 the federal tax rate for gasohol changed to the same rate as for gasoline, thus separation of gasohol consumption from the consumption of gasoline is no longer necessary during the FHWA HTF attribution process. Thus, the gasohol model was not reviewed nor updated under this current study. As a result, it is not discussed in this report.

1.2 PURPOSE OF THIS DOCUMENT AND ITS ORGANIZATION

The main purpose of this report is to make available a document that FHWA can use to better inform the states about the analysis process and estimation models currently used by the FHWA. The goal is, by improving the states' understanding of these models, FHWA can help the states improve the quality of the data they submit. Furthermore,

with better knowledge of current FHWA models, states can provide input and feedback to the FHWA for future model improvements.

This report includes seven chapters and three appendices. Chapter 1 provides an overview of the FHWA attribution process; a list of estimation models used during this process; and the reasons why these models were necessary. An overview of the off-highway gasoline consumption estimation system (i.e., the integrated system which includes several models) is given in Chapter 2. Explanations on the motivation for this 2008 update, as well as the areas where improvements were made in the updated 2008 system are also provided in Chapter 2. Additional reviews and analyses on the U.S. Environmental Protection Agency (EPA) NONROAD model, also conducted during this study, were discussed in Chapter 3. Detail descriptions of each individual model in the integrated system are presented in Chapter 4. For ease of discussion, models were categorized into two groups: consumption by truck and consumption by equipment. Consumption by public sectors is discussed separately in Chapter 5 of this report. The post-estimation attribution process is briefly described in Chapter 6 and is followed by a short summary in Chapter 7. Appendix A contains an example of the system output (State Worksheet). Appendix B lists data sources used in all off-highway models.

1.3 OVERVIEW OF THE ATTRIBUTION PROCESS

Basically, "attribution" is the annual process that FHWA conducts to determine a state's share of the overall on-highway motor-fuel consumption[2]. Results from this process are used in estimating amounts of the HTF receipts to be attributed to highway users in each state. This information is then used in distributing funds used in major highway programs to states through the apportionment process.

The attribution process starts when highway-related tax revenue are collected by the Internal Revenue Service (IRS) and subsequently assigned to the appropriate tax categories – one of which is the motor-fuel excise tax. However, the federal motor-fuel taxes are usually paid by oil companies at the terminal where the fuel is loaded into tanker trucks or rail cars. The IRS has no information on where or how the fuel is actually consumed. Therefore, FHWA has to rely on its own attribution process to determine on-highway use of motor fuels within each state.

The primary data sources on motor-fuel use are the motor-fuel gallons and motor-fuel tax revenues reported monthly to the FHWA by each state's taxation or revenue department. States use Form FHWA-551M ("*Monthly Motor-Fuel Consumption*") to report gross volume fuel consumption to the FHWA, for gasoline, gasohol, highway diesel fuel, and highway liquefied petroleum gases (LPG). Once a year, states also submit Form FHWA-556 ("*State Motor-Fuel Tax Receipts and Initial Distribution by Collection Agencies*") to report their annual motor-fuel tax revenue data.

[2] See booklet *Attribution and Apportionment of Federal Highway Tax Revenues: Process Refinements*, FHWA, U.S. Department of Transportation, January 2002.

These state-submitted data, however, are not sufficient for FHWA to accurately distribute HTF monies to the states. Tax legislation, tax forms, and administrative procedures vary significantly among the states. For example, exemptions or refunds for off-highway use or government use of motor fuels are handled quite differently in many states. Also, for some states, collection of certain data may not be required according to the legislative requirements of those states. In order to ensure accurate treatment of all states during the analysis of motor-fuel information, FHWA must make adjustments to the state data to account for these discrepancies. Furthermore, some adjustments are necessary in order to estimate missing or non-reported state data.

1.4 ESTIMATION MODELS USED IN FHWA ATTRIBUTION PROCESS

The steps related to the state motor-fuel analysis used by FHWA during the attribution process are complicated and, frequently, lengthy. A large number of mathematical and statistical formulas, as well as supplemental information from many other sources, have to be used in analyzing the motor-fuel data. The complexity of this process, in fact, reflects the wide variation among state taxation structures and methodologies for defining, capturing, and reporting data to the FHWA.

Several major steps in the motor-fuel analysis must be performed by FHWA prior to the start of the annual state-by-state analysis. These include estimation procedures that FHWA must perform for the following motor-fuel usage components:

1. off-highway gasoline consumption
   - Agriculture off-highway gasoline
   - Aviation off-highway gasoline
   - Industrial/commercial off-highway gasoline
   - Construction off-highway gasoline
   - Recreational boating off-highway gasoline
2. government use of gasoline
   - State, County, and Municipal use off-highway gasoline
   - Federal and State/County/Municipal use on-highway gasoline
3. on-highway gasohol consumption (three grades) [3]

Each of these components is estimated by utilizing a different set of procedures and formulas, i.e., models. These estimation models and their data sources, with the exception of the gasohol model, are described in detail later in this report.

Generally, the above mentioned estimation models are updated and run annually by FHWA analysts during the May-June timeframe. As stated, the FHWA must complete these estimations before the beginning of the annual state-by-state analysis, which normally starts around July. These estimates are based on the prior year's data for the analysis year since current-year data is not available at the time attribution estimations.

[3] The gasohol model currently used by the FHWA was developed by ORNL in 2003. This model will not be reviewed or updated under the current study and, therefore, is not discussed in this report.

For example, 2006 data was used during the 2007 analysis year. Figure 1.2 presents a time line for the annual state-by-state motor fuel analysis procedures. It includes a three-year analysis cycle. The process related to estimation models discussed in this report is highlighted in the figure.

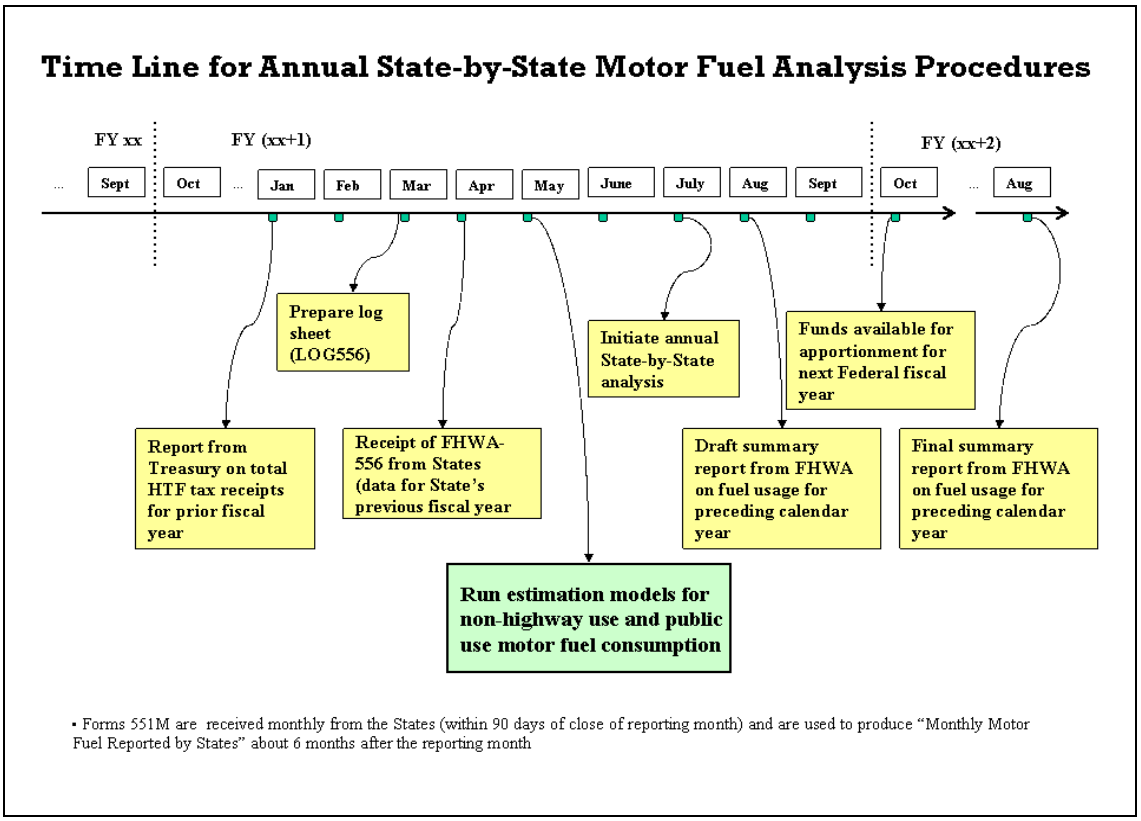

Figure 1.2 Time line for the annual motor fuel analysis process.

1.5 WHY ESTIMATION MODELS ARE NEEDED

The federal fuel taxes, which make up more than 80 percent of the HTF receipts, are imposed when the fuel is first removed from bulk storage and the tax is paid by the seller. Generally, these taxpayers are the oil companies. Although paid initially by a company, the costs of these fuel taxes become part of the purchase price of the products and are ultimately paid by the highway users. Using oil company tax data in the attribution process would be problematic, however, because the state in which the motor fuel tax is paid does not reflect where it will be shipped, stored, or used. Consequently, FHWA must estimate the HTF contributions from highway users by looking at tax revenue data in each state.

Typically, state revenue departments have data on motor fuels that are exempted, refunded, or taxed at other rates. From this type of data, FHWA may be able to identify the use of the fuel and, therefore, its place in attribution of HTF. Unfortunately, in many

cases, this data does not exist at the state level and FHWA must estimate fuel usage from other sources.

Motor-fuel tax programs vary from state to state. Often the states' motor-fuel information systems and the data that are submitted to FHWA are not comparable. Some states exempt or refund taxes for all fuel used by agencies of the federal government. A few states tax federal highway use of motor-fuel while the others also tax off-highway fuel uses by federal agencies. Similarly, rules on tax exemptions or refunds for motor fuel used by state, county and municipal government agencies also differ significantly among states. Rather than imposing the data collection and reporting burden to the states, FHWA has opted to estimate some of this data.

The estimation process developed by FHWA has been designed to accurately represent states' on-highway fuel use, and to produce meaningful results to fulfill attribution process needs. Note that, when FHWA estimates and state-submitted data are both available, FHWA makes judgments about the relative quality of the data and selects one or the other or some combination of the two data sets. Detailed descriptions of the current models are provided in the following sections.

2. OVERVIEW OF FHWA ESTIMATION MODELS

2.1 2002 INTEGRATED MOTOR-FUEL CONSUMPTION ESTIMATION SYSTEM

As discussed in Chapter 1, FHWA estimates private and commercial off-highway use of gasoline for individual states on an annual basis. These estimates are provided in five major fuel use categories: agricultural, aviation, industrial and commercial, construction, and marine (recreational boating). These estimates are used by FHWA in its efforts to separate on-highway and off-highway uses of gasoline. FHWA presents these estimates in Table MF-24 of *Highway Statistics*[4]. On-highway motor-fuel consumption is used by FHWA to quantify each state's share of HTF contributions and, in turn, is used in the apportionment process.

In addition to off-highway motor-fuel consumption, FHWA is also estimating on- and off-highway gasoline use by the public sector. Due to the characteristic differences between the public and the private and commercial sectors, and the availability of data sources, FHWA has to use a different modeling approach to estimate gasoline use by the public sector. Detailed discussions on public-use estimation models are addressed separately from those on the off-highway gasoline consumption estimation models in this report (see Chapters 3 and 4).

Figure 2.1 presents flows of the data sources and model components in the Integrated Motor-fuel Consumption Estimation System as developed in 2002. This system has been in use by the FHWA since 2003. Prior to the 2002 updates, FHWA analysts needed to access and update over 20 individual spreadsheet files in order to generate motor-fuel consumption estimates in their annual attribution process. Many of these procedures were only needed for interim calculations and/or temporary storage purposes and, as a result, redundant information was stored in multiple locations (i.e., spreadsheet files). The 2002 Integrated Motor-fuel Consumption Estimation System eliminated this redundancy and streamlined the operations of multiple off-highway and public-use models into one single file.

Furthermore, the operation of the 2002 Integrated System was enhanced by utilizing a color scheme which reflects the frequencies of data modification or update needs for areas in each worksheet. Areas that need to be updated on an annual basis (e.g., total fuel expenditures for the analysis year) are shaded differently than those that need only periodical attention (e.g., Census population data). In addition, areas that contain formulas that automatically perform updates as new data is entered are protected (i.e., locked) so that accidental alteration or deletion of these cells can be prevented. Data sources or related references and notes are also provided within the system. By moving the mouse pointer onto a specific cell (denoted by a red dot at its corner) in the worksheet, a comment box containing this information (i.e., data source, reference, or

[4] *Highway Statistics 2005* is an annual report published by Federal Highway Administration, U.S. Department of Transportation. See www.fhwa.dot.gov/policy/ohim/hs05/index.htm.

notes) will be shown. This feature provides a reminder to the analysts, as needed, about what information is needed and where to get it.

