DOE/EIA-M070(2008)

Transportation Sector Module of the National Energy Modeling System: Model Documentation 2008

October 2008

Office of Integrated Analysis and Forecasting
Energy Information Administration
U.S. Department of Energy
Washington, DC 20585

Update Information

This thirteenth edition of the *Transportation Sector Module of the National Energy Modeling System—Model Documentation 2008* reflects changes made to various sections of the transportation module over the past year for the *Annual Energy Outlook 2008*. These changes include:

Light Duty Vehicle (LDV) Module:

The new vehicle fuel economy calculation has been updated to reflect minimum fuel economy requirements specified in the Energy Independence and Security Act of 2007 and to implement a footprint based standard for light duty trucks. The calculation is now made for seven manufacturer groups: domestic cars, import cars, and five truck manufacturer groups. In addition to the traditional CAFE standard used for cars, light truck manufacturers can opt to comply to either the traditional standard or the footprint based standard through model year 2011 based on ease of compliance. Other updates to the LDV module include new travel demand coefficients.

Light Duty Vehicle Fleet Submodule:

The LDV Fleet Submodule was restructured to reflect recent compliance behavior of vehicle fleet operators covered under the Energy Policy Act of 1992.

Air Module:

The Air Module has been updated with the addition of a new submodule to track the movement of commercial aircraft (including both active and parked passenger and cargo aircraft) into and out of the United States. The difference between the demand for U.S. and non U.S. aircraft and the available supply of U.S. and non U.S. aircraft is determined. The submodule then moves aircraft between the U.S. and non U.S. regions until world demand and supply are in balance, or until no more aircraft are available.

The revised model also includes new regression equations for non U.S. Revenue Passenger Miles (RPM), non U.S. Sales of new aircraft, and non U.S. Revenue Ton Miles (RTM). A revised set of demand coefficients were also determined for passenger and cargo travel. The yield equation coefficients and demand equations for U.S. RPM, RTM, and aircraft Sales were revised. The input data for travel, sales, stock, efficiency, and consumption was updated.

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1. Introduction

The Transportation Sector Module of the National Energy Modeling System (NEMS) is a computer-based energy demand modeling system of U.S. transport sector. This report documents the objectives, analytical approach and development of the NEMS Transportation Sector Module. The report catalogues and describes critical assumptions, computational methodology, parameter estimation techniques, and module source code.

The document serves as a reference, providing a basic description of the NEMS Transportation Sector Model for interested analysts, users, and the public. It also facilitates continuity in model development that enables customers to undertake and analyze their own model enhancements, data updates, and parameter refinements.

Model Summary

The NEMS Transportation Sector Module encompasses a series of semi-independent modules that address different aspects of the transportation sector. The primary purpose of the comprehensive model is to provide projections of transportation energy demand by fuel type, including motor gasoline, distillate, jet fuel, and alternative fuels (such as ethanol and compressed natural gas [CNG]) that are increasingly being incorporated into the transportation sector. The current NEMS projection horizon extends to the year 2030 and uses 1995 as the start year. Projections are generated through separate consideration of energy consumption within the various modes of transport, including: private and fleet light-duty vehicles; aircraft; marine, rail, and truck freight; and various other transportation demands with minor overall impacts, such as mass transit, military, and recreational boating. This approach is useful in assessing the impacts of policy initiatives, legislative mandates that affect individual modes of travel, and technological developments.

The model also provides projections of selected intermediate values that are generated in order to determine energy consumption. These elements include estimates of passenger travel demand by light vehicle, air, or mass transit; estimates of the efficiency with which that demand is met; projections of vehicle stocks and the penetration of new technologies; and estimates of the demand for truck, rail, marine, and air freight transport that are linked to projections of industrial output, international trade, and energy supply.

The NEMS Transportation Sector Module consists of four modules developed to represent a variety of travel modes that are very different in design and utilization, save for their intended purpose of conveying passengers and/or freight. The four modules include: Light-Duty Vehicle, Air Travel, Freight Transport (Heavy Truck, Rail, and Marine), and Miscellaneous Energy Use. Each module, in turn, may be comprised of one or more submodules, consistent with the methodological requirements of the sector, and commensurate with the relative impact the sector has on overall transportation demand and energy use. A fifth inactive module exists in the Transportation Sector Module that is designed to estimate criteria emissions from highway vehicles. The five modules and their interactions are illustrated in Figure 1. A detailed description is provided in the subsequent chapters.

Scope and Organization

Publication of this document is supported by Public Law 93-275, Federal Energy Administration Act of 1974, Section 57(B) (1) (as amended by Public Law 94-385, Energy Conservation and Production Act), which states in part

> *...that adequate documentation for all statistical and forecast reports prepared...is made available to the public at the time of publication of such reports.*

In particular, this report is designed to meet EIA's model documentation standards established in accordance with these laws.

Model Archival Citation

This documentation refers to the NEMS Transportation Module as archived for the *Annual Energy Outlook 2008* (*AEO2008*).

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2. Model Overview

The Transportation Sector Module has been created to achieve the following objectives:

1. Generate projections of transportation energy demand at the national and the census division level.

2. Endogenously incorporate various technological innovations, macroeconomic feedback, infrastructural constrains, and vehicle choice in making the projections.

The transportation model is comprised of a group of modules that are sequentially executed in a series of program calls. The flow of information between these modules is depicted in Figure 1. The model receives inputs from NEMS, principally in the form of fuel prices, vehicle sales, economic and demographic indicators, and estimates of defense spending. These inputs are described in greater detail in the following section.

The range of policy issues that the transportation model can evaluate are: fuel taxes and subsidies; fuel economy performance by market class; Corporate Average Fuel Economy (CAFE) standards; vehicle pricing policies by market class; demand for vehicle performance within market classes; fleet vehicle sales by technology type; alternative-fuel vehicle sales shares; the California Low Emission Vehicle Program; reduction in vehicle miles traveled (VMT); and various other policies related to energy use and greenhouse gas emissions.

The modeling techniques employed in the Transportation Sector Module vary by module. The LDV module uses econometric models for forecasting passenger travel and new vehicle market shares and uses engineering and expert judgment for estimating fuel economy. The Air Module also uses econometrics for forecasting passenger travel demand and aircraft efficiency as well as other inputs such as jet fuel prices, population, per capita gross domestic product (GDP), and disposable income and merchandise exports. The Freight Module uses output from selected industries to estimate travel demand and energy consumption in each of three primary freight modes: truck, rail, and marine. The Miscellaneous Energy Use Module uses inputs from the Freight Module and fuel consumption by mass transit buses to forecast passenger travel and energy demand.

Light-duty vehicles are classified according to the six EPA market classes for cars and gross vehicle weight rating (GVWR) for light trucks. Freight trucks are divided into medium-light, medium-heavy, and heavy-duty market classes for fleet and non-fleet vehicles. Buses are subdivided into commuter, intercity, and school buses. The air transport module contains wide- and narrow-body aircraft, and regional jets. Rail transportation is composed of freight rail and three modes of personal rail travel: commuter, intercity and transit. Shipping is divided into domestic and international categories. Outputs from the models are provided to an integrating model which sends them to the supply modules.

Brief Description of Modules

The following is a brief description of each of the modules shown in Figure 1. Details of each modules and associated submodules are provided in the next section and include a description of the mathematical representation along with a graphical illustration of the structure of each module.

Light Duty Vehicle Module

The first module executed is the Light Duty Vehicle (LDV) Module, which makes projections of the attributes and sales distributions of new cars and light trucks. The LDV module provides estimates of new LDV fuel economy, the market shares of Alternate Fuel Vehicles (AFVs), and sales of vehicles to fleets. This information is passed to the LDV Fleet Submodule, a stock vintaging submodule that generates estimates of travel demand, fuel efficiency, and energy consumption by business, government, and utility fleets. The LDV Fleet Submodule subsequently passes estimates of vehicles transferred from fleet to private service to the LDV Stock Submodule, which also receives estimates of new LDV sales and fuel efficiency from the LDV Module. The LDV Stock Submodule generates travel, fuel economy, and fuel consumption estimates of the entire stock of household light duty vehicles. Information from the LDV Stock Submodule is subsequently passed to the Miscellaneous Energy Demand Module.

Air Travel Module

The Air Travel Module receives macroeconomic and demographic input from NEMS, including jet fuel prices, population, per capita gross domestic product (GDP), disposable income and merchandise exports, and subsequently uses an econometric estimation to determine the level of travel demand and a stock vintaging submodule to determine the size and characteristics of the aircraft fleet required to meet that demand. The output of this module also includes an estimate of the demand for jet fuel and aviation gasoline, which is subsequently passed to the Miscellaneous Energy Demand Module.

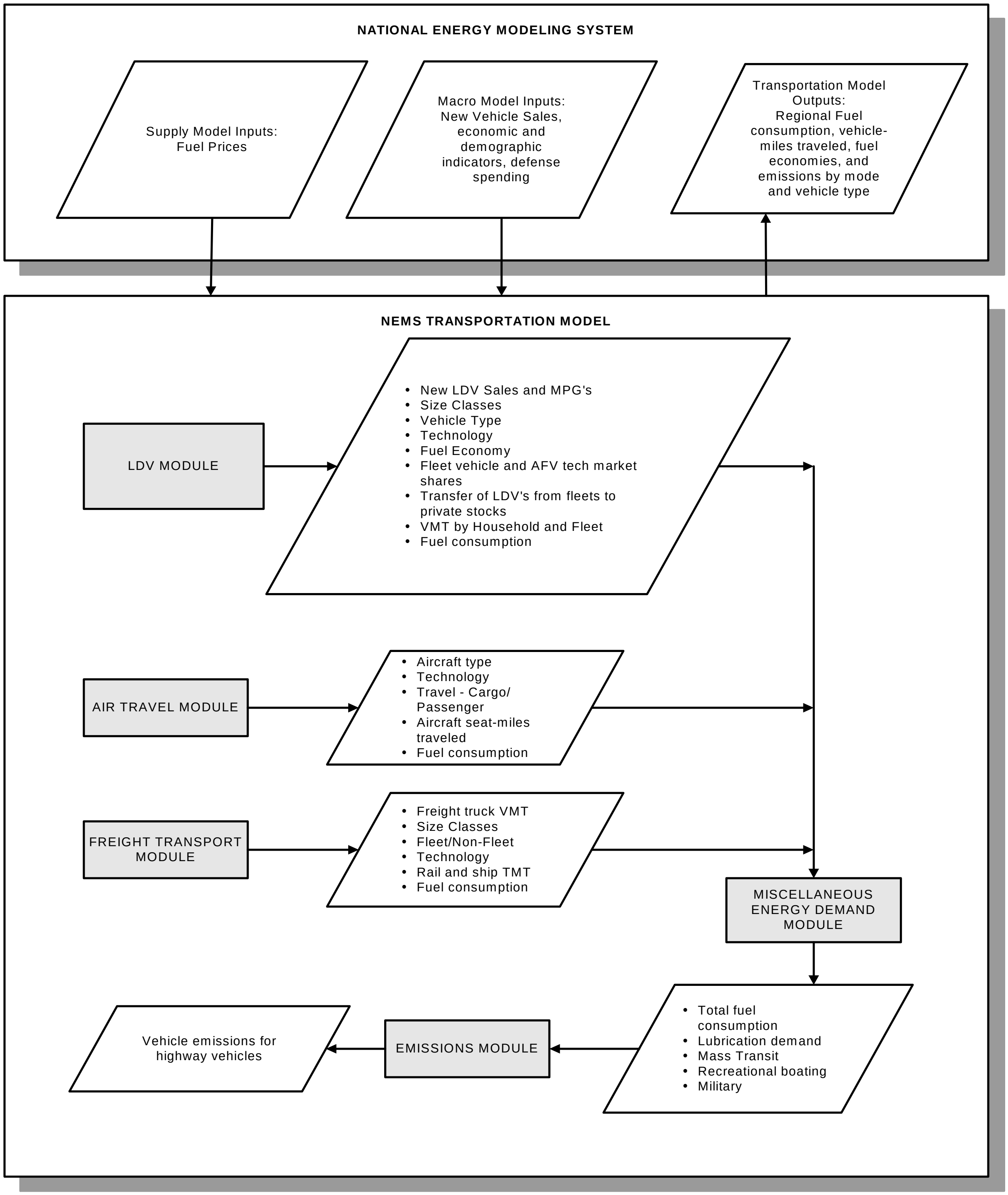
Freight Transport Module

The Freight Transport Module uses NEMS projections of real fuel prices, trade indices, and output from selected industries to estimate travel demand and energy consumption in each of three primary freight modes: truck, rail, and marine. Travel and fuel demand estimates are subsequently passed to the Miscellaneous Energy Demand Module.

Miscellaneous Energy Use Module

The Miscellaneous Energy Use Module receives estimates of military expenditures from NEMS to generate projections for military fuel demand: travel demand estimates from the LDV Stock Module and fuel efficiency estimates from the Freight Transport Module are used to calculate regional fuel consumption by mass transit buses; estimates of disposable personal income from NEMS are used to calculate the demand for fuel used in recreational boating; and the aggregate demand for highway travel, obtained from the preceding modules is used to estimate the demand for lubricants used in transportation. Passenger travel and energy demand by fuel type by Census Division for transit rail, commuter rail, and intercity rail is captured as well.

Figure 1. Structure of NEMS Transportation Sector Module



Note: Models main components are the shaded boxes. The emissions module is currently inactive.

Emissions Module

This module was developed to estimate emissions resulting from the consumption of fuels by highway vehicles. It is currently inactive.

Inputs and Outputs of the Model

The transportation model sends information on regional fuel consumption to NEMS, where it is integrated with the results of the economic, other demand, and supply models. In order to generate projections, the transportation model receives a variety of exogenous inputs from other NEMS models. The primary source of these inputs is the macroeconomic model, which provides projections of economic and demographic indicators. Other inputs exogenous to the transportation model but endogenous to NEMS include fuel prices projections from the various supply models.

The transportation model produces projections of travel demand, disaggregated by Census division, vehicle and fuel type; conventional and alternative vehicle technology choice; vehicle stock and efficiency; and energy demand. Within NEMS, the Transportation Model has an interactive relationship with the macroeconomic model and the various supply models, which provide the prices of transportation-related fuels at a given level of demand. In each year of the projection, NEMS performs several iterations in order to derive a set of fuel prices under which supply and demand converge. The reliance of each of the modules in the transportation model on these economic and price inputs is made clear in the detailed model specifications in the following section.

3. Model Structure

As described above, the NEMS Transportation Model is made up of an array of separate modules, each addressing different aspects of the transportation sector. These modules and key submodules are discussed in detail below.

The general theoretical approach taken, the assumptions that were incorporated, and the methodology employed are discussed for each module and submodule. The key computations and equations are then presented to provide a comprehensive overview of the transportation model. The equations follow the logic of the FORTRAN source code very closely to facilitate an understanding of the code and its structure. In several instances, a variable name will appear on both sides of an equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name.

Flowcharts are provided to facilitate the logic used in the modules where necessary, within the text or at the end of each section. These flowcharts are intended to be detailed, self-contained representations of the module or submodule calculations. Thus, for the sake of clarity, origins and destinations of external information flows are not specified. Also, a large number of data inputs exogenous to NEMS are supplied to the modules described below that comprise the transportation model. These data sets remain unchanged throughout the projection, and, to that extent, constitute a set of assumptions about current and future conditions.

The transportation model is structured so that the modal representation captured in the variables and output of each submodule is appropriately dimensioned for use in subsequent steps. Due to the differing methodological approaches and data requirements, each section is presented individually. Several subroutine calls are made within each module and submodule. Appendix C provides a mapping of the subroutines and the order in which they are called.

LDV Module

The LDV module tracks the purchases and retirements of cars and light trucks, projects their fuel efficiency, and estimates the consumption of a variety of fuels, based on projections of travel demand. The LDV Module shown in Figure 2 requires the largest number of exogenous inputs and primarily consists of seven submodules:

- Manufacturer Technology Choice Submodule (MTCS)
- Regional Sales Submodule
- Consumer Vehicle Choice Submodule (CVCS)
- LDV Fleet Submodule

- Class 2b Vehicle Submodule
- LDV Stock Accounting Submodule
- Vehicle Miles Traveled Submodule (VMTS)

Each submodule performs calculations at a level of disaggregation commensurate with the nature of the mode of transport, the quality of the input data and the level of detail required in the output. The projections are calculated for seven levels of manufacturer vehicle types, domestic/ import cars, and five light truck manufacturer groups, three domestic and two imports, and market class. Car and light trucks are each separated into six market classes. Each market class represents an aggregation of vehicle models that are similar in size and price, and are perceived by consumers to offer similar attributes. The car classes are similar to the U.S. Environmental Protection Agency (EPA) market classes, and are based on passenger car interior volume. Truck classification is based on vehicle inertia weight class [1] by truck type (pick-up, sport utility vehicle, and van). This leads to a total of 24 possible classes (6 market classes x 2 vehicle types x 2 manufacturer types), which are individually projected to 2030.

The fuel economy of new vehicles is impacted by changes in four factors:

1) Technology penetration
2) Level of acceleration performance achieved
3) Mix of vehicle classes and vehicle types (e.g. hybrid and diesels) sold
4) Vehicle fuel economy, safety and emission standards

Technological improvements to each of these market classes are then projected based on the availability of new technologies to improve fuel economy as well as their cost effectiveness under two user-specified alternative scenarios. The central assumptions involved in this technological projection are as follows:

1. All manufacturers can obtain the same benefits from a given technology, provided they have adequate lead time (i.e., no technology is proprietary to a given manufacturer in the long term).
2. Manufacturers will generally adopt technological improvements that are perceived as cost-effective to the consumer, even without any regulatory pressure. However, the term cost-effective needs to be interpreted in the manufacturer's context.

These projections also account for manufacturer lead-time and tooling constraints that limit the rate of increase in the market penetration of new technologies. Based on the technological improvements adopted, a fuel economy projection is developed for each of the manufacturers and market classes.

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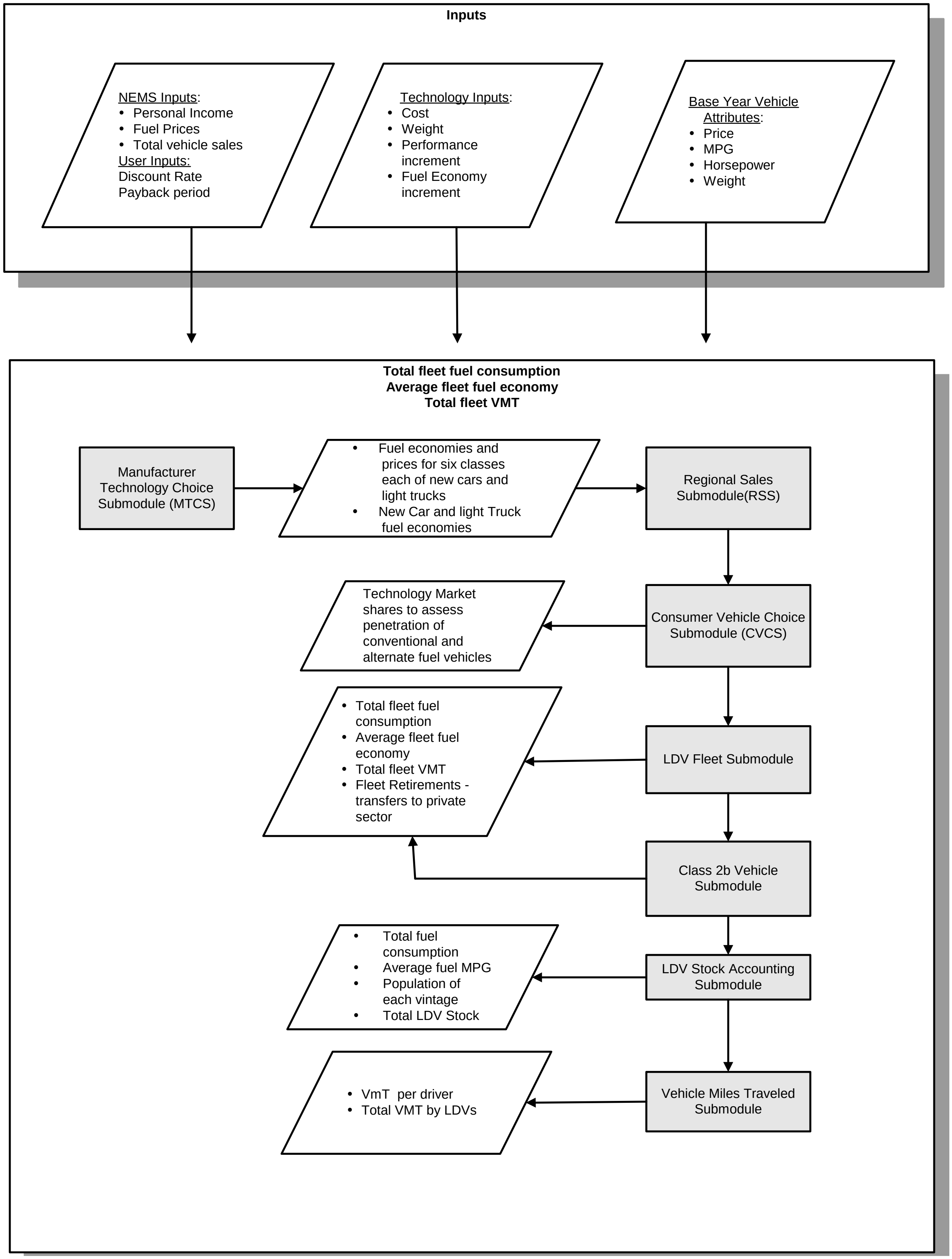
[1] The term “vehicle inertia weight class” means, with respect to a motor vehicle, its inertia weight class determined under40 CFR § 86.129-94. Under 40 CFR § 86.082-2, the inertia weight class is the class (a group of test weights) into which a vehicle is grouped based on its loaded vehicle weight in accordance with the provisions of 40 CFR part 86.

Figure 2. Structure of LDV Module



The fuel economy projection must then be adjusted to account for changes in technology and changes in consumer preference for performance. The demand for increased acceleration performance for each market class is estimated based on an econometric equation relating fuel prices and personal disposable income to demand for performance or horsepower, by market class. These relationships are used to project the change in horsepower, which is then used to project the change in fuel economy through an engineering relationship that links performance and fuel economy.

The change in the mix of market classes sold is projected as a function of fuel price, vehicle price, and personal disposable income. The sales mix by market class is used to calculate new fuel economy. For example, the MTCS utilizes econometric equations for the sales mix choice.[2] The submodule projects sales mix for the six car and six light truck classes, while import market shares are held at fixed values by market class based on historical estimates.
The LDV module also allows specification of CAFE standards by year, and of different standards for domestic and import vehicles, as well as the penalty (in dollars) per car per mile per gallon below the standard. The standards are accounted for in the projection by incorporating the penalty into the technology cost-effectiveness calculation in the submodules. Hence, if the penalty is not large it is assumed that manufacturers will adopt fuel-saving technology as long as it is cost-effective; that is, until the point where it becomes cheaper to pay the penalty for noncompliance. Thus, the companies are allowed to choose non-compliance as a cost-minimizing strategy, as may occur if penalties are set at unrealistic levels relative to the difficulty of achieving the CAFE standards.

Finally, the module also accounts for all known safety and emission standard changes during the projection period**.** These are generally limited to the 1995 to 2008 timeframe, however. Emission standards and safety standards increase vehicle weight, and in some cases decrease engine efficiency. Tier II emission standards are accounted for as well as the California Low Emission Vehicle (LEV) program, and the LEV program adopted by Massachusetts, Maine, and Vermont, Connecticut and Rhode Island, and California, New Jersey, New York, and Washington. Safety standards include fuel economy penalties for air bags; side intrusion and roof crush (rollover) strength requirements that are mandatory over the next ten years.

Manufacturers Technology Choice Submodule (MTCS)

The MTCS[3] submodule in the LDV Module produces estimates of new light duty vehicle fuel efficiency that are then used as inputs to other modules of the transportation model. It is a significant component of the transportation model because the demand for automotive fuel is directly affected by the efficiency with which that fuel is used. Due to the disparate characteristics of the various classes of light duty vehicles, this submodule addresses the commercial viability of up to sixty-three separate technologies within each of twelve vehicle market classes described above, four manufacturer groups, and sixteen vehicle/fuel types. The MTCS submodule projects fuel economy by vehicle class as shown in the flow chart in Figure 3. It begins with a baseline, describing the fuel economy, weight, horsepower and price for each

[2] Goldberg, U.S. Department of Commerce, Bureau of Economic Analysis, 1998.