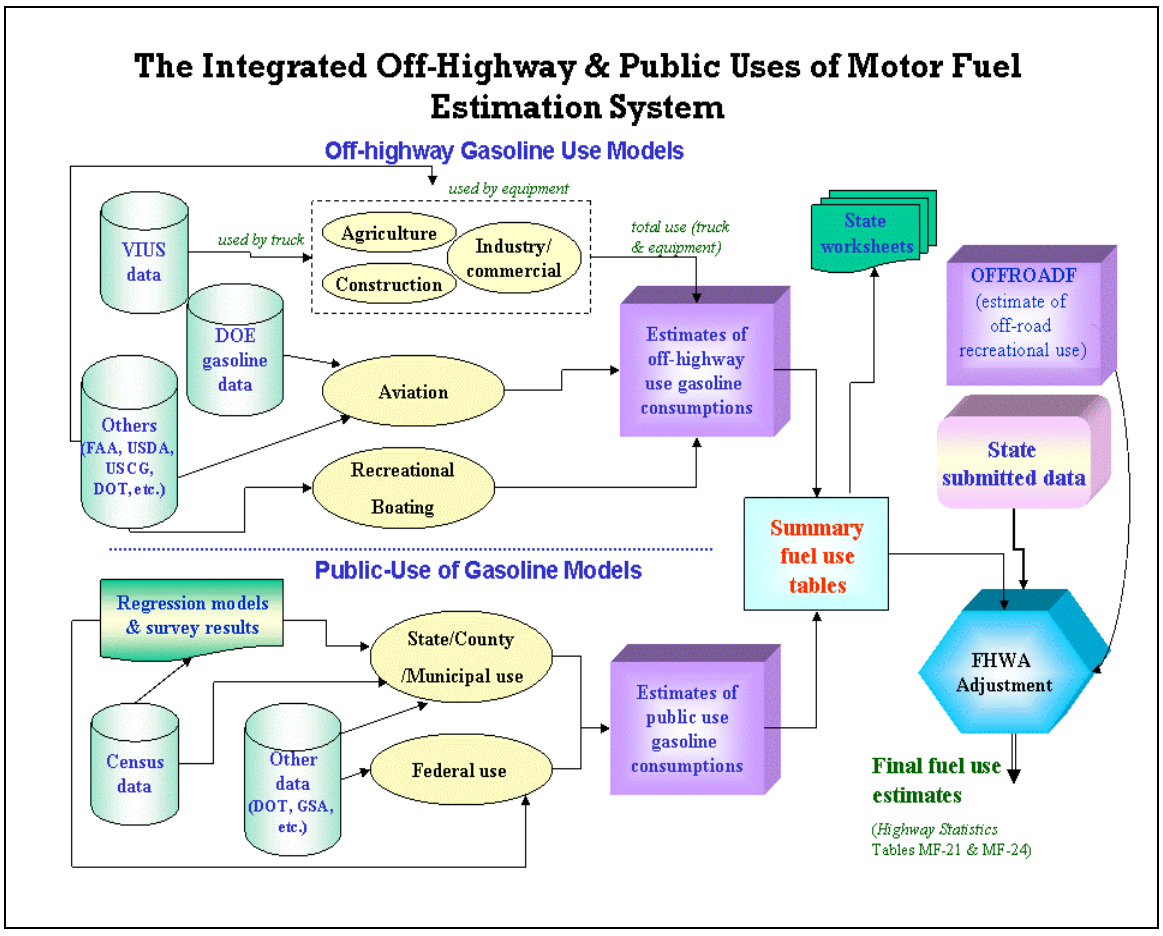

Figure 2.1 Model components in the integrated motor-fuel estimation system.

The 2002 Integrated Motor-Fuel Consumption Estimation System also provides a simple function that allows the FHWA analyst to generate individual State Worksheets. At the end of the model executions, motor-fuel consumption estimates can be automatically filled into corresponding state Worksheets with just a simple keystroke. These state Worksheets allow the analysts to easily add in other data needed for completing the annual attribution process. An example of the state Worksheet is provided in Appendix B of this report.

Although the operations of the off-highway and public-use motor-fuel consumption estimation models were greatly improved and data were updated to the latest available at that time (i.e., 2002), it is important to note that virtually all fundamental methods and assumptions used in these models stayed the same as they were when originally

developed in 1994[5]. Also, the methodology for estimating gasoline use in recreational vehicles (i.e., shown as module OFFROADF[6] in Figure 2.1), which includes fuel use by snowmobiles, off-road motorcycles, all-terrain vehicles, and off-road personal use of light trucks, was updated by ORNL in 1999[7]. Due to lack of reliable data, however, FHWA does not currently estimate fuel consumption for small equipment (e.g., lawnmowers, snow blowers, chain saws, etc.) uses.

2.2 MOTIVATION FOR 2008 MODEL REVIEW AND UPDATES

Since the 2002 model review and updates, several important changes have occurred in data sources that were utilized in the FHWA off-highway motor fuel consumption estimation models. Specifically, the Vehicle Inventory and Use Survey (VIUS) program has been terminated by the U.S. Bureau of Census, making the 2002 VIUS data the last set of that series.

The VIUS is a national sample survey conducted every five years by the U.S. Bureau of Census as a part of the Census for Transportation under the Economic Census. The VIUS data contain information on trucks owned by businesses and individuals, ranging from multi-trailer combination vehicles to pickups, vans, and minivans. Specifically, data elements contained in VIUS include: vehicle type, annual vehicle-miles of travel (VMT), major use of vehicle (e.g., agricultural, retail), percent of annual mileage for off-road use, engine type (e.g., gasoline, diesel), state in which the vehicle is registered, average fuel efficiency (i.e., miles per gallon [MPG]), and many other vehicle characteristics. Data from the VIUS was used as a major input for several components in the off-highway gasoline consumption estimation model. This includes models for agriculture, construction, and industrial/commercial sectors.

The discontinuation of VIUS does not pose an immediate threat to programs utilizing the VIUS data, because normally it takes 2-3 years before data from VIUS becomes available (e.g., until about 2009-2010). However, as pointed out above, the lack of VIUS data does pose a direct impact on several FHWA models. Identifying potential alternative resources to replace the VIUS data is one of the motivations to conduct another review and update of the FHWA models.

Furthermore, in the 2002 study, ORNL recommended that the NONROAD model developed by the EPA be explored further as a potential resource for the estimation of off-highway gasoline consumption. Due to budgetary constraint and other concerns, this recommendation was never explored. Within the last five years, the EPA NONROAD has gone through many improvements, making the potential of use of this information in the FHWA applications more appealing than before. Part of the 2008 model review

[5] Miaou, S. P. and A. Lu, *Estimating Non-highway Use of Gasoline and Gasohol*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, August 2004.
[6] The OFFROAD model was not reviewed under the current study and is not discussed in this report.
[7] Davis, S. C., L. F. Truett, and P. S. Hu, *Fuel Used for Off-Road Recreation: A Reassessment of the Fuel Use Model*, ORNL/TM-1999/100, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1999.

effort was, therefore, to examine the EPA NONROAD data and to determine the feasibility of using this information to enhance FHWA's off-highway fuel consumption models.

Aside from the above mentioned reasons, some new data sources, as well as changes on those data sources currently used, have become available since the 2002 model update. To ensure quality estimates are generated from the FHWA models, and that any recent motor-fuel use related changes are reflected in the model estimates, it is crucial that FHWA off-highway and public-use motor-fuel consumption estimation models (i.e., the Integrated Motor Fuel Consumption Estimation System) be updated. Note that updates discussed here are different from the annual data update process made by the FHWA analysts. The availability of new data and the changes in the current data sources often require formula changes as well as methodology changes in the models. This process typically results in an updated version of the "system" and, thus, the updated version from this study is referred as the 2008 Off-highway Gasoline Consumption Estimation Models.

3. REVIEW OF EPA NONROAD ESTIMATES TO FULFILL FHWA NEEDS

3.1 BRIEF DESCRIPTION OF THE EPA NONROAD2005 MODEL

In 1998, EPA began developing a mobile source emissions inventory model for nonroad equipment. This model, entitled NONROAD, provides a tool to predict emissions from nonroad engines, as well as the volume of fuel consumed by these engines. Though the EPA uses the model for emissions estimation, the model generated fuel consumption data that is of interest to the FHWA. The fuel consumption data produced by the NONROAD model include four fuel types: gasoline, diesel, LPG, and compressed natural gas (CNG). Each specific fuel type can be further broken down by equipment source category classification (SCC), horsepower rating, and geographic area (U.S., state, and county). The most recent version of NONROAD is NONROAD2005, which allows its users to model emissions for calendar years 1970 to 2050. Note that the NONROAD model does not include data for locomotives, aircraft, or commercial marine vessels. More detailed descriptions of the EPA NONROAD2005 Model can be found on the EPA web site[8].

3.1.1 Data Sources and Population of Non-road Gasoline-engine Equipment

The equipment types included in NONROAD2005 were chosen based on type of engine the equipment uses. For gasoline engines, both 2-stroke and 4-stroke engines are included. The NONROAD model uses EPA developed algorithms to estimate changes in the equipment population from a specific base year. The base years are the most recent years for which population data are available. Due to the availability of data (or lack thereof), the base year may be different, depending on the type of equipment.

The following ten tables (Tables 3.1 through 3.10) show the base year for each of the equipment types, along with their 2006 engine population and gasoline consumption data estimated from the NONROAD2005[9]. An average gallons-per-piece-of-equipment, calculated by dividing the total fuel consumption of the given equipment by its population, is also shown in these tables. Note that, each equipment type could include multiple types of horsepower engines (some with a wide range), thus, the average gallons shown are presented only as a rough reference. They are by no means representing the fuel economy measurement of this equipment.

Except for forklifts, all-terrain vehicles (ATVs), snowmobiles, and off-road motorcycles, the gasoline engine population data originally come from the NONROAD Engine and Vehicle Emission Study[10], which was provided by Power Systems Research (PSR), an independent marketing research firm. For many categories, the NONROAD2005 uses

[8] See http://www.epa.gov/oms/models/nonrdmdl/nr-eiip4.pdf and http://www.epa.gov/nonroad-diesel/2004fr.htm.
[9] *NONROAD Engine Population Estimates*, EPA-420-R-05-022, December 2005.
[10] *NONROAD Engine and Vehicle Emission Study*, EPA-21A-2001, November 1991.

the 2003 version of the PSR data which includes population estimates for the years 1996, 1998, 1999, and 2000.

Table 3.1 Agricultural Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	2-Wheel Tractors	5,521	1,299,548	235
1998	Agricultural Mowers	9,372	1,124,729	120
1998	Agricultural Tractors	2,989	5,555,190	1,859
1998	Balers	20,551	3,626,584	176
1998	Combines	34	37,194	1,094
1998	Irrigation Sets	3,583	9,659,248	2,696
1998	Sprayers	219,065	13,056,172	60
1998	Swathers	12,825	5,745,701	448
1998	Tillers > 6 HP	823,287	26,891,538	33
1998	Other Agricultural Equipment	25,800	8,330,940	323
	All	**1,123,027**	**75,326,843**	**67**

Table 3.2 Industrial Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	AC\Refrigeration	736	439,765	598
1998	Aerial Lifts	23,747	14,830,650	625
1996	Forklifts	13,330	49,174,037	3,689
1998	Sweepers/Scrubbers	15,999	11,852,547	741
1998	Terminal Tractors	889	4,815,845	5,417
1998	Other General Industrial Eqp	58,340	21,041,344	361
1998	Other Material Handling Eqp	1,379	1,040,406	754
1998	Other Oil Field Equipment	16,329	27,642,438	1,693
	All	**130,751**	**130,837,031**	**1,001**

Source for base year forklift population: EPA, "Draft Regulatory Support Document: Control of Emissions from Unregulated NONROAD Engines," EPA420-F-00-051, November 13, 2000.
Note: Share of forklifts using gasoline was taken from EPA-21A-20-2001 report.