[3] U.S. Department of Energy, Energy Information Administration, “Updates to the MTCS” provided by the consultant “Energy and Environmental Analysis”, 2001.

vehicle class in 2000. In each projection period, the submodule identifies technologies that are available in the current year. To project technological change, the entire fleet of new cars and light duty trucks are disaggregated into twelve market classes that are relatively homogenous in terms of consumer perceived attributes such as size, price and utility.

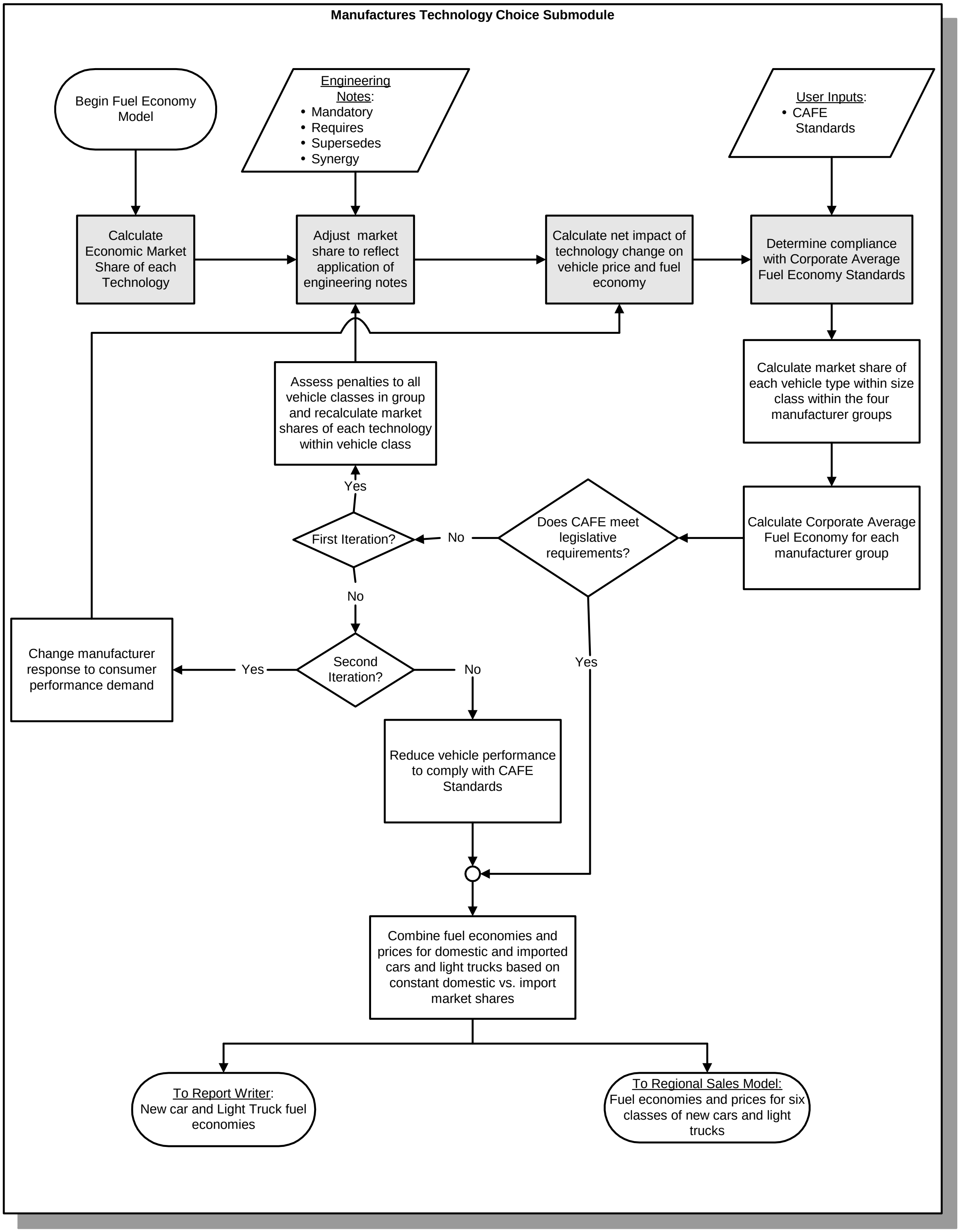
Each available technology is subjected to a cost effectiveness test that balances the cost of the technology against the potential fuel savings and the value of any increase in performance provided by the technology. The cost effectiveness is used to generate an economic market share for the technology. In certain cases there are adjustments that must be made to the calculated market shares. Some of these adjustments reflect engineering limitations to what may be adopted. Other adjustments reflect external forces that require certain types of technologies, including both safety and emissions technologies. All of these adjustments are referred to collectively as "Engineering Notes." There are four types of engineering notes: *Mandatory, Supersedes, Requires, and Synergistic*. These engineering notes are described in subsection 3 (pg. 24.).

Users of the submodule are able to specify one of two scenarios under which these projections are made. The first, identified as the "Standard Technology Scenario", permits the consideration of sixty-three automotive technologies whose availability and cost-effectiveness are either well documented or conservatively estimated. The second, identified as the "High Technology Scenario", modifies selected characteristics of the original matrix to render a more optimistic assessment of the cost and availability of technological improvements.

After all of the technology market shares have been determined, the baseline values for the vehicle class are updated to reflect the impact of the various technology choices on vehicle fuel economy, weight, and price. Next, based on the new vehicle weight, a no-performance-change adjustment is made to horsepower. Then, a technology-change adjustment and a performance-change adjustment, based on income, fuel economy, fuel cost, and vehicle class, are also made to horsepower. Finally, the fuel economy is adjusted to reflect the new horsepower.

Once these steps have been taken for all vehicle classes, the CAFE is calculated for each of the seven groups: domestic cars, import cars, three domestic light truck manufacturers, and two import light truck manufacturers. Each group is classified as either passing or failing the CAFE standard. When a group fails to meet the standard, penalties are assessed to all of the vehicle classes in that group, which are then reprocessed through the market share calculations. In the second pass, the technology cost effectiveness calculation is modified to include the benefit of not having to pay the fine for failing to meet CAFE. After this second pass the CAFE values are recalculated. The market share determination is bypassed on the third CAFE pass. The third CAFE pass simply alters the manufacturer response to consumer performance demand, so the technology penetrations determined to be cost effective during the second MTCS pass are equally applicable during the third pass and, therefore, are not recalculated. If CAFE is still not met after the second pass, then the horsepower increases will be deactivated and converted to equivalent fuel economy improvement, in effect, this assumes manufacturers will minimize their costs by reducing performance to comply with CAFE.

Figure 3. Manufacturers Technology Choice Submodule



This submodule follows the following steps in sequence.

1. Establish Alternate Fuel Vehicle (AFV) Characteristics Relative to Conventional Gasoline

This AFVADJ subroutine in MTCS establishes alternate fuel vehicle (AFV) characteristics relative to conventional gasoline. This is an initialization subroutine and calculates the price, weight, fuel economy and horsepower for the AFVs for all historic years through the base year in the MTCS. Most of these are set relative to the gasoline vehicle values as shown in the following equations. All of the incremental adjustments used for alternative fuel vehicles have been exogenously determined and are included in the data input file, trninput.wk1. In the equations that follow, FuelType represents the sixteen AFV types. These are gasoline, turbo direct-injection diesel, flex-fuel methanol and ethanol, dedicated ethanol, dedicated CNG and LPG, CNG and LPG bi-fuel, dedicated electric, diesel/electric hybrid, gasoline/electric hybrid, plug-in gasoline/electric hybrid, methanol fuel cell, hydrogen fuel cell, and gasoline fuel cell.

1) Calculate CVCS historic yearly values for car prices at different production levels.

a) Mini, Sub-Compact, Compact, and Two-Seaters at 2,500 units/year:

$$PRICE_{Year,FuelType} = PRICE_{Year,Gasoline} + AFVADJPR_{FuelType,1,Year} \quad \textbf{(1)}$$

where,

$AFVADJPR_{FuelType,1,Year}$ = the incremental price adjustment for a low production CVCS car.

and subscript 1 implies low production CVCS car.

b) Midsize and Large at 2,500 units/year:

$$PRICE_{Year,FuelType} = PRICE_{Year,Gasoline} + \frac{AFVADJPR_{FuelType,1,Year} + AFVADJPR_{FuelType,2,Year}}{2} \quad \textbf{(2)}$$

where,

$AFVADJPR_{FuelType,2,Year}$ = Incremental price adjustment for a low production CVCS truck.

and subscript 2 implies low production CVCS truck.

d) Mini, Sub-Compact, Compact, and Two-Seaters at 25,000 units/year:

$$PRICEHI_{Year,FuelType} = PRICE_{Year,Gasoline} + AFVADJPR_{FuelType,3,Year} \quad \textbf{(3)}$$

where,

$AFVADJPR_{FuelType,3,Year}$ = Incremental price adjustment for a high production CVCS car.

and subscript 3 implies high production CVCS car.

d) Midsize and Large at 25,000 units/year:

$$PRICEHI_{Year,FuelType} = PRICE_{Year,Gasoline} + \frac{AFVADJPR_{FuelType,3,Year} + AFVADJPR_{FuelType,4,Year}}{2} \quad \textbf{(4)}$$

where,

$AFVADJPR_{FuelType,4,Year}$ = Incremental price adjustment for a high production CVCS truck. and subscript 4 implies high production CVCS truck.

2) Calculate CVCS historic year prices for light duty trucks at different production levels.

a) Compact Pickups, Compact Vans and Compact Utility at 2,500 units/year:

$$PRICE_{Year,FuelType} = PRICE_{Year,Gasoline} + AFVADJPR_{FuelType,2,Year} \quad \textbf{(5)}$$

b) Standard Pickup, Standard Van and Standard Utility at 2,500 units/year:

$$PRICE_{Year,FuelType} = PRICE_{Year,Gasoline} + \frac{AFVADJPR_{FuelType,1,Year} + AFVADJPR_{FuelType,2,Year}}{2} \quad \textbf{(6)}$$

c) Compact Pickups, Compact Vans and Compact Utility at 25,000 units/year:

$$PRICEHI_{Year,FuelType} = PRICE_{Year,Gasoline} + AFVADJPR_{FuelType,4,Year} \quad \textbf{(7)}$$

d) Standard Pickup, Standard Van and Standard Utility at 25,000 units/year:

$$PRICEHI_{Year,FuelType} = PRICE_{Year,Gasoline} + \frac{AFVADJPR_{FuelType,3,Year} + AFVADJPR_{FuelType,4,Year}}{2} \quad \textbf{(8)}$$

3) Calculate historic year prices for all electric hybrid vehicles.

Electric Hybrid vehicles have an additional price adjustment in addition to those made above to account for battery cost. This adjustment applies to both cars and trucks. The adjustment is based on the adjusted cost for a midsize gasoline car and is scaled in accordance with the ratio of the weight of the gasoline version of the current vehicle to the weight of a midsize gasoline car. Additional learning curve adjustments are based on the Nickel Metal Hydride (Ni-MH) and Li-Ion batteries. This is because the Electric Vehicle/Hybrid cost reduction curve begins at the same time and proceeds at the same rate as that for Ni-MH and Li-Ion batteries.

a) Electric Hybrid at 2,500 units/year:

$$PRICE_{Year,ElectricHybrid} = PRICE_{ElectricHybrid} + X \quad \textbf{(9)}$$

where,

$$X = HEV\_BCST_{Year} * AFVADJPR_{ElectricHybrid,3,Year} * \frac{WEIGHT_{Year,Gasoline}}{WEIGHT_{Midsize,Domestic,Year,Gasoline}}$$

AFVADJPR = Incremental price adjustment for a EV/Hybrid vehicles

$WEIGHT_{Year,Gasoline}$ = Weight of a gasoline vehicle in the current year

$WEIGHT_{Midsize,Domestic,Year,Gasoline}$ = Weight of a midsize, domestic gasoline vehicle in the current year

HEV_BCST = Weighted average battery cost learning curve for HEV's

b) Electric Hybrid at 25,000 units/year:

$$PRICEHI_{Year,ElectricHybrid} = PRICE_{Gasoline} + Y \quad \textbf{(10)}$$

where,

$$Y = \left(HEV\_BCST_{Year} * AFVADJPR_{ElectricHybrid,3,Year} * \frac{WEIGHT_{Year,Gasoline}}{WEIGHT_{Midsize,Domestic,Year,Gasoline}} \right)$$

4) Calculate historic year values for the CVCS characteristics of fuel economy, weight, and horsepower.