Table 3.3 Commercial Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	Air Compressors	156,324	58,986,407	377
1998	Generator Sets	4,409,406	452,676,125	103
1998	Hydro Power Units	27,967	9,234,034	330
1998	Pressure Washers	2,063,853	197,937,807	96
1998	Pumps	1,212,707	126,809,342	105
1998	Welders	224,090	124,209,525	554
	All	**8,094,348**	**969,853,239**	**120**

Table 3.4 Construction and Mining Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	Bore/Drill Rigs	104,226	4,126,996	40
1998	Cement & Mortar Mixers	247,371	12,295,946	50
1998	Concrete/Industrial Saws	106,178	38,704,097	365
1998	Cranes	1,054	984,736	934
1998	Crushing/Proc. Equipment	8,149	1,647,459	202
1998	Dumpers/Tenders	29,098	1,918,006	66
1998	Other Construction Equipment	655	1,354,361	2,068
1998	Pavers	8,875	3,806,585	429
1998	Paving Equipment	121,732	13,895,031	114
1998	Plate Compactors	117,468	7,462,487	64
1998	Rollers	10,061	6,664,285	662
1998	Rough Terrain Forklifts	991	1,551,787	1,566
1998	Rubber Tire Loaders	1,580	3,730,073	2,361
1998	Signal Boards/Light Plants	1,458	290,827	199
1998	Skid Steer Loaders	10,079	5,750,582	571
1998	Surfacing Equipment	19,750	5,562,809	282
1998	Tampers/Rammers	158,325	6,302,128	40
1998	Tractors/Loaders/Backhoes	8,200	7,928,456	967
1998	Trenchers	31,321	11,854,645	378
	All	**986,570**	**135,831,297**	**138**

Table 3.5 Logging Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	Chain Saws > 6 HP	44,309	7,124,709	161
1998	Forest Eqp - Feller/Bunch/Skidder	625	135,158	216
1998	Shredders > 6 HP	273,233	12,339,513	45
	All	**318,168**	**19,599,380**	**62**

Table 3.6 Aviation Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	Airport Ground Support Equipment	1,907	2,160,665	1,133
	All	**1,907**	**2,160,665**	**1,133**

Table 3.7 Marine (Recreational Boating) Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	Inboard/Sterndrive	1,963,218	482,875,339	246
1998	Outboard	9,388,404	829,866,293	88
1998	Personal Water Craft	1,269,132	319,106,312	251
	All	**12,620,754**	**1,631,847,943**	**129**

Table 3.8 Recreational Equipment Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	ATVs	8,586,853	394,905,216	46
1998	Golf Carts	184,759	100,729,204	545
1998	Motorcycles: Off-Road	2,119,730	126,689,467	60
1999	Snowmobiles	2,095,127	534,846,684	255
1998	Specialty Vehicles/Carts	474,499	30,287,600	64
	All	**13,460,967**	**1,187,458,171**	**88**

Source for base year data:

- ATVs: Consumer Products Safety Commission, April 1998, Part 1, “Report 1997 ATV exposure Survey,” Bethesda, MD.
- Snowmobiles: ORNL, “Fuel Used for Off-Road Recreation: A Reassessment of the Fuel Use Model,” ORNL/TM-1999/100, July 1999.
- Motorcycles: Motorcycle Industry Council.
- Golf Carts and Specialty Vehicles/Carts: EPA, “Nonroad Engine and Vehicle Emission Study,” EPA-21A-2001, November 1991.

Table 3.9 Lawn and Garden Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
	Residential			
1996	Chain Saws < 6 HP	6,354,934	18,656,994	3
1998	Lawn & Garden Tractors	14,499,406	522,504,160	36
1996	Lawn mowers	39,851,739	197,162,857	5
1996	Leafblowers/Vacuums	8,955,775	18,774,477	2
1998	Rear Engine Riding Mowers	2,121,754	38,702,969	18
1998	Rotary Tillers < 6 HP	4,063,383	18,194,153	4
1998	Snowblowers	5,977,325	16,236,521	3
1996	Trimmers/Edgers/Brush Cutter	17,054,009	26,972,869	2
1998	Other Lawn & Garden Eqp.	714,185	18,940,541	27
	All	**99,592,511**	**876,145,541**	**9**
	Commercial			
1996	Chain Saws < 6 HP	888,089	75,746,007	85
1998	Chippers/Stump Grinders	32,928	37,490,970	1,139
1998	Commercial Turf Equipment	1,129,369	692,525,433	613
1998	Front Mowers	195,208	19,262,111	99
1998	Lawn & Garden Tractors	387,047	215,720,151	557
1996	Lawn mowers	1,850,700	147,359,556	80
1996	Leafblowers/Vacuums	1,286,907	198,323,586	154
1998	Rear Engine Riding Mowers	56,639	15,839,062	280
1998	Rotary Tillers < 6 HP	678,021	81,905,627	121
1998	Shredders < 6 HP	355,567	8,710,503	24
1998	Snowblowers	664,148	30,669,002	46
1996	Trimmers/Edgers/Brush Cutter	2,263,526	61,369,798	27
1998	Other Lawn & Garden Eqp.	849,040	22,598,939	27
	All	**10,637,189**	**1,607,520,744**	**151**

Table 3.10 Railway Maintenance Nonroad Equipment, 2006 Estimates

Base Year	Equipment	Population	Gasoline Use (Gallons)	Gallons per Equipment
1998	Railway Maintenance	13,552	1,295,111	96
	All	**13,552**	**1,295,111**	**96**

3.1.2 Fuel Consumption Estimation Process in the NONROAD2005 Model

The NONROAD2005 model uses the engine population, an average number of hours per year the engine is active, and other information about the engine to derive fuel consumption estimates. The formula below shows how the basic fuel consumption is calculated:

$$Fuel\ Consumption = Pop * Power * LF * A * FF$$

Where	Pop	=	Engine Population
	Power	=	Average Power (horsepower)
	LF	=	Load Factor (fraction of available power)
	A	=	Activity (hours per year)
	FF	=	Fuel Factor (gallons per horsepower-hour)

Other parameters (e.g., growth and scrap rates for population, seasonal adjustment for activity) are also used in the NONROAD2005 model to fine tune the estimates. In order to estimate the growth of the engine populations, in most cases, EPA extrapolates from a simple linear regression of the historical population by market sector and fuel type. In the case of off-road motorcycles and ATVs, growth projections supplied by the Motorcycle Industry Council were used. Snowmobile growth projections are based on information supplied by the International Snowmobile Manufacturers Association. Furthermore, the fuel factor also changes over time to reflect the increased fuel efficiency of newer engines entering the population.

3.1.3 Challenges

The NONROAD2005 model was built by the EPA to estimate emissions inventory rather than fuel consumption. However, emissions and fuel use go hand-in-hand because, with certain assumptions, one can be calculated from the other. When designing the model, EPA's emphasis was on diesel nonroad engines due to the Tier 4 emission standards for non-road diesel engines which were being phased in during 2008. Data were also collected on gasoline, CNG, and LPG nonroad engines, with 1998 as the base year for much of the data.

NONROAD2005 is a simulation model. The EPA programmed the NONROAD2005 model to allow backcasting and forecasting of emissions; the model can be used to produce estimates for years between 1970 and 2050. As with any model, however, the reliability declines as estimates are made further from the base year.

In order to meet new analysis needs, the EPA is designing a new model that will estimate emissions for both on-road and nonroad mobile sources. This new model, called the MOtor Vehicle Emission Simulator (MOVES), when fully implemented, will replace NONROAD and the EPA's current on-road model, MOBILE6.

3.2 COMPARISON OF ESTIMATES FROM 2002 FHWA MODELS AND EPA NONROAD2005 MODEL

To examine potential benefits of using EPA NONROAD2005 model in FHWA applications, as part of this 2008 study, gasoline consumption estimates generated from the 2002 FHWA off-highway gasoline consumption estimation models were compared to those produced from the EPA NONROAD2005 model. Before discussing the comparisons, however, it is important to note that there are differences in equipment coverage between these two models (i.e., FHWA and EPA) in every equivalent sector (e.g., agriculture, industrial, etc.).

3.2.1 Differences in Equipment Coverage

The discussions on differences in equipment coverage between the FHWA model and EPA NONROAD2005 are presented by sector type included in the FHWA off-highway estimation models. This includes categories on agriculture, industrial and commercial, construction, aviation, recreational boating, and miscellaneous.

Agriculture

The 2002 FHWA agriculture model produces (published in Table MF-24) an estimate on fuel used by trucks that may be registered for on-road use, but are operating off-road for agricultural purposes. It also includes another estimate on fuel used by farm equipment, which was based on a statistical regression approach associating the number of wheel tractors with the amount of off-highway agricultural gasoline use. The regression modeling approach used in the 2002 FHWA model, if adequately formulated with appropriate data, should have captured gasoline consumption by all farm-based equipment.

A closer examination of the major source data used in the FHWA model, i.e., USDA Agriculture Census data, revealed that the process of matching equipment covered under the USDA Census and the EPA NONROAD model is rather difficult. This is mainly due to differences in their data collection methods. Each program employed the methodology to collect information that can best serve its intended purpose. Basically, Agriculture Census collects data by surveying farmers/farm-operators while EPA gathers its data based on manufacturer sales and engine productions. Specifically, Agriculture Census data on machinery and equipment used in farm or ranch business was collected for the following items:

- Trucks (including pickups),
- Tractors less than 40-horsepower (excluding garden tractors),
- Tractors 40-99 horsepower,
- Tractors 100 horsepower or more,
- Grain and bean combines (self-propelled),
- Cotton pickers and strippers (self-propelled),

- Forage harvesters (self-propelled), and
- Hay balers.

Note that there is no "other machinery or equipment" category in the Agriculture Census survey form to capture information on items outside those specific equipment, however. Therefore, it is very possible that the actual number of equipment used in farm operations is higher than what was reported by the survey respondents (i.e., in-scope equipment from the Census).

On the other hand, the result produced from the NONROAD2005 model includes fuel use by all types of agricultural equipment, but not farm-based trucks. That is, under EPA NONROAD program, data on agricultural equipment are collected for the following types:

- two-wheel tractors including walk-behind 2-wheeled tractors for use in edible produce or other intensive farming;
- Agricultural tractors including large and small agricultural tractors, most prevalent farm equipment type;
- Combines including self-propelled combined harvesting and cleaning equipment;
- Baler equipment that bales from loose or windrowed hay or other forage mowed crop
- Agricultural mower equipment for mowing, not intended for later baling or harvesting;
- Sprayers including small (backpack) and large (self-propelled) powered equipment designed specifically for spraying;
- Tillers >6 HP, primarily small tillers similar to those used on lawn and garden applications intended to be used in edible produce or other intensive farming;
- Swather equipment designed to cut crops for later baling or harvesting including windrowers;
- Other agricultural equipment which includes other various cultivation equipment types, include harvesters or other special cultivating equipment; and
- Irrigation sets which include agricultural pumps and pivot wheel irrigation equipment to distribute water to fields or livestock.

Clearly EPA's agricultural equipment list contains more types of equipment than those included under the USDA Agriculture Census. Based on 2007 Agriculture Census, the total number of farm machinery and equipment (excluding trucks) used for farm operations in the United States was approximately 5,547 thousand units. However, based on NONROAD2005 estimate, the national number of agricultural equipment in 2007 totaled at about 3,360 thousand units, which is significantly different from USDA's estimated number (about 40% less in number of units). Considering USDA included specific equipment in farm operations while EPA counted all engines in agricultural equipment, the actual discrepancy between the two sources could be higher than 40%.

Industrial and Commercial

The 2002 FHWA model estimated the off-highway industrial and commercial gasoline use by trucks only. No industrial and commercial equipment were considered in the FHWA consumption estimation model.

The NONROAD2005 model does not include trucks, but has many different types of industrial equipment, commercial equipment, and logging equipment. Thus, there is no overlap in the data provided by these two models. Note that the FHWA model is VIUS-based which includes mining within the "industrial" category while NONROAD2005 combines mining with construction instead. Table 3.11 lists all equipment types included under the NONROAD2005 model.

Table 3.11 Industrial and Commercial Equipment Coverage

2002 FHWA Model	NONROAD2005
Registered trucks used for off-road industrial and commercial purposes	Air Compressors
	Generator Sets
	Hydro Power Units
	Pressure Washers
	Pumps
	Welders
	AC/Refrigeration
	Aerial Lifts
	Forklifts
	Other General Industrial Equipment
	Other Material Handling Equipment
	Sweepers/Scrubbers
	Terminal Tractors
	Chain Saws > 6 HP
	Forest Eqp - Feller/Bunch/Skidder
	Shredders > 6 HP

Construction

The 2002 FHWA off-highway construction gasoline use model only accounts for fuel consumed by trucks that are used in off-road construction. No other construction equipment is included in the estimates.

The NONROAD2005 model, on the other hand, does not include trucks, but it includes 19 different types of equipment used for construction and mining purposes (see Table 3.12). There is no overlap in the data provided by these two models. However, as stated above, the 2002 FHWA model includes mining under the industrial and commercial sector; NONROAD2005 includes mining with construction.

Table 3.12 Construction Equipment Coverage

2002 FHWA Model	NONROAD2005
Registered trucks used for off-road construction	Bore/Drill Rigs
	Cement & Mortar Mixers
	Concrete/Industrial Saws
	Cranes
	Crushing/Proc. Equipment
	Dumpers/Tenders
	Pavers
	Paving Equipment
	Plate Compactors
	Rollers
	Rough Terrain Forklifts
	Rubber Tire Loaders
	Signal Boards/Light Plants
	Skid Steer Loaders
	Surfacing Equipment
	Tampers/Rammers
	Tractors/Loaders/Backhoes
	Trenchers
	Other Construction Equipment

Aviation

Aviation gasoline used by general aviation airplanes is included in the 2002 FHWA model. On the other hand, airport ground support equipment is the only aviation-related equipment included in the NONROAD2005 model. There is no overlap in estimates provided by these two models.

Marine

Gasoline consumption in recreational boating is currently estimated by the FHWA model. All recreational power boats registered with the states are considered in the FHWA estimates. Most states require registration for all water craft with a motor, though some states exempt certain small vessels. The NONROAD2005 model also estimates fuel use for similar recreational boats, including personal water craft (i.e., Jet-Ski).