Fuel Economy Calculation:

$$FE_{Year,FuelType} = FE_{Year,Gasoline} * \left(1 + AFVADJFE_{FuelType,Year}\right) \quad \textbf{(11)}$$

where,

AFVADJFE = Input Fuel Economy adjustment, relative to gasoline vehicles.

a) Weight Calculation:

$$WEIGHT_{Year,FuelType} = WEIGHT_{Year,Gasoline} * \left(1 + AFVADJWT_{FuelType,Year}\right) \quad \textbf{(12)}$$

where,

AFVADJWT = Input Weight adjustment, relative to gasoline vehicles.

b) Horsepower Calculation:

$$HP_{Year,FuelType} = HP_{Year,Gasoline} * \left(1 + AFVADJHP_{FuelType,Year}\right) \qquad \textbf{(13)}$$

where,

AFVADJHP = Input Horsepower adjustment, relative to gasoline vehicles.

2. Calculate Technology Market Shares

The MTCS first determines the cost effective market shares of technologies for each vehicle class and then calculates the resulting fuel economy, weight, horsepower, and price through the subroutine FEMCALC. In each projection period this function is called three times. During the first pass, technology market shares are calculated for all vehicle classes. In the second pass, the technology market shares are recalculated for vehicles in groups failing to meet the CAFE standards. During this pass, the cost effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFE.[4] If a vehicle group continues to fail to meet CAFE standards after the second pass, no further adjustments to technology market shares are made. Rather, in the third pass, it is assumed that the manufacturers focus solely on CAFE compliance at the expense of increased performance.

For each vehicle class, FEMCALC follows these steps:

A. Calculate the economic market share for each technology

B. Apply the engineering notes to control market penetration

   - Adjust the economic market shares though application of the following three types of engineering notes: mandatory notes, supersedes notes, and requires notes.

   - Adjust the fuel economy impact through application of the synergy engineering notes

C. Calculate the net impact of the change in technology market share on fuel economy, weight and price

D. Estimate EV, PHEV, Hybrid, and Fuel Cell Characteristics

E. Adjust horsepower based on the new fuel economy and weight

F. Readjust fuel economy based on the new horsepower, and price based on the change in horsepower

Each step is described in more detail below. Note that all of the calculations in this section take place within loops by Group (domestic and import cars and light trucks), Class, and Fuel Type. In the interest of legibility, these dimensions are not shown in the subscripts, except to clarify the relationship.

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[4] See the variable REGCOST in Equation 20.

The cost effective market share calculation for each technology is based on the cost of the technology, the present value of the expected fuel savings and the perceived value of performance, see Figure 4. These are addressed in turn below.

a) Fuel Savings Value

For each technology, the expected fuel savings associated with incremental fuel economy impacts is calculated. The time decision to introduce a particular technology is made at least three years before actual introduction in the marketplace, and is based on the expected fuel prices at the time of introduction rather than actual fuel prices.

Nominally, fuel costs three years ago and the annual rate of fuel price change are used to estimate expected dollar savings. However, since prices can spike and since manufacturing decisions will not be based on one-year spikes, the three-year ago and rate-of-change prices used for this calculation are actually the five year running average price and the difference between the three-year ago five year average price and the four-year ago five year average price. The expected present value of fuel savings is dependent on the expected price of fuel; how long the purchaser is willing to wait to recover the initial investment (the payback period); and the distance driven over the period. This estimation involves the following three steps:

1) Calculate the fuel cost slope (PSLOPE), used to extrapolate linearly the expected fuel cost over the desired payback period, constraining the value to be equal to or greater than zero:

$$FIVEYR\_FUELCOST_1 = \frac{1}{5} * \sum_{i=Year-8}^{Year-4} FUELCOST_i$$
$$FIVEYR\_FUELCOST_2 = \frac{1}{5} * \sum_{i=Year-7}^{Year-3} FUELCOST_i \qquad \textbf{(14)}$$
$$PSLOPE = MAX\left(0, FIVEYR\_FUELCOST_1 - FIVEYR\_FUELCOST_2\right)$$

where,

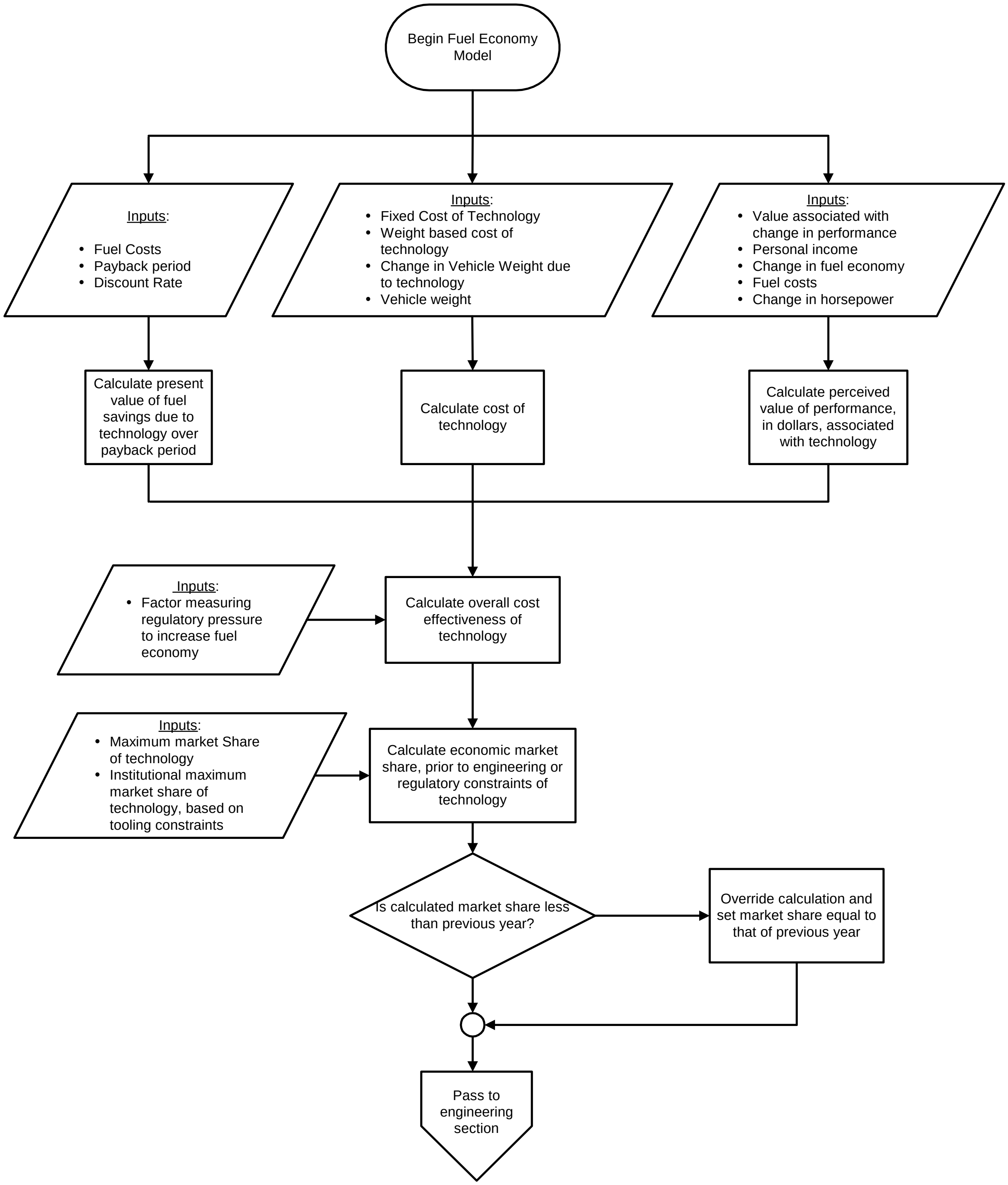
FUELCOST = the price of fuel in the specified prior years.

i = index representing the year considered,

2) Calculate the expected fuel price (PRICE_EX) in year i (where i goes from 1 to PAYBACK):

$$PRICE\_EX_{Year=i} = PSLOPE * \left(i+2\right) + FIVEYR\_FUELCOST_1 \qquad \textbf{(15)}$$

Figure 4. Economic Market Share Calculation



3) For each technology, calculate the expected present value of fuel savings (FUELSAVE) over the payback period:

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{Year-1}} - \left(\frac{1}{1 + DEL\_FE_{itc} * FE_{Year-1}} \right) \right) * PRICE\_EX_i * (1 + DISCOUNT)^{-i} \quad \textbf{(16)}$$

where,

VMT = Annual vehicle-miles traveled

itc = The ***i***ndex representing the ***t***echnology ***c***hoice under consideration

i = index,1,2,…,PAYBACK, defined locally

FE = Fuel economy

DEL_FE = Fractional change in fuel economy associated with technology *itc*

PAYBACK = User-specified payback period

DISCOUNT = User-specified discount rate

a) Technology Cost

Technology cost has both absolute and weight dependent components. The absolute component is a fixed dollar cost for installing a particular technology on a vehicle. Most technologies are in this category. The weight dependent component is associated with the material substitution technologies, where a heavy material is replaced with a lighter one. This component is split between an absolute and relative weight-based cost. The technology cost is a function of the amount of material, which is, in turn, a function of how heavy the vehicle was to begin with. The technology cost equation includes all these components:

$$\begin{aligned} TECHCOST_{itc} = {} & DEL\_COSTABS_{itc} + \\ & DEL\_COSTWGT_{itc}\left(ABS(DEL\_WGTABS_{itc}) + ABS(DEL\_WGTWGT_{itc}) * WEIGHT_{Year-1,FuelType}\right) \end{aligned} \quad \textbf{(17)}$$

where,

TECHCOST = Cost per vehicle of technology *itc*.

DEL_COSTABS = Absolute cost of technology *itc*.

DEL_COSTWGT = Weight-based change in cost ($/lb).

DEL_WGTABS = Fractional change in absolute weight-based cost associated with technology *itc*.

DEL_WGTWGT = Fractional change in relative weight-based cost associated with technology *itc*.

WEIGHT = Original vehicle weight for different fuel type vehicles.

b) Learning Cost Adjustment

The technology cost is adjusted to include the multiplicative total of four individual cost curve adjustments (production volume, manufacturing advances, design advances, and scientific advances). The four influences introduced into the cost calculation are intended to represent potential cost changes due to production volume economies of scale and potential scientific, manufacturing, and design advances. Manufacturing advances can generally be thought of as improvements to non-mature production techniques, such that unit production costs decline at a rate that exceeds that associated with economies of scale alone. Design advances reflect improvements in the cost effectiveness of production due to refinements in the fundamental design of a specific technology. Scientific advances can generally be thought of as fundamental changes in the understanding of specific technologies that lead to more cost effective approaches than currently available.

$$TECHCOST_{itc} = TECHCOST_{itc} * LEARN\_COST\_MULTIPLIER_1 * LEARN\_COST\_MULTIPLIER_2 * LEARN\_COST\_MULTIPLIER_3 * LEARN\_COST\_MULTIPLIER_4 \quad \textbf{(18)}$$

where,

$LEARN\_COST\_MULTIPLIER_1$ = Cost adjustment due to scientific advances.

$LEARN\_COST\_MULTIPLIER_2$ = Cost adjustment due to manufacturing advances.

$LEARN\_COST\_MULTIPLIER_3$ = Cost adjustment due to design advances.

$LEARN\_COST\_MULTIPLIER_4$ = Cost adjustment due to production volume economies of scale.

c) Performance Value

Although there are a number of technological factors that affect the perceived performance of a vehicle, in the interests of clarity and simplicity it was decided to use the vehicle's horsepower to weight ratio is a proxy for the general category of performance. The perceived value of performance is a factor in the cost effectiveness calculation. The value of performance for a given technology is positively correlated with both income and vehicle fuel economy and negatively correlated with fuel prices.

$$VAL\_PERF_{itc} = VALUEPERF * PERF\_COEFF * \frac{INCOME_{Year}}{INCOME_{Year-1}} * \left(1 + DEL\_FE_{itc}\right) * \frac{FUELCOST_{Year-1}}{FUELCOST_{Year}} * DEL\_HP_{itc} \quad \textbf{(19)}$$

where,

VAL_PERF = Dollar value of performance of technology *itc*

VALUEPERF = Value associated with an incremental change in performance

PERF_COEFF = Parameter used to constrain vehicle performance

DEL_FE = The fractional change in fuel economy of technology *itc*

DEL_HP = Fractional change in horsepower of technology *itc*

FUELCOST = Actual price of fuel (in the given year)

d) Economic Market Share

The market share of the considered technology, based on fuel savings or on performance, is determined by first evaluating the cost effectiveness of technology *itc* as a function of the values described above:

$$COSTEF\_FUEL_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + \left(REGCOST * FE_{Year-1} * DEL\_FE_{itc}\right)}{TECHCOST_{itc}} \quad \textbf{(20)}$$

$$COSTEF\_PERF_{itc} = \frac{VAL\_PERF_{itc} - TECHCOST_{itc}}{TECHCOST_{itc}} \quad \textbf{(21)}$$

$$MKT\_FUEL_{itc} = \frac{1}{1 + e^{MKT\_1COEFF * COSTEF\_FUEL_{itc}}} \quad \textbf{(22)}$$

$$MKT\_PERF_{itc} = \frac{1}{1 + e^{MKT\_2COEFF * COSTEF\_PERF_{itc}}} \quad \textbf{(23)}$$

where,

COSTEF_FUEL = A unit less measure of cost effectiveness based on fuel savings of technology, etc.

COSTEF_PERF = A unit less measure of cost effectiveness based on performance of technology, etc.

REGCOST[5] = A factor representing regulatory pressure to increase fuel economy, in $ per miles per gallon (MPG)

TECHCOST = Cost of the considered technology

VAL_PERF = Performance value associated with technology *itc*

MKT_FUEL = Market share based on fuel savings

MKT_PERF = Market share based on performance

MKT_1COEFF = -4 if COSTEF_FUEL < 0, and -2 otherwise

[5] During pass 1 REGCOST has a value of 0. During passes 2 and 3 it is set to REG_COST, which is a user input. This penalty is discussed in the earlier section entitled Calculate Technology Market Shares.

MKT_2COEFF = -4 if COSTEF_PERF < 0, and -2 otherwise

The two separate market shares are combined to determine the actual market share for the technology.

$$ACTUAL\_MKT_{itc,Year} = PMAX_{itc} * MAX(MKT\_FUEL_{itc} * MKT\_PERF_{itc}) \quad \textbf{(24)}$$

where,

ACTUAL_MKT = Economic share, prior to consideration of engineering or regulatory constraints.

PMAX = Institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in a separate subroutine.

This subroutine (FUNCMAX) sets the current year maximum market share based on the previous year's share (see Table 1).

Note: If the manufacturer does not satisfy CAFE, production can be accelerated to reach 100 percent penetration in half the time and continue at that pace for every year thereafter.

e) Market Share Overrides

Existing technologies are assumed to maintain their market shares unless forced out by later technologies. If the cost effectiveness calculation yields an economic market share that is below the market share in the previous period then the calculated value is overridden:

$$ACTUAL\_MKT_{itc,Year} = MAX(ACTUAL\_MKT_{itc,Year-1}, ACTUAL\_MKT_{itc,Year}) \quad \textbf{(25)}$$

Finally, the economic market share is bounded above by the maximum market share, MKT_MAX or 1.0, whichever is smaller:

$$ACTUAL\_MKT_{itc,Year} = MIN(1, MKT\_MAX_{itc}, ACTUAL\_MKT_{itc,Year}) \quad \textbf{(26)}$$

where,

MKT_MAX = Maximum market share for technology *itc*

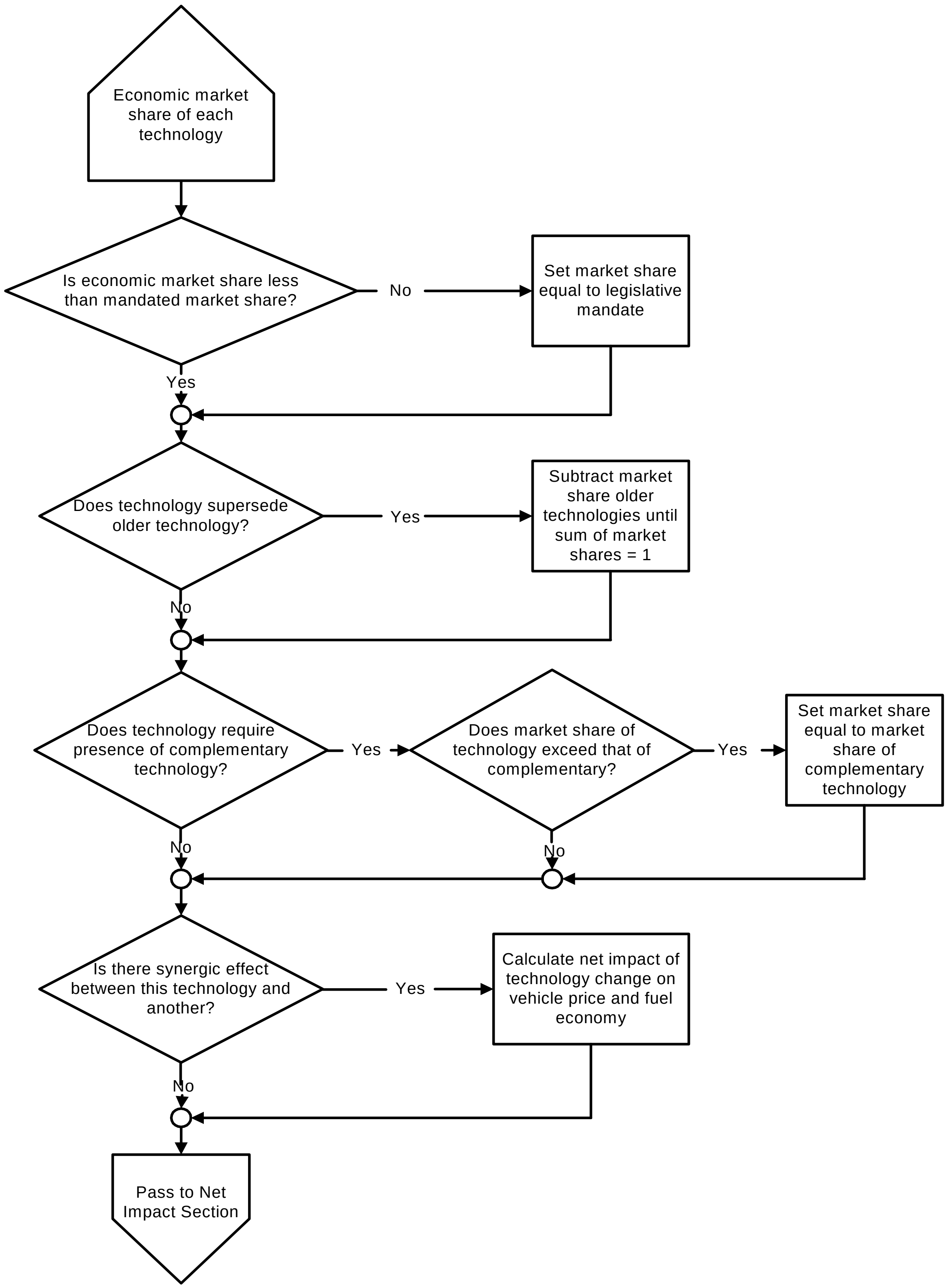
3. Apply the Engineering Notes

The engineering notes consist of a number of overrides to the economic cost effectiveness calculations done in the previous step. The three types of notes (mandatory, supersedes and requires) directly affect the technology market share results obtained above. The other type of note, synergy, does not affect the market share and is applied after all other engineering notes have been applied, see Figure 5.

Table 1. Maximum Light Duty Vehicle Market Penetration Parameters (percent)

Years in Market	New PMAX (Domestic)	New PMAX (Import)
1	1	1
2	2	10
3	5	20
4	10	30
5	18	40
6	26	50
7	34	60
8	42	70
9	50	80
10	58	90
11	66	95
12	74	100
13	82	100
14	90	100
15	93	100
16	97	100
17	100	100

Figure 5. Engineering Notes



a) Mandatory Notes

These are usually associated with safety or emissions technology that must be in place by a certain year. For example, air bags are mandatory in 1994. If the number of phase-in years is between 0 and 1, adopt the full market share immediately. The market share is modified to ensure that the mandated level of technology is achieved:

$$ACTUAL\_MKT_{itc,Year} = MAX\left(ACTUAL\_MKT_{itc,Year}, MANDMKSH_{itc,Year}\right) \quad \textbf{(27)}$$

where,

MANDMKSH = Market share for technology *itc* that has been mandated by legislative or regulatory action

If the number of phase-in years is greater than 1, adopt a proportional share of the total mandatory share, MANDMKSH, each year. Since both the base and maximum market penetrations can vary by vehicle class, the actual market share logic must adopt annual shares in proportion to the allowable market share spread for each vehicle class, with the technology base year, BaseYear, penetration, MKT_PEN, defined by the base share for the class.

$$ACTUAL\_MKT_{itc,Year} = X \quad \textbf{(28)}$$

where,

$$X = MAX\begin{pmatrix} ACTUAL\_MKT_{itc,Year}, \\ MKT\_PEN_{itc,BaseYear,FuelType} + PHASESHR_{Year} * \left(MKT\_MAX_{itc} - MKT\_PEN_{itc,BaseYear,FuelType}\right) \end{pmatrix}$$

PHASESHR = Fraction of the total mandatory share in year, Year.

The economic market share is bounded above by the maximum market share, or MKT_MAX:

$$ACTUAL\_MKT_{itc,Year} = MIN\left(ACTUAL\_MKT_{itc,Year}, MKT\_MAX_{itc}\right) \quad \textbf{(29)}$$

b) Supersedes Notes

Superseding technology notes define technologies that functionally overlap and therefore will not be present on the same vehicle. For example, if technology X is a more sophisticated version of technology Y, either one but not both can appear on a particular vehicle and the market share of technology X *plus* the market share of technology Y must not exceed the maximum allowable market share for the basic technology. Since technology cost effectiveness is determined on an individual technology basis, such situations are handled by so-called “superseding” technology code that adjusts cost effective market shares for individual technologies in accordance with functional overlaps. To correctly handle the relationship between more than two technologies, the superseding technology engineering notes that define the relationship and the adjustment of the cost effective market shares in accordance with that relationship must be designed to treat all affected technologies concurrently.

Market shares are further adjusted so the sum does not exceed the maximum market penetration of the group. Calculate aggregate market share of superseding technologies, *ino*, related to technology *itc*:

$$TOT\_MKT_{itc,Year} = \sum_{ino=1}^{num\_\sup} ACTUAL\_MKT_{ino,Year} \tag{30}$$

where,

TOT_MKT = Total market share of the considered group of technologies

ino = Index identifying the technologies in the superseding group related to technology *itc*

num_sup = Number of technologies in the superseding group related to technology itc.

Identify the largest maximum market share for the group of technologies, *ino*, related to technology *itc*:

$$MAX\_SHARE = MAX\left(MKT\_MAX_{ino}\right) \tag{31}$$

where,

MAX_SHARE = Maximum allowable market share of the group, *ino*.

If the aggregate market share (TOT$MKT) is greater than the maximum share (MAX$SHARE), reduce the excess penetration of those technologies that are in the group of related technologies, as follows:

1) Calculate the reduction in market share of a superseded technology, ensuring that the decrement does not exceed that technology's total share:

$$DEL\_MKT_{itc} = TOT\_MKT_{itc,Year} - MAX\_SHARE \tag{32}$$

where,

DEK_MKT = Amount of the superseded technology’s market share to be removed

itc = Index indicating superseded technology

2) Adjust the market share of the superseded technology to reflect the decrement

$$ACTUAL\_MKT_{itc,Year} = ACTUAL\_MKT_{itc,Year} - DEL\_MKT_{itc} \tag{33}$$

3) Adjust total market share to reflect this decrement

$$TOT\_MKT_{itc,Year} = MAX\_SHARE \quad (34)$$

c) Requires Notes

These notes control the adoption of technologies, which require that other technologies also be present on the vehicle. For example, since the technology Variable Valve Timing II requires the presence of an Overhead Cam, the market share for Variable Valve Timing II cannot exceed the sum of the market shares for Overhead Cam 4, 6 & 8 cylinder engines. This note is implemented as follows:

1) For a given technology *itc*, define a group of potential matching technologies, *req*, one of which must be present for *itc* to be present.