Miscellaneous

The Miscellaneous category in Table MF-24 is used by the FHWA to capture off-highway consumption reported by the state, and was determined by the FHWA that the state-reported data were not represented in other categories. Although not included as part of the current off-highway models (as mentioned earlier in this report), FHWA could decide to use estimates generated by the OFFROAD model (for recreational off-road vehicle) to make adjustments during its attribution process. The OFFROAD model, however, does not separate the fuel use by fuel types (i.e., gasoline or diesel).

There is no similar miscellaneous category in NONROAD2005. Instead, there are additional categories of nonroad equipment in the NONROAD2005 model which are not currently accounted for by the FHWA. Some of these additional equipment categories are substantial users of gasoline, which includes: commercial and residential lawn and garden equipment, recreational off-road vehicles, and railway maintenance. The individual equipment types in those categories are listed below in Table 3.13.

Table 3.13 Equipment in NONROAD2005 that is not in FHWA model

Commercial Lawn and Garden
Chain Saws < 6 HP
Chippers/Stump Grinders
Commercial Turf Equipment
Front Mowers
Lawn & Garden Tractors
Lawn mowers
Leaf blowers/Vacuums
Rear Engine Riding Mowers
Rotary Tillers < 6 HP
Shredders < 6 HP
Snow blowers
Trimmers/Edgers/Brush Cutter
Other Lawn & Garden Eqp.
Residential Lawn and Garden
Chain Saws < 6 HP
Lawn & Garden Tractors
Lawn mowers
Leaf blowers/Vacuums
Rear Engine Riding Mowers
Rotary Tillers < 6 HP
Snow blowers
Trimmers/Edgers/Brush Cutter
Other Lawn & Garden Eqp.
Recreational
ATVs
Golf Carts
Motorcycles: Off-Road
Snowmobiles
Specialty Vehicles/Carts
Railway Maintenance

3.2.2 Estimates of Off-highway Gasoline Consumption

Total gasoline consumption for each sector, as covered under the 2002 FHWA off-highway models, was estimated using the 2002 FHWA model and again with the NONROAD2005 model. Comparisons of the results generated from both FHWA and EPA models were done at the national and state-specific levels.

National Level

Table 3.14 shows the FHWA model estimates as published in Table MF-24 of the *Highway Statistics* and the estimates produced by the NONROAD2005 model. The data year used for both models is 2006.

Table 3.14 Total Off-highway Gasoline Consumption in 2006 (in million gallons)

Sector	FHWA Model	NONROAD2005
Agriculture (some equipment overlaps)	1,229	75
Industrial and Commercial (no overlaps, FHWA includes mining)	1,197	1,120
Construction (no overlaps, NONROAD2005 includes mining)	552	136
Aviation (no overlaps)	346	2
Marine/recreational boating (measuring same population in general)	1,237	1,632
Miscellaneous/others (no overlaps)	284	3,672

As noted earlier, these two models are measuring different equipment populations in most cases; a direct comparison is therefore **NOT** possible in most sectors. The closest comparison that can be made is in the Marine sector. Both models estimate the amount of gasoline used by recreational boats (including personal water craft). However, the FHWA model considered only registered boats while EPA's model focused on engine populations. This might explain why NONROAD2005 has a higher estimate than the one based on the FHWA model.

State Level

Table 3.15 shows the estimates from the FHWA and EPA models generated at the state level. The first data column includes all NONROAD2005 estimated fuel use, while the second data column includes only the NONROAD2005 equipment that fit in one of the categories used by the FHWA (i.e., agriculture, aviation, industrial and commercial, construction, and marine). The third data column (right-most) is estimates taken directly from Table MF-24 of the *Highway Statistics*, which is produced using FHWA models. Again, the data year used for both models is 2006.

Table 3.15 Total Off-Highway Gasoline Consumption in 2006 (thousand gallons)

	All equipment in NONROAD	Equipment in NONROAD that fits MF-24	FHWA Table MF-24
Alabama	111,362	58,153	86,653
Alaska	37,690	8,070	29,995
Arizona	119,202	40,716	75,753
Arkansas	69,668	34,627	83,668
California	690,095	277,790	324,222
Colorado	102,335	31,777	74,635
Connecticut	74,288	36,435	45,818
Delaware	24,677	14,802	20,830
District of Columbia	4,274	1,982	7,774
Florida	491,058	275,469	319,301
Georgia	182,764	77,970	152,187
Hawaii	21,044	9,532	9,980
Idaho	48,439	16,884	42,919
Illinois	234,209	103,732	165,633
Indiana	119,904	46,914	89,210
Iowa	76,217	36,141	141,861
Kansas	52,972	25,939	73,330
Kentucky	81,886	40,278	117,127
Louisiana	117,884	74,727	96,120
Maine	64,695	19,292	21,393
Maryland	117,492	49,726	73,320
Massachusetts	124,722	61,650	61,108
Michigan	336,977	128,794	178,013
Minnesota	239,109	89,307	158,282
Mississippi	68,034	38,506	86,195
Missouri	133,106	68,988	129,260
Montana	26,554	10,813	37,118
Nebraska	37,285	18,851	65,770
Nevada	51,597	16,587	38,352
New Hampshire	47,147	19,629	31,486
New Jersey	186,192	98,530	94,494
New Mexico	30,895	12,549	36,557
New York	357,310	184,099	174,845
North Carolina	192,783	88,214	186,509
North Dakota	24,907	13,080	34,074
Ohio	248,690	104,275	178,114
Oklahoma	81,519	41,589	106,678
Oregon	87,369	39,509	66,639
Pennsylvania	228,449	82,993	127,515
Rhode Island	17,516	9,257	10,861
South Carolina	102,339	51,616	88,816
South Dakota	23,344	11,539	40,882
Tennessee	125,490	60,391	87,090
Texas	397,871	188,938	329,017
Utah	54,587	20,752	39,262
Vermont	22,884	6,423	13,818
Virginia	152,637	61,946	104,538
Washington	142,763	67,784	94,291
West Virginia	36,523	12,454	24,929
Wisconsin	197,122	68,571	115,674
Wyoming	19,998	6,762	53,022
All	**6,568,208**	**2,930,728**	**4,844,938**

* exclude fuel use by recreational, lawn and garden (commercial/residential), and railroad maintenance equipment.

Again, coverage of equipment in the FHWA model and the EPA NONROAD2005 model is quite different. Although these estimates are presented in the same table, it was not intended for a direct comparison between these two models. Table 3.15 is used merely to show the order of magnitude in the estimates.

According to the NONROAD2005 model, the lawn and garden category accounts for more than half of nonroad gasoline use in several states, including Nevada, Arizona, Hawaii, Maryland, California, Virginia, the District of Columbia, and Colorado. Recreational vehicle gasoline use accounts for more than half of the nonroad gasoline use in the States of Alaska, Maine, Vermont, and Wyoming. Lawn and garden equipment is not included in the FHWA model.

As mentioned before, in addition to farm equipments, FHWA estimates of off-highway gasoline consumption for agricultural purposes also includes gasoline used by trucks that are used in off-road farm operations. To examine the magnitude of differences in estimates produced from FHWA and EPA models, Table 3.16 shows FHWA estimates in two separate components, one for truck and the other for farm equipment, by state. As can be seen from Table 3.16, the VIUS-based estimate (i.e., for truck) is the dominant part of the off-highway gasoline consumption; regardless which model is used for estimating the gasoline consumption by farm-based equipment. Generally, estimates produced from NONROAD2005 are only a fraction of the farm-based equipment estimate generated from the FHWA model. This is consistent with the finding reported in the previous section stating that the NONROAD farm equipment population is about 40% less than what was estimated under the Agriculture Census. Note that year 2005 data was used as an example for this comparison because of its data availability (i.e., separate numbers for VIUS and farm equipment).

Regarding recreational boating (see Table 3.17), estimates from the NONROAD2005 model are bigger than those produced by the FHWA model in almost all states. This might be due to differences in the definition of equipment population. As pointed out earlier, FHWA considered only registered boats while EPA includes no such restrictions. The only exceptions were for the States of Alaska, South Carolina, and Wyoming; gallon estimates for these states were similar in their respective order of magnitudes for results from both models, however. Data used in this comparison is obtained from the latest *Highway Statistics* Table MF-24 (results produced using the FHWA model), which is for year 2006.

Table 3.16 Off-highway gasoline consumption for agriculture sector in 2005 (1,000 gallons)

State	FHWA truck off-road ag.	FHWA farm eq.	NONROAD2005
Alabama	10,874,704	13,225	496
Alaska	585,107	193	8
Arizona	1,865,022	2,987	221
Arkansas	11,016,705	17,965	1,852
California	26,528,761	30,921	2,103
Colorado	7,084,452	11,540	1,080
Connecticut	1,786,530	2,619	33
Delaware	314,093	1,654	108
D.C.	106,437	0	0
Florida	20,779,527	12,728	575
Georgia	12,737,719	15,237	806
Hawaii	350,964	911	27
Idaho	5,323,402	9,216	1,071
Illinois	8,339,575	29,828	5,604
Indiana	7,600,266	19,715	2,965
Iowa	11,103,206	36,297	5,959
Kansas	13,785,601	21,003	4,713
Kentucky	11,009,673	28,973	1,237
Louisiana	907,768	11,208	828
Maine	677,611	3,796	98
Maryland	2,780,426	8,458	318
Massachusetts	735,645	3,212	40
Michigan	7,629,094	28,468	1,696
Minnesota	9,555,012	46,193	4,818
Mississippi	14,835,496	15,394	1,028
Missouri	12,288,439	28,376	3,263
Montana	7,085,091	9,875	2,171
Nebraska	13,557,210	21,341	4,306
Nevada	857,683	1,208	136
New Hampshire	1,128,820	1,720	24
New Jersey	1,561,612	6,462	110
New Mexico	4,003,385	4,124	213
New York	8,388,585	30,429	955
North Carolina	10,102,118	19,541	1,070
North Dakota	7,852,671	13,129	4,945
Ohio	4,548,471	26,030	2,494
Oklahoma	14,765,989	19,814	1,914
Oregon	5,881,351	11,178	775
Pennsylvania	2,526,971	38,833	1,013
Rhode Island	196,837	489	4
South Carolina	7,660,376	8,001	341
South Dakota	11,487,692	14,175	3,351
Tennessee	4,114,378	26,442	1,084
Texas	18,634,939	60,635	4,409
Utah	2,550,642	4,683	239
Vermont	1,210,990	4,067	113
Virginia	10,222,852	16,247	652
Washington	10,685,796	11,571	1,216
West Virginia	935,764	5,484	161
Wisconsin	5,722,638	44,979	2,217
Wyoming	3,894,851	3,771	323
US Total	**360,178,947**	**804,344**	**75,181**

Table 3.17 Recreational Boating Gasoline Consumption in 2006 (1,000 gallons)

State	FHWA	EPA NONROAD2005	Percent difference from FHWA
Alabama	27,032	39,274	45%
Alaska	6,626	5,365	-19%
Arizona	16,141	19,846	23%
Arkansas	18,023	21,391	19%
California	71,755	117,418	64%
Colorado	7,246	8,863	22%
Connecticut	14,436	22,900	59%
Delaware	8,830	11,863	34%
D.C	382	712	86%
Florida	165,142	189,957	15%
Georgia	26,643	37,182	40%
Hawaii	1,995	4,849	143%
Idaho	7,541	9,889	31%
Illinois	34,913	41,500	19%
Indiana	16,294	17,557	8%
Iowa	14,263	15,801	11%
Kansas	5,332	7,585	42%
Kentucky	18,500	24,257	31%
Louisiana	35,244	53,341	51%
Maine	5,853	13,683	134%
Maryland	25,033	32,397	29%
Massachusetts	18,995	35,919	89%
Michigan	75,949	88,502	17%
Minnesota	48,419	58,427	21%
Mississippi	19,289	26,950	40%
Missouri	29,841	41,321	38%
Montana	3,826	4,369	14%
Nebraska	5,145	6,311	23%
Nevada	5,571	7,868	41%
New Hampshire	9,336	13,610	46%
New Jersey	44,318	55,979	26%
New Mexico	3,049	5,473	80%
New York	66,910	93,626	40%
North Carolina	37,397	50,290	34%
North Dakota	3,466	3,996	15%
Ohio	45,494	54,796	20%
Oklahoma	20,131	23,678	18%
Oregon	12,648	21,736	72%
Pennsylvania	28,967	36,010	24%
Rhode Island	4,971	5,214	5%
South Carolina	38,302	35,033	-9%
South Dakota	3,321	4,593	38%
Tennessee	25,919	36,251	40%
Texas	51,502	83,356	62%
Utah	8,258	10,585	28%
Vermont	2,074	3,693	78%
Virginia	28,321	37,405	32%
Washington	26,823	39,015	45%
West Virginia	5,148	6,771	32%
Wisconsin	31,945	42,234	32%
Wyoming	4,789	3,206	-33%
U.S. Total	**1,237,348**	**1,631,848**	**32%**

3.2.3 A brief Examination of Trend and Patterns in Consumption Estimates

When examining estimates from multiple years, for most sectors the gasoline consumption estimates from the NONROAD2005 model are fairly consistent from one year to the next (see Table 3.18). The largest growth in gasoline use was in recreational equipment, such as ATVs, motorcycles, and snowmobiles; about an 18% increase over the time frame from 2003 to 2006. On the other hand, gasoline consumed by industrial equipment showed approximately an18% decrease over the same time period.