2) Sum the market shares of the matching technologies (*req*), ensuring total market share is no more than 1.0:

$$REQ\_MKT = MIN\left(\sum_{req} ACTUAL\_MKT_{req,Year-1}, 1.0\right) \quad (35)$$

where,

REQ_MKT = Total market share of those technologies that are required for the implementation of technology *itc*, indicating that technology's maximum share

3) Compare REQ_MKT to the market share of technology *itc*:

$$ACTUAL\_MKT_{itc,Year} = MIN\left(ACTUAL\_MKT_{itc,Year}, REQ\_MKT\right) \quad (36)$$

It is at this point that the adjusted economic market share, $ACTUAL\_MKT_{itc}$, is assigned to the variable $MKT\_PEN_{itc,Year}$, by market class and group, for use in the remainder of the calculations.

$$MKT\_PEN_{itc,Year} = ACTUAL\_MKT_{itc,Year} \quad (37)$$

d) Synergistic Notes

Synergistic technologies are those that, when installed simultaneously, interact to affect fuel economy. A vehicle with synergistic technologies will not experience the change in fuel economy predicted by adding the impact of each technology separately. Conceptually such interactions could yield either greater or lower fuel economy; however, in all cases observed in the MTCS the actual fuel economy is lower than expected. For example, Variable Valve Timing I is synergistic with 4-Speed Automatic Transmissions. If both are present on a vehicle then the actual fuel economy improvement is 2 percent below what would be expected if the technologies were simply added together with no regard for their interaction.

Synergy adjustments are made once all other engineering notes have been applied. Market share affected by synergy effects between two technologies is estimated as the probabilistic overlap between the market shares of the two technologies. Mathematically, this market share is expressed as the product of the market shares of the two technologies. The incremental market share overlap for a single year is equal to the cumulative estimated overlap (based on cumulative estimated market penetrations) for the current year minus the cumulative estimated overlap for the previous year. Note also, that the input value of SYNR$DEL, the synergistic effect of related technologies on fuel economy, is negative so that the estimated synergy loss will also be negative and should be treated as an additive parameter.

$$SYNERGY\_LOSS_{itc} = \sum_{syn} \left(MKT\_PEN_{itc,Year} * MKT\_PEN_{syn,Year} - MKT\_PEN_{itc,Year-1} * MKT\_PEN_{syn,Year-1} \right) * SYNR\_DEL_{itc,syn} \quad \textbf{(38)}$$

where,

SYNERGY_LOSS = Estimated synergy loss for all technologies synergistic with technology, *itc.*

Syn = Set of technologies synergistic with technology itc.

SNR_DEL = Synergistic effect of related technologies on fuel economy.

4. Calculate Net Impact of Technology Change

The net impact of changes in technology market shares is first calculated for fuel economy, weight and price. Horsepower is dependent on these results and must be calculated subsequently. For a given technology *itc*, the change in market share since the last period (DELTA_MKT) is calculated as follows:

$$DELTA\_MKT_{itc} = MKT\_PEN_{itc,Year} - MKT\_PEN_{itc,Year-1} \quad \textbf{(39)}$$

$DELTA\_MKT_{itc}$ is used to calculate the incremental changes in fuel economy, vehicle weight, and price due to the implementation of the considered technology.

a) Fuel Economy

Current fuel economy for a vehicle class is calculated as the previously adjusted fuel economy plus the sum of incremental changes due to newly adopted technologies:

$$FE_{year} = FE_{Year-1} + FE_{Year-1} * \left[\sum_{itc=1}^{NUMTECH} DELTA\_MKT_{itc} * DEL\_FE_{itc} * SYNERGY\_LOSS_{itc} \right] \quad \textbf{(40)}$$

where,

NUMTECH = Number of newly adopted technologies

b) Vehicle Weight

Current weight for a vehicle class is modified by the incremental changes due to newly adopted technologies. As with the technology cost equation, the weight equation has both absolute and variable components. Most technologies add a fixed number of pounds to the weight of a vehicle. With material substitution technologies the weight change depends upon how much new material is used, which is a function of the original weight of the vehicle. The weight equation includes both absolute and weight dependent terms in the summation expression. For any given technology, one term or the other will be zero.

$$WEIGHT_{Year,FuelType} = WEIGHT_{Year,FuelType} + DELTA\_MKT_{itc} * \left(DEL\_WGTABS_{itc} + WEIGHT_{Year,FuelType} * DEL\_WGTWGT_{itc}\right) \quad \textbf{(41)}$$

where,

DEL_WGTECH = Change in weight (lbs) associated with technology *itc*

DEL_WGTWGT = Fractional change in vehicle weight due to technology itc

WEIGHT = Vehicle weight, by market class, group, and fuel type initialized to the previous year's value and modified with each iteration of the submodule.

c) Vehicle Price

Current price for a vehicle class is calculated as the previous price plus the sum of incremental changes in the technology cost due to newly adopted technologies. This calculation is used to equally scale up both low volume prices, at 2,500 units/year, and high volume prices, at 25,000 units/year, as described in Equations 1 through 10:

$$PRICE_{year} = PRICE_{Year-1} + \sum_{itc=1}^{NUMTECH} DELTA\_MKT_{itc} * TECHCOST_{itc} \quad \textbf{(42)}$$

where,

PRICE = Vehicle price, by market class and group, initialized to the previous year's value and subsequently modified with each iteration of the submodule.

5. Estimate EV and Fuel Cell Characteristics

The characteristics of electric and fuel cell vehicles, including weight, battery cost, and fuel economy must then be calculated in separate subroutines prior to the estimation of market shares.

a) Electric Vehicles

This set of calculations, contained within the subroutine EVCALC estimates battery cost, vehicle price (low and high volume sales), weight and fuel economy for electric vehicles. Fuel economy is in kilowatt-hours/mile (wall plug.)

The first step in EVCALC is determination of the battery weight and cost for lead acid, Ni-MH, and Li-Ion batteries. The numerical constants in the equations represent the result of exogenous analysis and professional judgment on the part of the model developers.

Weight and cost of a lead acid battery

$$BATTERY1\_WT = 0.60 * WEIGHT_{Year,Gasoline}$$
$$and \qquad \textbf{(43)}$$
$$BATTERY1\_COST = BATTERY1\_WT * 2.30 * 1.75 + 1500$$

where,

BATTERY1_WT	=	Weight of a lead acid battery large enough to provide adequate range and performance
BATTERY1_COST	=	Cost of a lead acid battery
0.60	=	Fraction of vehicle weight accounted for by the battery system
$2.30	=	Cost/pound of a lead acid battery
1.75	=	Cost multiplier to determine retail price
$1,500	=	Fixed cost amortization per unit EV
WEIGHT	=	Weight of a gasoline vehicle

2) Weight and cost of a Ni-MH battery

$$BATTERY2\_WT = 0.203 * WEIGHT_{Year,Gasoline}$$
$$and \qquad \textbf{(44)}$$
$$BATTERY2\_COST = BATTERY2\_WT * 8.20 * 1.75 + 1500$$

where,

0.203	=	Fraction of vehicle weight accounted for by the battery system
BATTERY2_WT	=	Weight of a Ni-MH battery large enough to provide adequate range and performance
BATTERY2_COST	=	Cost of a Ni-MH battery
$8.20	=	Cost/pound of a Ni-MH battery
1.75	=	Cost multiplier to determine retail price
$1,500	=	Fixed cost amortization per unit EV
WEIGHT	=	Weight of a gasoline vehicle

3) Weight and cost of a Li-Ion battery

$$BATTERY3\_WT = 0.15 * WEIGHT_{Year,Gasoline}$$
$$and \qquad \textbf{(45)}$$
$$BATTERY3\_COST = BATTERY3\_WT * 20.86 * 1.75 + 1500$$

where,

0.15 = Fraction of vehicle weight accounted for by the battery system

BATTERY3_WT = Weight of a Li-Ion battery large enough to provide adequate range and performance

BATTERY3_COST = Cost of a Li-Ion battery

$20.86 = Cost/pound of a Li-Ion battery

1.75 = Cost multiplier to determine retail price

$1,500 = Fixed cost amortization per unit EV

WEIGHT = Weight of a gasoline vehicle

The next step is to apply a learning curve adjustment to the cost of the battery. It is assumed that there is a 25 percent cost reduction per decade for lead acid, Ni-MH, and Li-Ion batteries. The learning curves have been pre-calculated and are initialized in data input file, trninput.wk1. The lead acid curve begins immediately, while the Ni-MH and Li-Ion battery costs do not begin to go down until after 2003.

4) Learning curve adjustment for battery costs

$$BATTERY1\_COST = BATTERY1\_COST * LEADACID\_COST_{Year}$$
$$and$$
$$BATTERY2\_COST = BATTERY2\_COST * NIMHY\_COST_{Year} \qquad \textbf{(46)}$$
$$and$$
$$BATTERY3\_COST = BATTERY3\_COST * LION\_COST_{Year}$$

where,

LEADACID_COST = Cost reduction learning curve for a lead acid battery

NIMHY_COST = Cost reduction learning curve for a Ni-MH battery

LION_COST = Cost reduction learning curve for a Li-Ion battery

Next, the average price of an electric vehicle battery is determined based on the expected market shares of lead acid, Ni-MH, and Li-Ion batteries:

5) Average price of an electric vehicle battery

$$BATTERY_{Year,ElectricVehicle} = BATTERY1\_COST * (1 - NIMHY\_MKTSH_{Year}) + BATTERY2\_COST * NIMHY\_MKTSH_{Year} + BATTERY3\_COST * LION\_MKTSH_{Year} \quad \textbf{(47)}$$

where,

BATTERY = Average price of an electric vehicle battery

NIMHY_MKTSH = Expected market share of Ni-MH batteries

LION_MKTSH = Expected market share of Li-Ion batteries

Finally, Price, Weight and Fuel Economy are calculated:

6) Electric Vehicle Price

$$PRICE_{Year,ElectricVehicle} = PRICE_{Year,ElectricVehicle} + BATTERY_{Year,ElectricVehicle} \quad \textbf{(48)}$$

Since PRICEHI (high production AFV) uses the same equation as PRICE (with the substitution of PRICEHI for PRICE on both sides on the equation), it is not shown separately.

7) Electric Vehicle Weight

$$WEIGHT_{Year,ElectricVehicle} = \frac{BATTERY1\_WT}{0.375} * (1 - NIMHY\_MKTSH_{Year}) + \frac{BATTERY2\_WT}{0.22} * NIMHY\_MKTSH_{Year} + \frac{BATTERY3\_WT}{0.22} * LION\_MKTSH_{Year} \quad \textbf{(49)}$$

8) Fuel Economy (miles/Kilowatt-hour wall plug)

$$FE_{Year,ElectricVehicle} = \frac{0.8 * 2200}{0.16 * WEIGHT_{Year,ElectricVehicle}} \quad \textbf{(50)}$$

a) Hybrid Electric Vehicles (HEV)

In addition to those adjustments for battery costs for electric vehicles, HEV vehicles scale the EV battery costs downward based on an average HEV mid-market class vehicle. These results are then adjusted further to account for the 12 EPA market classes, 6 cars and 6 light trucks, relative to a mid-sized vehicle, using gasoline vehicle weight as the scaling factor.

$$PRICE_{Year,HEV} = PRICE_{Year,Gasoline} + HEV\_BCST_{Year} * X \quad \textbf{(51)}$$

where,

$$X = AFVADJPR_{Year,HEV} * \frac{WEIGHT_{Year,class,Gasoline}}{WEIGHT_{Year,mid-size,Gasoline}}$$

b*) Fuel Cell Vehicles*

The subroutine FCCALC calculates fuel cell cost, vehicle price for low volume sales, at 2,500 units per year, and high volume sales, at 25,000 units per year, and fuel economy for methanol, hydrogen, and gasoline fuel cell vehicles, respectively. Note that although values for fuel cell vehicles are calculated for the early years, the penetration of these vehicles is restricted until 2005. Hydrogen supply is expected to be a major problem for fuel cell vehicles. In the following equations the *FC* subscript refers to methanol, hydrogen, and gasoline fuel cells.

1) Fuel Cell Cost

$$FUELCELL_{Year,FC} = 30 * \frac{WEIGHT_{Year,Gasoline}}{2200} * FUELCELL\_COST_{Year,FC} \quad \textbf{(52)}$$

where,

FUELCELL = Cost of the fuel cell

FUELCELL_COST = Exogenous input for the cost of the fuel cell in $/kw

WEIGHT = Weight of a gasoline vehicle

2) Battery Power required to initially power the vehicle

$$BATTERY\_POWER = 20 * \frac{WEIGHT_{Year,Gasoline}}{2200} \quad \textbf{(53)}$$

where,

BATTERY _POWER = Required battery power in Kw

3) Weight of Battery

$$BATTERY\_WT = 2.2 * \frac{BATTERY\_POWER}{0.5} \quad \textbf{(54)}$$

where,

2.2 = Base battery weight in lbs.

BATTERY_WT = Weight of the battery

4) Cost of Battery

$$BATTERY_{Year,FC} = 2.30 * BATTERY\_WT * LEADACID\_COST_{Year} \quad \textbf{(55)}$$

where,

BATTERY = Cost of the lead acid battery

\$2.30 = Initial cost per pound for the battery

$LEADACID\_COST_{Year}$ = Cost reduction learning curve for a lead acid battery

5) Add Battery to cost of fuel cell and calculate retail price

$$FUELCELL_{Year,FC} = \left(FUELCELL_{Year,FC} + BATTERY_{Year,FC} + TANKCOST_{FC}\right) * 1.75 + 1500 \quad \textbf{(56)}$$

where,

TANKCOST = Cost of the hydrogen storage tank: \$0 for methanol and gasoline FC, \$3,000 for hydrogen FC

1.75 = Cost multiplier to determine retail price

\$1,500 = Fixed cost amortization per unit fuel cell vehicle

6) Fuel Cell Vehicle Price for low volume and high volume production

$$PRICE_{Year,FC} = PRICE_{Year,FC} + FUELCELL_{Year,FC} \quad \textbf{(57)}$$

7) Fuel Cell Fuel Economy (gasoline equivalent mpg)

$$FE_{Year,FC} = \frac{1}{GALPERMILE_{FC} * \frac{WEIGHT_{Year,Gasoline}}{1000}} \quad \textbf{(58)}$$

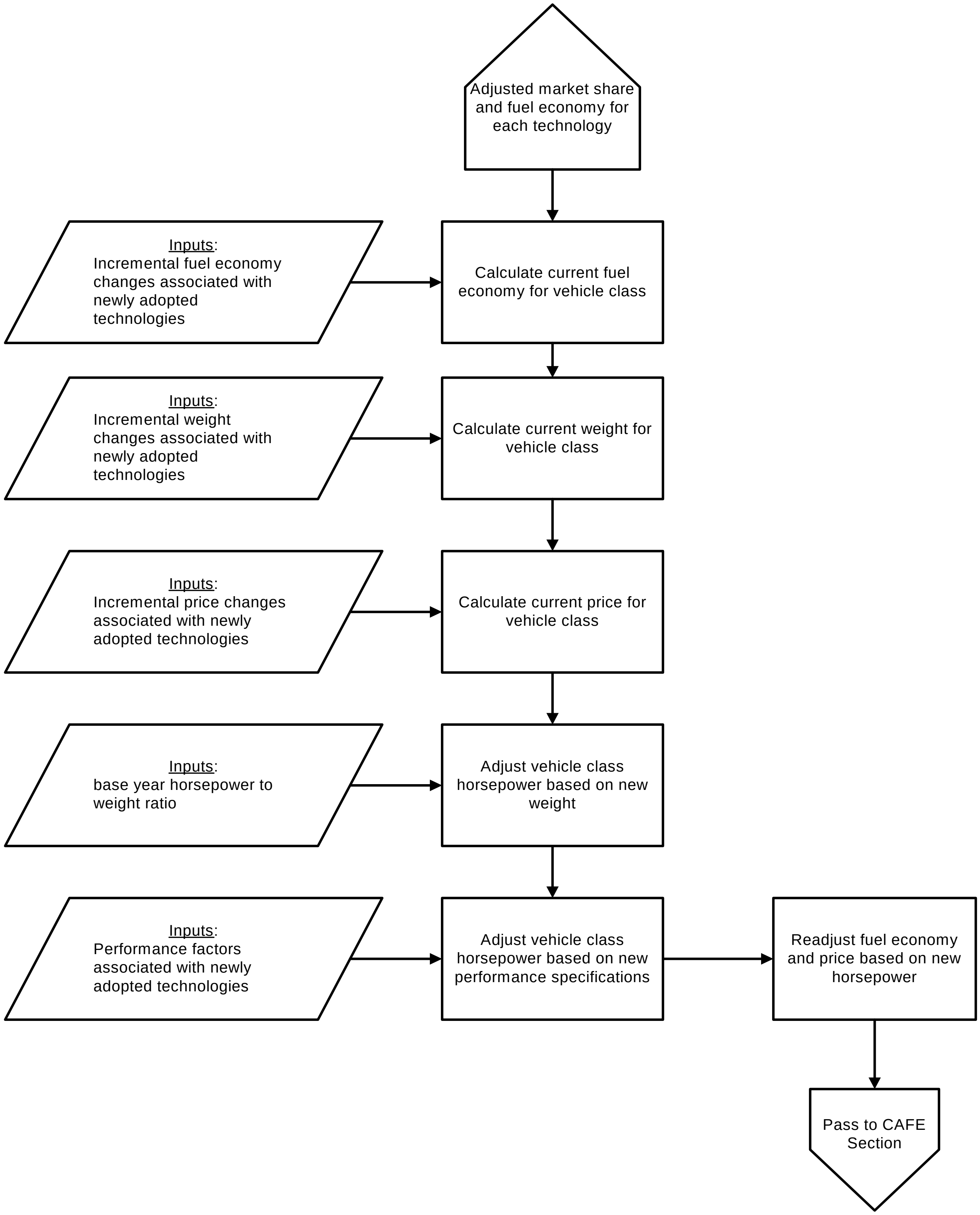
where,

GALPERMILE = 0.00625 for Methanol FC, 0.00570 for Hydrogen FC, and 0.00667 for Gasoline FC

6. Impact of Technology on Horsepower

Calculating the net impact of changes in technology share on vehicle horsepower is a three-step process. See Figure 6.

Figure 6. Weight and Horsepower Calculations



a) Unadjusted Horsepower

First, horsepower is calculated on the basis of weight, assuming no change in performance. This initial estimate simply maintains the horsepower to weight ratio observed in the base year.

Assuming a constant horsepower/weight ratio for cars and light trucks:

$$HP_{Year,FuelType} = WEIGHT_{Year,FuelType} * \frac{HP_{Year-1,FuelType}}{WEIGHT_{Year-1,FuelType}} \quad \textbf{(59)}$$

where,

HP = Vehicle horsepower

WEIGHT = Vehicle weight

Dedicated Electric vehicles and Fuel Cell vehicles do not have horsepower adjustments. Their horsepower is set at 20 percent below equivalent gasoline vehicles, adjusted for weight difference:

$$HP_{Year,FuelType} = 0.8 * WEIGHT_{Year,FuelType} * \frac{HP_{Year,Gasoline}}{WEIGHT_{Year,Gasoline}} \quad \textbf{(60)}$$

where,

FuelType = Dedicated Electric and Fuel Cell vehicles

b) Adjust Horsepower

The second step adjusts the total horsepower, TTL$ADJHP, of which there are two components. The first component is an adjustment associated with the various technologies adopted, TECH$ADJHP, and the second component is due to any additional consumer performance demand, PERF$ADJHP. Adjustments to horsepower are done for cars and light trucks at the market class and AFV technology level, with the exceptions noted above.

c) Technology Adjustment

Calculate the annual horsepower adjustment due to technology introductions, which is equal to the sum of incremental changes due to newly adopted technologies:

$$TECH\_ADJHP_{year} = \sum_{itc=1}^{NUMTECH} \left(DELTA\_MKT_{itc} * DEL\_HP_{itc} \right) \quad \textbf{(61)}$$

where,

DEL_HP = the fractional change in horsepower by technology type

d) Consumer Preference Adjustment

The next step is to calculate the annual horsepower adjustment due to consumer preference for performance. The initial calculation is based on household income, vehicle price, fuel economy, and fuel cost.

$$PERF\_ADJHP_{Year} = \left(\frac{INCOME_{Year}}{INCOME_{Year-1}}\right)^{0.9} * \left(\frac{PRICE_{Year-1}}{PRICE_{Year}}\right)^{0.9} * \left(\frac{FE_{Year}}{FE_{Year-1}}\right)^{0.2} * \left(\frac{FUELCOST_{Year-1}}{FUELCOST_{Year}}\right)^{0.2} - 1 \qquad \textbf{(62)}$$

where,

PERF_ADJHP = Performance Vehicle horsepower adjustment factor

The calculated consumer demand for horsepower is initially unconstrained as the projection begins, but is multiplicatively adjusted downward to decrease consumer performance demand as the projected horsepower-to-weight ratio approaches its constrained limit, PERFCAP. Calculate the value of PERF_COEFF, the parameter used to constrain the incremental value of additional vehicle performance. This parameter decreases as performance increases so that the incremental value of additional performance declines. The demand that has accrued between 1990 and 2000 DEMAND_USED, must be accounted for through the use of parameter USEDCAP.

$$DEMAND\_USED = \left(PERFCAP - HP\_WGT_{BaseYear}\right) * \left(\frac{USEDCAP}{1 - USEDCAP}\right) \qquad \textbf{(63)}$$

where,

DEMAND_USED = Demand accrued between 1990 and 2000

PERFCAP = Performance cap

HP_WGT = Horsepower to weight ratio in the given year, in this case BaseYear

USEDCAP = Input parameter

$$PERF\_COEFF_{Year} = 1 - \left(\frac{HP\_WGT_{Year} - HP\_WGT_{BaseYear} + DEMAND\_USED}{PERFCAP - HP\_WGT_{BaseYear} + DEMAND\_USED}\right) \qquad \textbf{(64)}$$

where,

PERF + COEFF =Performance coefficient, and lies between 0 and 1.

$$PERF\_ADJHP_{Year} = PERF\_ADJHP_{Year} * PERFFACT * PERF\_COEFF_{Year} \quad \textbf{(65)}$$

where,

PERFFACT = Performance factor, exogenous input from trninput.wk1.

Also, if CAFE standards are not achieved after the second (CAFE compliance) pass through FEMCALC, the additional consumer demand for performance is set to zero (or the minimum value required to maintain a sufficient horsepower-to-weight ratio) to allow manufacturers to focus on CAFE compliance rather than satisfy increased performance demands.