Table 3.18 NONROAD2005 Model Gas Consumption Estimates, 2003-2006

	(Million gallons of gasoline)			
Sector	**2003**	**2004**	**2005**	**2006**
Agricultural Equipment	75	78	75	75
Airport Equipment	2	2	2	2
Commercial Equipment	934	958	955	970
Construction and Mining Equipment	146	146	139	136
Industrial Equipment	159	155	139	131
Lawn and Garden Equipment (Commercial)	1,613	1,634	1,605	1,608
Lawn and Garden Equipment (Residential)	879	895	877	876
Logging Equipment	20	20	20	20
Pleasure Craft	1,660	1,665	1,642	1,632
Railroad Equipment	1	1	1	10
Recreational Equipment	1,005	1,079	1,128	1,188
All	**6,494**	**6,633**	**6,583**	**6,638**

The FHWA model also produced results that do not widely vary from year to year over the same period of time (Table 3.19). Annual total NONROAD estimates were consistently higher than FHWA estimates in the corresponding year. This is clearly due to the inclusion of lawn and garden equipment in the NONROAD model, which is not within the scope of the FHWA model. Due to the difference in coverage, FHWA estimates are generally not comparable to NONROAD estimates at the sector level.

Table 3.19 FHWA Gasoline Consumption Estimates, 2003-2006

	Million gallons of gasoline			
Sector	**2003**	**2004**	**2005**	**2006**
Agriculture	853	1,094	1,078	1,229
Aviation	305	314	334	346
Industrial & Commercial	1,227	1,315	1,215	1,197
Construction	570	609	558	552
Marine	1,107	1,033	1,261	1,237
Miscellaneous	355	262	266	284
All	**4,417**	**4,627**	**4,713**	**4,845**

4. THE 2008 OFF-HIGHWAY GASOLINE CONSUMPTION ESTIMATION MODELS

Methodologies implemented in the 2008 FHWA off-highway gasoline consumption estimation models are, in most cases, identical to the 2002 version. The only exceptions in methodology changes were in the components that deal with off-highway gasoline use by farm equipment. In addition to the change in methods, changes in data sources for several models were also implemented. This included data sources that only require periodic updates (e.g., VIUS data), as well as those sources that were "altered" (e.g., change publication or re-categorization) or became available since the 2002 update (e.g., boating survey).

4.1 MODEL COMPONENTS

As shown in Figure 4.1, the off-highway gasoline consumption estimation models contain five components (shown in yellow shaded ovals). Gasoline consumption by the economic sectors of agricultural, industrial/commercial, and construction obviously can involve both trucks (used for off-highway purposes) and other types of equipment (e.g., wheel tractors). Motor-fuel consumption for each of these three sectors is therefore computed as the sum of two estimates, one from trucks operating off-road and another from other equipment utilized by the given sector. Aviation and marine uses, on the other hand, include aircraft and recreational boats. Fuel consumed by these two sectors does not include the use of trucks, so their gasoline consumption estimates are generated from the use of other equipment only. Due to this distinction, discussions on the methodologies applied for estimating gasoline consumption by these five sectors are separated into two groups: (1) off-highway gasoline consumption by truck and (2) off-highway gasoline consumption by other equipment.

4.2 OFF-HIGHWAY GASOLINE CONSUMPTION BY TRUCK – AGRICULTURE, CONSTRUCTION, AND INDUSTRIAL/COMMERCIAL

4.2.1 Data Sources

The major data set used in estimating off-highway uses of gasoline by truck is based on survey data collected by U.S. Bureau of Census under the VIUS program. As indicated previously in Chapter 2, the VIUS contains information such as annual VMT, average MPG, and the percent of off-road travel by trucks with gasoline engines. The 2002 VIUS, which is the last of this data series, was used in the 2008 FHWA model. Additional data sources for estimating the VIUS-based off-highway gasoline consumption by truck include: Ward's *Motor Vehicle Facts and Figures* and FHWA's *Highway Statistics*. The separation of gasoline and gasohol consumption also used data from Table MF-33GA of the *Highway Statistics*.

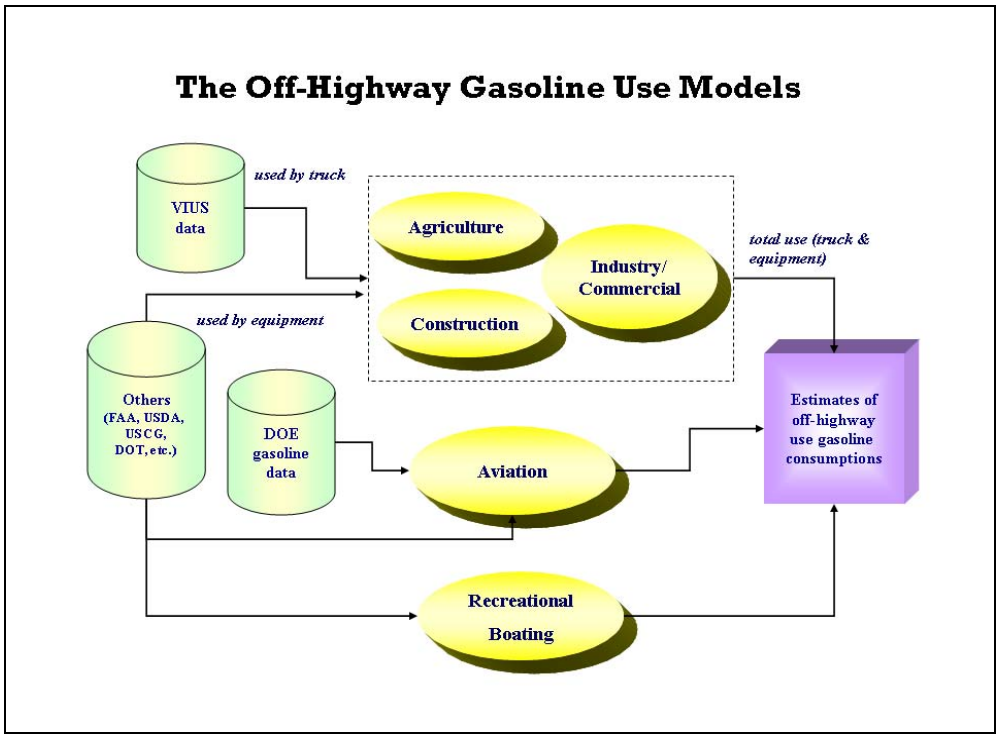

Figure 4.1 Off-highway Gasoline Consumption Estimation Models.

4.2.2 Estimation Method in Brief

Prior to the data analysis, VIUS categories on major-use by truck were grouped to identify records belonging in each of the three sectors of interests: agriculture, construction, and industrial/commercial. Fundamentally, estimation methods for these three sectors are the same. That is, the VIUS-based estimation methodology was not sector-specific.

Note that VIUS data was not used directly in the off-highway fuel consumption estimation models because it does not provide the required details, such as separating on- and off-highway fuel efficiency or giving the percentage of off-road travel occurring within each state. Instead, VIUS data was analyzed to derive ratios for on-highway over non-highway MPG for each major-use category and truck type. Furthermore, state of registration information from the VIUS was assumed to be where the off-road travel took place by each truck, although in reality the state of registration might not necessarily represent where the truck operates.

The MPG ratios derived from VIUS were then used in computing off-highway gasoline use by state[11]. Because VIUS is a survey of vehicles selected based on a statistical sampling method, each record (which represents a vehicle in the survey) also includes an expansion factor that can be used to "inflate" the sample to its national representation (i.e., the universe). As mentioned previously, the 2002 Integrated Off-highway and

[11] Detailed descriptions on this method can be found in *Estimating Non-highway Use of Gasoline and Gasohol*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, August 1994.

Public Use Motor-fuel Consumption Estimation System uses information derived from 1997 VIUS[12]. The updated 2008 System uses information derived from 2002 VIUS, which is the latest available data from this series.

Since VIUS was conducted in a 5-year interval, VIUS-based off-highway consumption estimates need to be adjusted to provide estimates for each non-VIUS year. This adjustment is necessary so changes that might have occurred during the interim years (i.e., years between VIUS programs) could be captured and reflected in the respective estimates. To make such adjustments, additional data sources were used to compute a growth factor for non-VIUS years. These data sources include Ward's *Motor Vehicle Facts and Figures* and the *Highway Statistics* publication series by FHWA. The estimated gasoline-use growth factor is essentially a combined factor based on three growth rates: the number of trucks in operation, average VMT per truck, and average MPG for trucks. These growth rates and the final gasoline consumption growth factor are automatically calculated in the Integrated System, using annual updated data entered by FHWA analysts.

Prior to the 2008 Integrated System, the next step would be to separate gasohol from gasoline consumption. This was done by utilizing additional data obtained from Table MF-33GA, and Table MF-33GLA of the *Highway Statistics*. Because gasohol and gasoline were no longer taxed at different rates, separation of these two fuel types within the FHWA models became unnecessary. Thus, the VIUS module in the 2008 Integrated System was modified to remove gasohol-related calculations.

At this point in the process, the resulting state-level estimates of the off-highway gasoline consumption by truck for the agriculture sector and the industrial/commercial sector were ready to be combined with estimates produced from the equipment consumption model (described later in Section 4.3 of this Chapter). Estimates generated for off-highway gasoline consumption by truck in the construction sector were treated differently, however.

Rather than using the state-level consumption estimates directly, as in the other two sectors, only the estimated national total was retained as a control total. Allocation of this national total to state level estimates is addressed in the next Section. The rationale of handling the construction sector differently was based on the assumption that VIUS does not provide information in a timely fashion to reflect current construction activities within each state.

Again, VIUS is no longer available as a data source in the future because it was terminated prior to the would-be-scheduled update of 2007. This part of the off-highway fuel consumption estimation models will be impacted in the not-so-distant future. A model redesign effort will need to be considered in order to ensure accuracy in FHWA estimates.

[12] The 2002 integrated system originally used data from the 1997 VIUS when it was developed in 2002. The 2002 VIUS data was not released until late 2004. An interim update of that system was made during 2007 to implement 2002 VIUS data into the models.

4.3 OFF-HIGHWAY GASOLINE CONSUMPTION BY EQUIPMENT - AGRICULTURE, CONSTRUCTION, INDUSTRY/COMMERCIAL, AVIATION, AND RECREATION BOATING

In addition to gasoline consumption by trucks operated for off-highway purposes, equipment used for off-highway purposes also consume gasoline. The amount of gasoline consumed by equipment used in the five economic sectors was included in the 2008 FHWA integrated off-highway gasoline consumption estimation system. The five sectors are agriculture, construction, industrial/commercial, aviation, and marine (i.e., recreational boating).

For each sector, gasoline consumption estimated from off-highway use of equipment in each state was combined with those estimated from the off-highway use of trucks for the corresponding state to generate the total off-highway gasoline consumption estimate for FHWA attribution purposes. Because methodologies used in each sector-specific model were different, they are discussed separately in the following subsections.

4.3.1 Agricultural Equipment

In addition to farm trucks, farm equipment (e.g., wheel tractors, cotton pickers, etc.) also consume gasoline. The estimation procedures for off-highway gasoline consumption by farm equipment are a bit more complicated than those for the other four sectors.

Data Sources

The main data source used in estimating off-highway gasoline consumption by farm equipment (other than trucks) for the agriculture sector was obtained from the USDA. Specifically, data collected under the *Census of Agriculture*[13] and the annual *Farm Production Expenditures* are published by USDA's National Agricultural Statistics Services (NASS). Additional data used in this estimation model also includes *Petroleum Marketing Annual* from Energy Information Administration (EIA), Department of Energy and *Highway Taxes and Fees* published by the FHWA.

Due to changes in published USDA data, the method for estimating gasoline consumption by agricultural equipment has been revised significantly. As a result, this component of the 2008 FHWA Integrated System is significantly different from those in the 2002 or earlier versions. More discussions on the changes in USDA data and associated model modifications are described below.

Estimation Method

As in the earlier agriculture model, this FHWA agriculture model assumes that farm equipment was used solely for off-highway purposes. Note that gasohol was not used by

[13] Agriculture Census 2007 website: http://www.agcensus.usda.gov/Publications/2007/index.asp.

farm equipment as had been assumed in prior versions of agriculture model[14]. Since gasohol was no longer separated from gasoline for the FHWA attribution purpose, this assumption was not needed for the 2008 models.

As previously stated, a few changes made in USDA publications in recent years have impacted the FHWA model significantly. First, the USDA no longer separates gasoline expenditure by state in its *Census of Agriculture* reports, although it continues to publish information on total fuel expenditure by State for the Census year. Because of this data change, development of an alternative method, that does not rely on gasoline-to-total fuel ratios computed from the *Census of Agriculture* data, is required for the FHWA 2008 model. Secondly, USDA's Farm Production Regions were changed from ten to five regions in 2004[15]. This change impacted FHWA formulas when estimating shares of fuel expenditure for states within the regions. Thus reconstruction of formulas for this purpose is also necessary.

Not all USDA publication changes are impacting FHWA applications negatively, however. Instead of publishing total fuel expenditure data only at regional level as in the past, USDA began publishing total fuel expenditure data for each of the 15 "Leading Cash Receipts" states since the *Farm Production Expenditures* 2004 Summary report (published July 2005). Regional level statistics were provided for other non-published states. Although not at the same level of detail, the USDA also publishes total gasoline expenditure at the regional level in the *Farm Production Expenditures* annual report.

The processes needed in estimating off-highway gasoline consumption by agriculture equipment are briefly described below.

a) Estimating total fuel expenditure by State in analysis-year

The farm equipment consumption model began with the estimation of annual state total fuel expenditure in agricultural operations during the analysis year. Since total fuel expenditure in each of the top-15 states is readily available from the *Farm Production Expenditures* report of the analysis-year (thus "known"), FHWA only needs to estimate total fuel expenditures for the 35 non-published states and Washington, D.C. Using detailed state-level total fuel expenditures data from the Census-year (i.e., 2007 *Census of Agriculture*), a share for each non-published state within its corresponding region can be calculated. Assuming these shares stay the same in the analysis-year, the regional total from the non-published states (i.e., regional fuel expenditure total subtracts those from "known" states within the given region) can be distributed accordingly to estimate fuel expenditures by those states.

[14] Farm equipment that operates on diesel fuel is not in-scope because off-highway diesel is dyed and therefore is non-taxable. Moreover, this assumption was made due to data limitations encountered during the model development in 1994.

[15] USDA stated that: *this change improves the overall quality of regional estimates and allows NASS to publish state-level expenditure estimates without disclosing data for unpublished states.* See page 2 of *Farm Production Expenditures 2003 Summary*, USDA, 2004.

Note that statistics reported in the *Farm Production Expenditures* annual report excluded the States of Alaska and Hawaii, although geographically these two states could be in the West Region. Thus, the above described method was not applicable to the estimate of fuel expenditures for these two states. Instead, a simple supplemental method was applied to generate estimates for Alaska and Hawaii. Assuming changes between the Census-year and the analysis-year for the two states are at the same rate as that in the lower-48 states, total fuel expenditure for Alaska (or Hawaii) can be estimated for the analysis-year. This was done by multiplying Alaska (or Hawaii) fuel expenditure data from the Census-year by a factor, which was computed using the value resulting from the total fuel expenditures reported in the *Farm Production Expenditure* summary for the analysis year divided by the same information for the Census-year.

b) *Generating total gasoline gallons in Census-year*

As noted above, gasoline expenditures at the state level were no longer available in the *Census of Agriculture* publication. To derive state-level gasoline expenditure estimates, total fuel expenditure data from the *Census of Agriculture* was supplemented with information on regional gasoline shares extracted from the *Farm Production Expenditures* summary report for the Census-year. Due to the lack of available data, a simple assumption was applied in estimating state-level gasoline expenditures in the Census-year. Assuming states within a given region all have the same gasoline-to-total-fuel expenditure share (from *Farm Production Expenditures*), estimates of gasoline expenditures by state can be computed.

The state-level expenditures estimated from the above process were then converted to gallons using gasoline price (obtained from *Petroleum Marketing Annual* published by the EIA) and gasoline tax information (obtained from *Highway Taxes and Fees* published by the FHWA) for the Census-year.

c) *Estimating ratio of off-highway use gasoline gallons in Census-year*

The methodology for estimating off-highway use gasoline gallons was not changed in the 2008 FHWA model. That is, the same method used previously was kept in the current updated system. State-level off-highway gasoline use by agricultural farm equipment in Census-year was based on a statistical regression model (developed by ORNL in 1994). This regression model was developed using information gathered from the *Census of Agriculture*, which established a relationship between the off-highway agricultural gasoline use and the number of farm equipment units used by farmers within each state during the Census year. The ratio of off-highway use gasoline gallons by a state, in a given Census year, was computed by dividing its regression-estimated off-highway gasoline gallons into the associated total estimate in the above process (i.e., step b).

d) *Generating total gasoline gallons in analysis-year*

Similar to step (b) the total gasoline expenditure by state in the analysis-year can be estimated using results from step (a) and regional gasoline shares extracted from the *Farm Production Expenditures* summary report for the analysis-year. That is, by applying the simple assumption that states within a given region all have the same gasoline-to-total-fuel expenditure share, estimates of gasoline expenditures by state can be computed. The resulting state-level expenditures were then converted to gallons using the gasoline price obtained from the EIA and gasoline tax information from the FHWA for the analysis year.

e) *Estimating off-highway gasoline gallons by farm equipment*

By assuming the ratios of off-highway use gasoline from step (c) remain the same in the analysis year, the off-highway agricultural gasoline consumption by farm equipment in each state can be generated.

By combining estimates for farm trucks and estimates for farm equipment, the process of estimating the off-highway agricultural uses of gasoline and gasohol by state is complete. Note that similar to the VIUS, the *Census of Agriculture* is also under a five-year data collection cycle. The 2008 FHWA consumption estimation model uses the data from 2007 *Census of Agriculture*.

4.3.2 Construction

Similar to agriculture, motor-fuel can be consumed by both equipment and vehicles used off-highway for construction purposes. The majority of vehicles used for off-highway construction purposes are expected to be trucks and vans, particularly single-unit heavy trucks. Therefore, this estimation was included under the VIUS framework discussed earlier. However, most construction equipment, which includes surfacing equipment, loaders, cranes, cement and mortar mixers, etc., is not licensed for highway use and is generally powered by diesel fuel. Since FHWA motor-fuel reporting currently does not include off-highway diesel usage, this equipment is not accounted for.

Data Sources

In addition to the use of VIUS data, as covered under the truck-use model, a major data source used in estimating off-highway gasoline consumption for construction purposes is the *Statistical Abstract of the United States*. This report is published annually by the Census Bureau.

Estimation Method

The computation process in the construction module is more straightforward than that in the agriculture module. As described earlier, the national total of off-highway motor-fuel consumption by truck for construction purposes was estimated under the VIUS-based

model (Section 4.2 in this Chapter). State-by-state estimates of construction use of gasoline were not produced from that model. Instead, dollar-values of non-residential construction contracts in each state were obtained from the "Construction Contracts" table[16] of the latest edition of *Statistical Abstract of the United States* and used to calculate state shares (i.e., percent of contracts in a given state). These state-shares were then used to distribute the VIUS-estimated U.S. total to each state. This approach was based on a rationale that data on non-residential construction contracts published in the *Statistical Abstract* is more up-to-date than what was derived from the VIUS data. Using such an approach is thus expected to generate estimates that can better reflect construction activities that occurred within the state.

4.3.3 Industrial/Commercial

Data Sources

Similar to those in the construction sector, the majority of vehicles used for off-highway industrial and commercial purposes are expected to be vans and trucks, mostly for shipping products and materials. Therefore, VIUS data can be used as a major data source for this part of the estimates. The VIUS data on off-road use of trucks in manufacturing, mining, forestry, wholesale and retail trade business, utilities, services, rental, and for-hire transportation business were included under this category.

Estimation Method

Off-highway use of gasoline by the industrial and commercial sectors was estimated in the same general manner as for the agriculture and construction sectors. Motor fuels can be consumed by both equipment and trucks used off-road for industrial and commercial purposes. Industrial and commercial gasoline consumption by trucks that operated off-road was already estimated in the VIUS-based module.

Industrial and commercial equipment, which includes forklifts, sweepers, scrubbers, material handling equipment, generators, pumps, welding equipment, etc., could also consume gasoline. In 2002 , due to lack of available data on gasoline consumption by engines in the above-mentioned equipment, the FHWA Off-highway Gasoline Consumption Estimation Models only consider gasoline consumption by trucks operating off-road in industrial and commercial sectors. Though fuel use data on this equipment is currently available from EPA, it was not used in the 2008 update due to compatibility issues discussed below.

Challenge in Current FHWA Industrial and Commercial Models

As discussed in Chapter 2 of this report, the EPA NONROAD2005 model produces estimates on gasoline consumption for equipment used in industrial and commercial

[16] Information from the "Construction Contracts" table is not available from the online publication. Census stated: *The complete publication including this copyright table is available for sale from the U.S. Government Printing Office and the National Technical Information Service*.

sectors. Based on the NONROAD model, over 1 million gallons of gasoline were consumed in 2006 by equipment categorized for industrial and commercial uses. This indeed indicates a significant amount of gasoline consumption by off-road activities in these two sectors that were not currently accounted for by the FHWA model.

Note that there is a data compatibility issue in this case between the FHWA and NONROAD models. As pointed out previously, the mining sector was included in the industrial and commercial category in the FHWA model, but not in the NONROAD model (with construction instead).

4.3.4 Aviation

Data Sources

Two major sources of data were used in estimating aviation gasoline consumption. The first data source is the *Prime Supplier Sales Volumes* on aviation gasoline (in gallons) from EIA[17]. This data is collected by EIA, on a monthly basis, from all firms identified as suppliers who made the first sales of the products. This information is also published in the *Petroleum Marketing Annual* publication. The second data source is statistics on "hours flown by general aviation" for each state obtained from the *General Aviation and Part 135 Activity Survey*[18] results (Table 2.3 in CY 2007 report). The survey is conducted annually by the Federal Aviation Administration (FAA).

Estimation Method

The estimation procedure for off-highway gasoline consumption in the aviation sector is relatively straightforward. For most states, annual totals from the EIA aviation gasoline consumption as published in the *Petroleum Marketing Annual* (Table 46 in 2008 report), or downloaded from EIA website, can be used directly. Due to confidentiality concerns, however, data for some states and Washington, D.C. were not disclosed by EIA. These missing data (i.e., those withheld by EIA) have to be estimated by the FHWA.

A statistical regression model was included in the FHWA consumption estimation model. This regression model used a relationship established between existing EIA data on "aviation gasoline consumption" and FAA data on "hours flown by general aviation by states" to estimate gasoline consumption for states that are either missing or not disclosed by the EIA. Total aviation gasoline consumption and total hours flown reported in FAA publication *FAA Aerospace Forecasts*[19] were used to compute average gasoline consumption per hour flown[20]. This average was then multiplied by the sum of total number of hours flown for the 50 states and Washington, D.C. to generate a "control

[17] Monthly and annual data on aviation gasoline product can be downloaded from EIA website at: http://tonto.eia.doe.gov/dnav/pet/pet_cons_prim_a_EPPV_P00_Mgalpd_m.htm.
[18] See http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2007/.
[19] Available at URL: http://www.faa.gov/data_research/aviation/
[20] FAA statistics include Puerto Rico and other U.S. Territories that are not in scope for the FHWA application.

total" for aviation gasoline. Regression-estimated aviation gasoline consumption results, on states with missing or undisclosed EIA numbers, were then adjusted by their shares of the difference between the "control total" and the sum of those fully-reported states. Each state's share was determined by dividing its estimated amount (from the regression equation) into the sum of all regression-estimates for states with missing data.

Challenge in Current Aviation Model

Note that the statistical regression equation used in this model was developed in 1994. It is suggested that, at the minimum, a recalibration of the model should be done to obtain updated parameters for this application. Furthermore, by design, the current aviation model is in some way over-"penalizing" states with missing EIA data. Regardless of the extent of missing data (e.g., missing 1 month or missing 12 months), the known values of all involved states were ignored and replaced by their regression estimated amounts; which were then readjusted with a portion of the "left over" control total. Although this is a reasonable approach in general, states with only one/two missing monthly data tend to be overly adjusted under this method. A revision of the current methodology to eliminate this weakness, and to improve its accuracy, should be considered by the FHWA.

4.3.5 Marine - Recreational Boating

Since nearly all commercial vessels are powered by diesel fuel, the marine sector of interest for FHWA is limited to recreational boating using outboard motors. The fundamental issue here was to determine the number of powered boats in each state and the average amount of gasoline each boat uses for recreational purposes.

Data Sources

The primary data source used for estimating gasoline consumption by recreational boating use in the 2008 FHWA model was based on statistics produced from the *National Recreational Boating Survey*. This was a major survey of boating sponsored by U.S. Coast Guard (USCG resulting in two sets of data from surveys conducted in 1991 and 2002. Additional data sources used in this module include *Boating Statistics* published annually by USCG; *Statistical Abstract of the United States*; and income data from the Census.

Estimation Method

The year 2002 was used as the base-year for this part of the modeling effort because data on the latest number of powered boats in each state were from the *2002 National Recreational Boating Survey*. Using data extracted from the annual *Boating Statistics* on the number of registered boats by state for the base-year and the latest year, a growth rate for the number of registered boats between these two years can be computed for each state. These growth rates are then applied to the base-year data to derive the estimated number of powered boats for the most current year by state.

Using the median household income data by state from the Census, for both 2002 and the latest year, a growth rate of the household income can be computed for each state. These state-level growth rates were further corrected using the Consumer Price Index, taken from the *Statistical Abstract of the United States*, to adjust for inflation during the time period. These adjusted growth rates were then applied to the 1991 "average annual gallons used per boat" (i.e., average fuel efficiency per boat) to produce estimates for the target year. Note that 1991 fuel efficiency data was used because information on this data item was not available from the 2002 survey.

The estimated "average gallons used per boat" was then multiplied by the number of powered boats for each corresponding state to obtain the estimates of total fuel consumption in recreational boating by state. These estimates are adjusted one more time to account for boats that are powered by fuels other than gasoline (i.e., diesel). This adjustment was made using information on the gasoline/diesel split, obtained from the 2002 *National Recreational Boating Survey*.

Challenge in FHWA Boating Model

Clearly the main limitation of current FHWA model is on its outdated data source. Although the 2002 survey provided some updated information, some 1991 data elements were no longer available (e.g., average annual gallons per boat). Because no similar updated data could be identified, the 1991 survey data was still in use. A private source, *Boating Registration Statistics* published by the National Marine Manufacturers Association (NMMA), also provides statistics on recreational boating. The NMMA also conducts special surveys periodically to study issues relevant to boating. For instance, in 2008, a survey was conducted by Michigan State University with funding support from NMMA to examine the effect of fuel prices on traditional powerboat owners boating habits. It might be possible to approach NMMA for special tabulations that could be useful for FHWA applications.

4.4 TOTAL COMBINED OFF-HIGHWAY GASOLINE CONSUMPTION

All state level off-highway consumption estimates results from the above-discussed components are combined into a single table (i.e., total off-highway gasoline consumption). If a state-submitted number was also available for any of these major-use categories, the FHWA will evaluate the quality of the reported data and compare it to the model-estimated value before accepting the state-reported number. The final off-highway fuel consumption estimates are published in Table MF-24 of the annual *Highway Statistics*.

5. ESTIMATION OF GASOLINE CONSUMPTION BY PUBLIC SECTOR

FHWA estimates motor-fuel usage by the public sector for the same reasons that it estimates off-highway gasoline consumption. Because taxation policies in some states treat public use of motor-fuel differently from others, using state submitted data without adjustment would create inconsistent and incompatible results that could not be used to fairly distribute federal funds to the states. The public sector includes federal, state, county, and municipal governments. On the federal level, only civilian use of motor-fuel is taken into consideration. Federal military motor-fuel use is exempted from tax liability.

The FHWA estimation model for gasoline consumption by the public sector contains two components. As shown in Figure 2.1, motor-fuel consumed by federal civilians in each state and those consumed by State, County, and Municipal (SCM) governments are estimated separately using two different approaches. These approaches are discussed below. Note that public sector models in the 2008 FHWA integrated motor fuel consumption estimation system have not changed from earlier years. The methodologies used were the same as those originally developed; only the data has been updated over the years.

5.1 FEDERAL CIVILIAN MOTOR-FUEL CONSUMPTION ESTIMATION MODEL

Data Sources

Data used for estimating federal civilian fuel consumption was compiled using various information sources, including publications produced by federal and private organizations. The number of federally owned vehicles that are operated by civilian departments and used in each state is obtained from Table MV-7 of the *Highway Statistics*. Note that there is a one-year lag on this publication; data used in the analysis year is therefore one year behind. Data for the annual estimates of "gallons used per vehicle" are obtained from the *Federal Motor Fleet Report*[21] published by the U. S. General Services Administration (GSA).

Estimation Method

The methodology used in estimating Federal Civilian highway use of motor-fuel for all states was developed by ORNL in 1994[22]. The methodology was based on the simple concept of multiplying the number of vehicles by the average gallons consumed per vehicle to derive the total amount of fuel used. The estimation process is presented in

[21] Federal Motor Vehicle Fleet Report: for fiscal year 1999, published by U.S. General Services Administration (GSA), 2001.

[22] See *Estimating Public Uses of Motor Fuel: Phase II*, ORNL/TM-12737, by Miaou, S. P., S. C. Davis, J. R. Young, S. G. Strang, and A. Lu, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1994.

Figure 5.1. Unlike the off-highway fuel consumption estimation models, the process of estimating the federal-use motor-fuel consumption is rather straightforward. The estimation process begins with extracting data from Table MV-7 of the latest publication of *Highway Statistics* to update the associated input cells contained in the FHWA integrated system. Data of interest in this case is the number of federally owned cars/vans, buses, trucks, and motorcycles that are operated by civilian departments and used in each state.

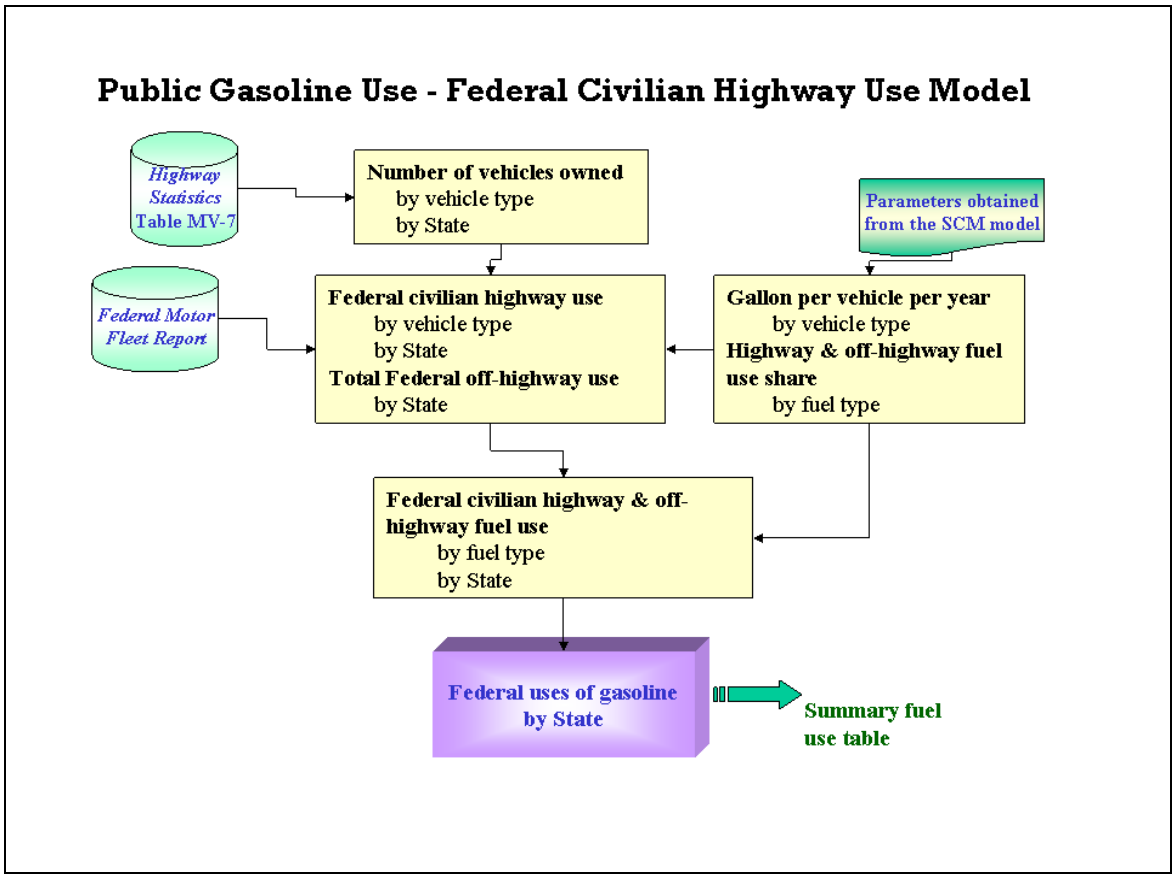

Figure 5.1 Process flow of the federal component of the Public Use model.

Information taken from the latest GSA report includes data on fuel consumption and average in-use vehicle inventory for various vehicle types by federal agency. Using these GSA data, estimates of per-vehicle fuel consumption by vehicle type are calculated. Note that GSA data is not separated by fuel type. Additional processing is therefore required in order to generate the needed level of detail. To accomplish this, several parameters (or "coefficients") needed for distributing fuel consumption into different fuel types, as well as breaking fuel usage into on- and off-highway uses are obtained from the SCM module (discussed in the SCM subsection below). The estimates for federal on-highway and off-highway fuel consumption, by vehicle type and by state, are further disaggregated into gasoline, gasohol, and diesel fuels by state.

5.2 MODEL FOR ESTIMATING FUEL USE BY STATE, COUNTY, AND MUNICIPAL GOVERNMENTS

Data Sources

The original method for estimating motor-fuel consumption by SCM governments for all states was based on results from a study conducted by ORNL for FHWA in 1994. The study used population and land-area of a region (e.g., state, county, or city) to estimate fuel used in that region. These regional population and land-area data are obtained from the U.S. Census.

In addition to the Census data, a statistical sampling survey of SCM governments in the U.S. was also conducted as part of the 1994 study. The survey data and results were used to develop the basic estimation equations used in this SCM module.

Estimation Method

The SCM fuel consumption estimation process is presented in Figure 5.2. The methodology is fairly simple and straightforward.

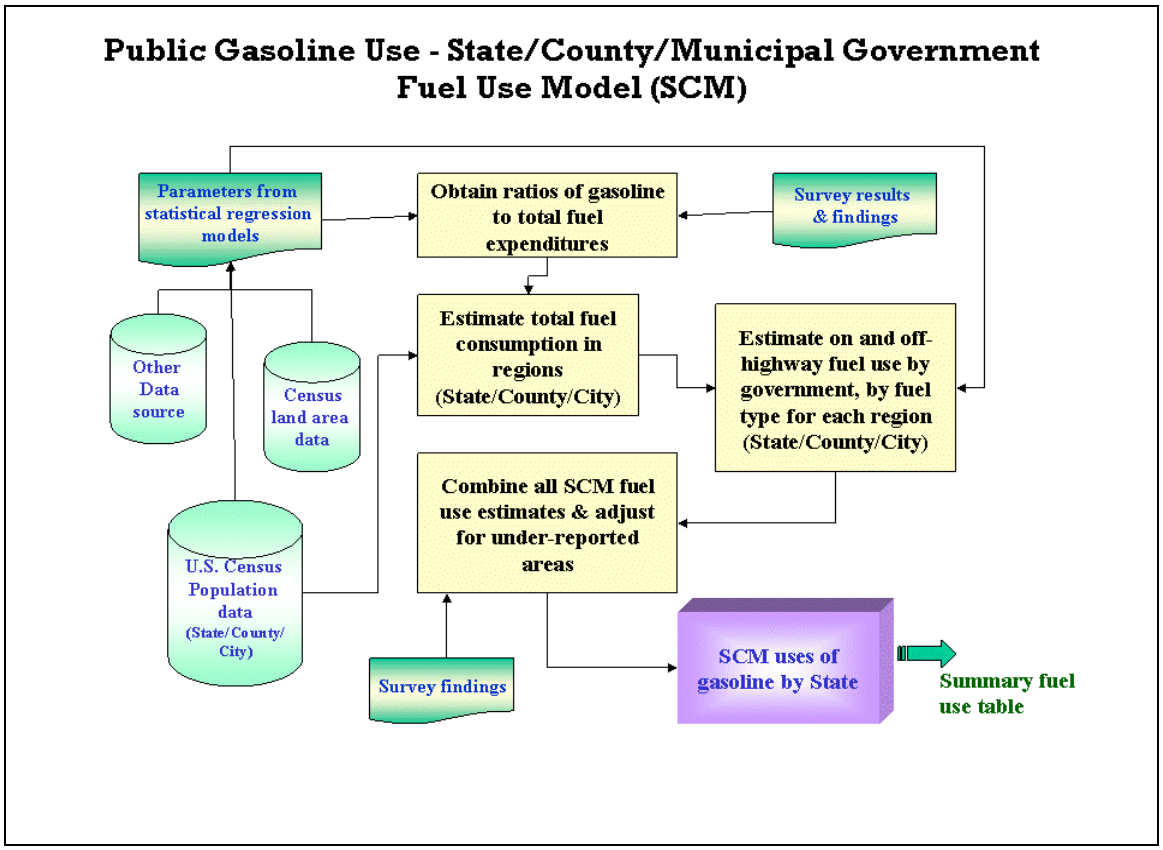

Figure 5.2 Process flow of the SCM component in the Public Use model.

Parameters (or coefficients) from regression equations developed by ORNL under the 1994 SCM study are used as a part of the input data for the current FHWA SCM estimation model. These regression equations established relationships between fuel consumption, population, and land-size for each type of region using the Decennial Census data. Detailed technical descriptions on these regression equations and how they were developed have been documented in an ORNL technical report[23].

As mentioned previously, several percentages derived from the sample survey data are also used as inputs for this SCM module. These percentages are used to divide the total fuel consumption estimates into on-highway and off-highway uses, as well as to distribute them among different fuel types.

Once fuel consumption estimates for each type of geographic SCM region are computed, they are combined to produce a set of total SCM estimates. To account for underreporting in certain areas under the SCM sample survey (e.g., school systems), then a final adjustment is made to the estimates prior to finalizing the SCM fuel consumption result table.

Results from the SCM component are combined with results from the federal civilian component to generate a total public-use motor-fuel consumption estimate by state. The estimate is then used in the MF-20 analysis where FHWA determines whether state-submitted or model-generated data should be used.

[23] *Estimating Public Uses of Motor Fuel: Phase II*, ORNL/TM-12737, by Miaou, S. P., S. C. Davis, J. R. Young, S. G. Strang, and A. Lu, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1994.

6. POST ESTIMATION ATTRIBUTION PROCESS

Once FHWA completes the estimation processes and calculates state motor-fuel consumption for off-highway, public, and gasohol uses, the annual state-by-state analysis begins. This normally starts around June-July of the year following the analysis-year (see Figure 2 in Section I). FHWA begins its preparation of an annual FHWA-551M Summary for a state as soon as the monthly motor-fuel data are completed for that state. FHWA checks the total from FHWA Form-551M against Form-556 to ensure reported consumption (in gallons) and receipts (in dollars) are within acceptable limits. Additional adjustments may be required when differences are identified. Depending on the scale of such differences, FHWA may contact a state for an explanation.

FHWA conducts the motor-fuel gallon analysis under a data processing component called MF-20 Analysis. The MF-20 file for each state contains consumption by fuel type (gasoline and special fuels), use (highway/off-highway), and tax status (exempt, refunded, at-other-rate, etc.). The purpose of the MF-20 Analysis is to subdivide fuel consumption into several categories. The most important categories are highway versus off-highway use. The distinction between public versus private and commercial is secondary. At this point in the process, estimates generated by the FHWA models for off-highway and public uses are automatically entered in the MF-20 spreadsheet for the applicable state. Using these data, FHWA proceeds with other components in the attribution process. These processes are out of the scope of this report and are not included here. Descriptions of these processes can be found in the FHWA attribution and apportionment booklet.

In addition to using the estimates from the consumption estimation models to aid the FHWA attribute process, final estimates from these models are also used in producing *Highway Statistics* motor-fuel-related tables for the analysis year. For example, the off-highway gasoline consumption by major uses is published in Table MF-24. A summary of the off-highway and public uses is included in Table MF-21. On-highway use of motor-fuels by state is given in Table MF-27. Besides these motor-fuel-related tables, model-generated estimates are also used by the FHWA in calculating state shares of the HTF receipts. Therefore, these consumption estimates directly affect the data quality in several highway finance tables published in the *Highway Statistics* (e.g., Tables FE-9 and FE-221) as well.

7. SUMMARY

The vast majority of state-submitted estimates of motor-fuel consumption are for on-highway use. Only 2-3% of the total consumption is in question as to on- or off-highway use in the states. The consumption estimation processes described in this report are needed to ensure consistency among states. Moreover, because of the differences in state data reporting, FHWA has to evaluate and adjust the data submitted by the states to account for any inequality when reporting certain fuel uses. By improving the states' understanding of these models, FHWA can help the states improve the quality of the data they submit. With better knowledge of current FHWA models, states can also provide input and feedback to the FHWA for future model improvements.

The Off-Highway Gasoline Consumption and Public-Use Gasoline Models were originally developed in 1994. The models underwent system integration and data updates in 2002-2003, and continued with the latest model updates in 2008. The off-highway gasoline consumption is estimated in five major categories: agricultural, industrial and commercial, construction, aviation, and marine; each sector is estimated individually in a separate module within the model. These data are published in Table MF-24 of the annual FHWA *Highway Statistics*. The quality of these fuel use estimates, therefore, directly affects the data quality in several fuel use and highway finance tables published in the *Highway Statistics*.

Under the 2008 study, each module in the 2003 version of the Off-Highway Gasoline Consumption Model was examined to identify data source changes that occurred since 2003; and to perform needed updates if the data source was changed (either removed or new data elements were added). Among the five modules, only the agricultural model required a significant methodological change, which was due to changes in the input data (i.e., USDA data) to the agricultural component of the off-highway model. The revised model utilizes information not published before (e.g., annual data on fuel expenditures for the top-15 states). A change on the estimation of total agricultural gasoline consumption was also necessary because such data was no longer provided under the Agriculture Census. Estimation methods used in all other off-highway categories were generally not changed, although slight changes in data sources were made. Table 7.1 shows a summary of the data sources used for each sector.

There are some challenges concerning the data used in several modules of the current FHWA off-highway models. The agricultural, industrial and commercial, and construction models all use data from the VIUS, which was discontinued after the 2002 survey. This is a growing concern for the future when updated data are no longer available for applications that rely on the VIUS; a concern that is widely spread across many federal agencies (DOE, DOT, EPA, etc.). One of the FHWA offices is currently undertaking some initial steps to search for a resolution to "replace" or "reproduce" the VIUS. A review of the off-highway motor fuel models would be necessary after results from such a VIUS-effort are published.

Table 7.1. Data Sources for FHWA Off-Highway Estimates

Agricultural	
Agriculture Census	Farm Production Expenditure
Motor Vehicle Facts & Figures	Petroleum Marketing Annual
Highway Statistics	Highway Taxes & Fees
Vehicle Inventory & Use Survey	
Industrial and Commercial	
Vehicle Inventory & Use Survey	Highway Statistics
Motor Vehicle Facts & Figures	
Construction	
Vehicle Inventory & Use Survey	Highway Statistics
Motor Vehicle Facts & Figures	Statistical Abstract of the United States
Aviation	
General Aviation & Part 135 Activity Surveys	Petroleum Marketing Annual
Marine	
Boating Statistics (US Coast Guard)	National Recreational Boating Survey (2002)
Statistical Abstract of the United States	U.S. Boating Registration Statistics (NMMA)
Census household income data	

During the 2008 update of the off-highway gasoline consumption model, new sources of data that might have the potential to improve the off-highway consumption estimates were explored. The EPA NONROAD2005 model was examined for its potential usefulness in FHWA applications, either as a supplement to existing components or as a substitute for other areas. The NONROAD2005 model is a simulation model which is programmed to produce emissions estimates for years between 1970 and 2050. The model includes data on the population of off-road equipment and estimated fuel use of the equipment. As with any model, the reliability of the estimates declines as forecasts are made further from the base year.

Under this study, estimates on equipment population and their fuel uses for the year 2006 were generated from the NONROAD2005 model and examined against the FHWA off-highway fuel use estimates by category (agricultural, industrial and commercial, construction, aviation, and marine). In all but marine sectors, the NONROAD model and the FHWA model each cover different equipment population and their fuel consumptions are therefore, not comparable, although they may complement each other in some cases. Under the agriculture sector, aside from not including the farm-based trucks, the NONROAD model included many types of off-road equipment that were not collected by the USDA (i.e., FHWA's main data source for the agriculture model). However, a comparison of the national number of agricultural equipment, between USDA Census and NONROAD, indicated a significant undercount in NONROAD agricultural equipment population.

For the marine sector, which is the only comparable sector between the two models, total fuel consumption estimated from both models were generally similar in magnitude. The FHWA and the NONROAD model both estimate the use of gasoline in power boats,

although the NONROAD model also includes personal water craft. In addition to the five sectors (agricultural, industrial and commercial, construction, aviation, and marine), there are also some categories of equipment in the NONROAD model that are not currently in the FHWA estimates. These include commercial and residential lawn and garden equipment, along with other equipment. Results from the NONROAD2005 data were not used to update the FHWA model due to several issues as discussed in this report, including the historical compatibility with previous FHWA estimates and the uncertainty of model results as the data move away from the base year.

The data used in the Public-Use model, which estimates gasoline consumption by the public sector, are updated annually, but their underlying methodology has not been revised since 1994. The model relies on a regression equation that was generated based on survey data collected during its model development effort in 1994. The major challenge in updating the public-use estimation models, thus, is the lack of data. It will require a significant data collection effort to gather the needed information. Because of this, estimation models for the public sector were not updated under the 2008 study. This is an area of consideration for future improvements if resources can be allocated.

Furthermore, due to resource limitation, several components of the off-highway model that utilized regression modeling approaches were not recalibrated under the 2008 study. This recalibration would be desirable in order to improve model accuracies.

APPENDIX A. AN EXAMPLE OF STATE WORKSHEET

NONHIGHWAY AND PUBLIC USE GASOLINE WORKSHEET - 2003

(THOUSANDS OF GALLONS)

USE		FHWA ESTIMATE	EXEMPT	FULLY REFUNDED	TAXED AT PREVAILING RATE	TAXED AT OTHER RATE	TOTAL	COMMENTS
AGRICULTURE		16,529						
AVIATION		6,671						
INDUSTRIAL & COMMERCIAL		14,913						
CONSTRUCTION		10,284						
RECREATIONAL BOATING		22,356						
FEDERAL-HIGHWAY USE		5,785						
SCM HIGHWAY USE		43,033						
SCM NONHIGHWAY		2,244						
MISCELLANEOUS NONHIGHWAY								
TOTAL NONHIGHWAY		70,754						
TOTAL PUBLIC USE		51,062						
LOSSES:	ACTUAL							
	1 PERCENT FLAT							
	TOTAL							

APPENDIX B. DATA SOURCES FOR MODELS

Table C.1 Estimating Off-Highway Gasoline Consumption

Data Source	Data Provider	Frequency	Estimating Fuel Use By	Most Recent Publication[24]	Data Items or Other Remarks
Census of Agriculture	NASS/ USDA	5 year	Agricultural equipment	2007	Total fuel expenditures and number of selected machinery and equipment by state. http://www.agcensus.usda.gov/Publications/2007/index.asp
Farm production Expenditures	NASS/ USDA	annual	Agricultural equipment	2009	Farm production expenditures on total fuel by region and state-level fuel expenditures for the leading 15 states. Also total gasoline expenditures by region. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1066
Petroleum Marketing Annual	EIA/DOE	annual	Agricultural equip. Aviation	2008	Gasoline price by state; aviation gasoline sales by state. http://www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum_marketing_annual/pma.html
Vehicle Inventory & Use Survey	US Census	5 year	All trucks used for off-road purposes	2002	State level data on VMT, MPG, annual mileage, and percentage of off-road driving. The series has been discontinued in 2007. http://www.census.gov/svsd/www/vius/2002.html
Motor Vehicle Facts & Figures	Ward's Communi-cation	annual	All trucks used for off-road purposes	2007	Total trucks in operation (U.S. total) based on R. L. Polk.
Highway Statistics	FHWA/ DOT	annual	All but boating and aviation	2007	Specifically, tables VM-1, MF-33GA, and MF-101. http://www.fhwa.dot.gov/policyinformation/statistics/2007/
Boating Statistics	USCG	annual	Recreational boating	2008	Number of registered boats by state. http://www.uscgboating.org/statistics/Boating_Statistics_2008.pdf
Statistical Abstract of the U.S.	US Census	annual	Construction Recreational boating	2009	Total values of non-residential construction contracts by state. Heating-degree days, land area, and CPI by state. http://www.census.gov/compendia/statab/2009edition.html

[24] The year given is for the most recent publication available at the completion time of this report. Depending on its release date, an earlier edition of the data might be used in the 2008 FHWA system.

Data Source	Data Provider	Frequency	Estimating Fuel Use By	Most Recent Publication[24]	Data Items or Other Remarks
National Recreational Boating Survey	USCG		Recreational boating	2002	Number of powered boats; fuel consumption; gasoline/diesel split by state.
U.S. Boating Registration Statistics	NMMA	annual	Recreational boating	2008	Number of power boats. http://www.nmma.org/facts/
State Energy Profile, State Energy Data System	EIA/DOE		Aviation	2007	Table F2: Aviation Gasoline and Jet Fuel Consumption, Price, and Expenditure Estimates by Sector, 2006. http://www.eia.doe.gov/emeu/states/sep_fuel/html/pdf/fuel_av_jf.pdf
General Aviation And Part 135 Activity Surveys	FAA/DOT	annual	Aviation	2007	Total hours flown by state & US total aviation gasoline consumption. http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/

Table B.2 Data Sources for Models - Estimating Government Use (i.e., Public-use) of Gasoline

Data Source	Data Provider	Frequency	Estimating Fuel Use By	Most Recent Update	Data Items or Other Remark
Highway Statistics	FHWA/ DOT	annual	Federal government	2007	Table MV-7 on publicly owned vehicles. http://www.fhwa.dot.gov/policyinformation/statistics/2007/
Federal Fleet Report	GSA	annual	Federal government	2008	Fuel consumption & number of vehicles for cars/vans, buses, & trucks. http://www.gsa.gov/Portal/gsa/ep/contentView.do?contentType=GSA_BASIC&contentId=24171
Population projection and land area	US Census	annual	SCM government	2008	Annual population and land size by state, county, and city. http://www.census.gov/popest/states/states.html, http://www.census.gov/popest/counties/counties.html, and http://www.census.gov/popest/metro/metro.html.
Responses from 1992 "Government Use of Motor Fuel Questionnaire"	FHWA/ DOT	N/A	Federal and SCM governments	1992	Percent of on/off-highway use; percent of gasoline/diesel use.