The total horsepower adjustment is now calculated:

$$TTL\_ADJHP_{Year} = TECH\_ADJHP_{Year} + PERF\_ADJHP_{Year} \quad \textbf{(66)}$$

e) Maximum Limit on Total Horsepower Adjustment

The total horsepower adjustment for a given projection year is constrained in several ways. First, the total adjustment in any one year is limited to 10 percent. If an adjustment greater than 10 percent is calculated by the econometric algorithms described above, the additional consumer demand portion is adjusted downward first since the fuel economy impacts of this demand are not yet considered in the fuel economy projections. If it is not possible to obtain the full level of downward adjustment from the additional consumer demand portion of the horsepower adjustment, the remainder is taken from the technology-based adjustment. The magnitude of any technology-based horsepower giveback, HP_GIVEBACK, is tracked and converted into equivalent fuel economy since the basic fuel economy projection already incorporates the full impact of technology-based horsepower adjustments. Hence, if total horsepower adjustment, TTL_ADJHP, is greater than 10 percent:

$$\begin{aligned} HP\_GIVEBACK_{Year} &= TTL\_ADJHP_{Year} - 0.1 \\ PERF\_ADJHP_{Year} &= PERF\_ADJHP_{Year} - HP\_GIVEBACK_{Year} \end{aligned} \quad \textbf{(67)}$$

If the consumer demand for performance, PERF_ADJHP, is non-negative then leave the technology adjustment, TECH_ADJHP, unchanged. Otherwise, decrease the technology adjustment by this performance adjustment (noting PERF_ADJHP is negative):

$$TECH\_ADJHP_{Year} = TECH\_ADJHP_{Year} + PERF\_ADJHP_{Year} \quad \textbf{(68)}$$

Now, calculate the modified total horsepower adjustment:

$$TTL\_ADJHP_{Year} = TECH\_ADJHP_{Year} + PERF\_ADJHP_{Year} \quad \textbf{(69)}$$

f) Maximum Limit on Horsepower to Weight Ratio

Also impose a maximum limit on the horsepower to weight ratio so that performance characteristics do not become unreasonable. If the horsepower to weight ratio is too high, first subtract any consumer preference for performance, PERF_ADJHP, since the fuel economy effect is not considered until later. If there is further need to lower the horsepower to weight ratio then decrease any additional required horsepower demand from the technology-based part of the adjustment, TECH_ADJHP, and track this "giveback", since HP_GIVEBACK must be converted back into fuel economy equivalent.

g) Horsepower to Weight Ratio Must Ensure Drivability

Finally, make sure the horsepower to weight ratio stays above that required for drivability, HP_WGT_MIN, (either 95 percent of the base year value or 0.04 for two-seaters, 0.033 otherwise; whichever is lower). If an upward adjustment is required to satisfy this constraint, it is added to the additional consumer demand portion of the planned horsepower adjustment since the fuel economy impacts of this demand are not yet considered in the fuel economy projections. Additional demand need not be specially tracked since it is reflected in PERF_ADJHP, which is automatically converted to fuel economy equivalent in the algorithms that follow.

The next series of statements calculate the desired and resulting horsepower demand. The desired demand is the difference between the minimum horsepower adjustment, MIN_ADJHP, and the total horsepower adjustment. Adding the desired demand to the current horsepower adjustment produces the total horsepower adjustment:

$$\begin{aligned}
MIN_ADJHP_{Year} &= \left(\frac{HP_WGT_MIN_{BaseYear}}{HP_WGT_{Year}} - 1 \right) \\
PERF_ADJHP_{Year} &= PERF_ADJHP_{Year} + MIN_ADJHP_{Year} - TTL_ADJHP_{Year} \\
TTL_ADJHP_{Year} &= TECH_ADJHP_{Year} + PERF_ADJHP_{Year}
\end{aligned} \tag{70}$$

h) Final Horsepower Adjustment for CAFE Compliance

If CAFE standards are not achieved after the second (CAFE compliance) pass through FEMCALC, the technology-based horsepower adjustment is also constrained to the maximum of zero or that level of adjustment required to maintain the minimum allowable horsepower-to-weight ratio. In other words, in the third pass, take back all the technology driven horsepower demand except that required to maintain the minimum horsepower to weight ratio. The magnitude of any technology-based horsepower giveback is tracked and converted into equivalent fuel economy. Thus, a third pass through FEMCALC allows manufacturers to focus solely on CAFE compliance at the expense of increased performance.

$$\begin{aligned}
EXCESS_ADJHP_{Year} &= MIN(TECH_ADJHP_{Year}, TTL_ADJHP_{Year} - MIN_ADJHP_{Year}) \\
TECH_ADJHP_{Year} &= TECH_ADJHP_{Year} - EXCESS_ADJHP_{Year} \\
TTL_ADJHP_{Year} &= TECH_ADJHP_{Year} + PERF_ADJHP_{Year}
\end{aligned} \tag{71}$$

Compute the horsepower give back;

$$HP\_GIVEBACK_{Year} = HP\_GIVEBACK_{Year} + EXCESS\_ADJHP_{Year} \tag{72}$$

The current year horsepower is then calculated as initial horsepower times the final horsepower adjustment.

$$HP_{Year,FuelType} = HP_{Year,FuelType} * (1 + TTL\_ADJHP_{Year}) \tag{73}$$

7. Readjust Fuel Economy And Price

Once the horsepower adjustment has been determined, the final fuel economy, vehicle price, and vehicle range is calculated.

a) Fuel Economy

Fuel economy is adjusted up or down in accordance with the sum of consumer driven horsepower adjustment and any horsepower giveback. Horsepower giveback is horsepower demand already considered in fuel economy estimates, but not actually taken. Therefore, fuel economy estimates need to be adjusted upward for any giveback. Technology driven affects are already accounted for in the technology incremental fuel economy values. Note that the consumer and giveback estimates are aggregated into the consumer preference parameter to facilitate the series of ensuing fuel economy and price algorithms, recognizing of course that giveback is negative demand.

$$PERF\_ADJHP_{Year} = PERF\_ADJHP_{Year} - HP\_GIVEBACK_{Year} \quad \textbf{(74)}$$

$$ADJFE_{Year} = -0.22 * PERF\_ADJHP_{Year} - 0.56 * SIGN * PERF\_ADJHP_{Year}^{2} \quad \textbf{(75)}$$

where,

SIGN = -1, if PERF_ADJHP < 0, and +1 otherwise.

The final vehicle fuel economy is then determined as follows:

$$FE_{Year} = FE_{Year} * \left(1 + ADJFE_{Year}\right) \quad \textbf{(76)}$$

b) Vehicle Price

Vehicle price is finally estimated:

$$PRICE_{Year} = PRICE_{Year} + PERF\_ADJHP_{Year} * VALUEPERF_{Year} \quad \textbf{(77)}$$

Note that as these are final adjustments, the results do not feed back into the horsepower adjustment equation.

The above equations result in an estimate of the market shares of the considered technologies within each class of vehicle. The effective range for each vehicle class is then calculated. The implication is that market penetration is affected and changes over time.

c) Vehicle Range

For most vehicles, range is a function of tank size and fuel economy as shown in below:

$$RANGE_{Year,FuelType} = TANKSIZE * FE_{Year,Gasoline} * \left(1 + AFVADJRN_{FuelType}\right) \quad \textbf{(78)}$$

where,

RANGE = Vehicle range

TANKSIZE = Tank size for a gasoline vehicle of the same market class

AFVADJRN = Range adjustment, relative to gasoline vehicle (exogenous, from Block Data)

The range adjustment factor (AFVADJRN) is derived through engineering judgment and is based on current gasoline vehicle tank sizes, likely relative fuel capacity for alternative vehicles and the actual base year relative fuel economies of gasoline and AFVs.

The range for electric battery vehicles is set to 80 miles. This is an engineering judgment of the best performance likely to be obtained from a production electric powered vehicle in the foreseeable future. The next step is to calculate the market shares of each vehicle class within each CAFE group.

8. Calculate Class Market Shares

This routine calculates vehicle class market shares within each corporate average fuel economy group (i.e., Domestic Cars, Import Cars, Domestic Trucks and Import Trucks.) Car market shares for each class are derived by calculating an increment from the previous year's value. The market share increment (or decrement) is determined by the following equation:

$$DIFFLN_{Year} = A*\ln\left(\frac{Year}{Year-1}\right) + B*\ln\left(\frac{FUELCOST_{Year}}{FUELOST_{Year-1}}\right) + C*\ln\left(\frac{INCOME_{Year}-\$13,000}{INOME_{Year-1}-\$13,000}\right) + D*\ln\left(\frac{PRICE_{Year,Gasoline}}{PRICE_{Year-1,Gasoline}}\right) \quad \textbf{(79)}$$

where,

DIFFLN = the log market share increment from the year, Year

A, B, C, D = coefficients, elasticities, exogenously introduced from trninput.wk1

Class Market Shares

Solve for the log-share ratio:

$$RATIO\_LN = DIFFLN_{Year} + \ln\left(\frac{CLASS\_SHARE_{class,group,nhtsalyr}}{1-CLASS\_SHARE_{class,group,nhtsalyr}}\right) \quad \textbf{(80)}$$

where,

RATIO_LN = Log of the market share ratio of the considered vehicle class

CLASS_SHARE = Class market share, assigned to the appropriate vehicle class and group

class = 6 Vehicle Classes

group = 7 CAFE Groups

nhtsalyr = last year of NHTSA historical data

Solve for the class market share:

$$CLASS\_SHARE_{class,group,Year} = \frac{e^{RATIO\_LN}}{1+e^{RATIO\_LN}} \tag{81}$$

Normalize so that shares total 100 percent within each CAFE group:

$$CLASS\_SHARE_{class,group,Year} = \frac{CLASS\_SHARE_{class,group,Year}}{\sum_{class=1}^{6} CLASS\_SHARE_{class,group,Year}} \tag{82}$$

9. Calculate CAFE

This routine calculates the corporate average fuel economy for each of the seven CAFE groups:

1) Domestic Cars
2) Import Cars
3) Trucks – Manufacturer Group 1 - Domestic
4) Trucks – Manufacturer Group 2 – Domestic
5) Trucks – Manufacturer Group 3 - Domestic
6) Trucks – Manufacturer Group 4 - Imports
7) Trucks – Manufacturer Group 5 - Imports

For each vehicle group the CAFE calculation proceeds as follows:

$$CAFE_{group,Year} = \frac{\sum_{class=1}^{6} CLASS\_SHARE_{class,group,Year}}{\sum_{class=1}^{6} \frac{CLASS\_SHARE_{class,group,Year}}{FE_{class,group,Year}}} \tag{83}$$

This CAFE estimate is then compared with the legislative standard for the seven manufacturer groups for each year. There are two standards, the traditional standard, represented by the exogenous variable, $CAFE\_STAND_{Group,Year}$, and the alternative standard, $FPMpgGrp_{Group,Year}$, computed as follows. First, the MPG standard, $FPMpg_{Class,Group,Year}$, is computed for each class in each group based on the footprint,

$$FPMpg_{class,group,Year} = \left(\left(\frac{1}{A_{Year}} \right) + \left(\frac{1}{B_{Year}} - \frac{1}{A_{Year}} \right) \frac{e^{\frac{F\,\mathrm{Print}_{class,group,Year} - C_{Year}}{D_{Year}}}}{1 + e^{\frac{F\,\mathrm{Print}_{class,group,Year} - C_{Year}}{D_{Year}}}} \right)^{-1} \quad \textbf{(84)}$$

where,

A = the maximum fuel economy target for trucks by year

B = the minimum fuel economy target for trucks by year

C = the footprint midway between by year

D = the rate of change parameter by year

FPrint = the footprint for each class and group of trucks by year

Second, the alternative footprint mpg standard for the group, $FPMpgGrp_{Group,Year}$, weighted by class is calculated.

$$FPMpgGrp_{group,Year} = \frac{\sum_{class=1}^{6} CLASS\_SHARE_{class,group,Year}}{\sum_{class=1}^{6} \frac{CLASS\_SHARE_{class,group,Year}}{FPMpg_{class,group,Year}}} \quad \textbf{(85)}$$

The CAFE standard to be used is then decided. Cars will always use the traditional standard. For light trucks, if the year is before 2008 use the traditional standard. If the year is between 2008 and 2011, the standard is chosen in the following manner. If the alternative footprint mpg standard is less than the traditional standard, the alternative standard is chosen. Otherwise, the traditional standard is chosen. If the alternative standard is chosen then the group must continue to use it in later years. In the year 2012 and later use only the alternative method.

Finally, the individual vehicle group CAFE is compared to the CAFÉ standard used and passes if CAFE is greater or equal to the CAFE standard used.

10. Forced CAFE Standard

This algorithm describes the case where light duty vehicles are forced to meet the CAFE standard by increasing the sales of hybrid and diesel vehicles, followed by a corresponding decrease in the sale of gasoline vehicles.

If the meeting of the CAFE standard switch is set, CAFEMEET=1, then the CAFETEST routine is called after completing the third pass of MTCS. New vehicle sales are re-computed for the alternative fuel types, CAFETYP, in the following order: gas hybrids, diesels, and diesel hybrids.

The order of vehicle types used in the calculations is: for cars, the standard types by size are used, and for light duty trucks, small SUV, small vans, small pickups, large SUV, large pickups, and large vans. For each vehicle group the CAFE calculation proceeds as follows.

For any of the four vehicle groups described above that fail to meet the CAFE standard the following new set of sales are computed. First, calculate the share of total sales, DEL_SALES, due to each CAFETYP:

$$DEL\_SALES_{vt,class,CAFETYP} = DEL\_APSHR * \sum_{FuelType=1}^{NUMFUELS} AVSALES_{vt,class,11,FuelType} \tag{86}$$

where,

DEL_APSHR = 0.005

AVSALES = Sales of new vehicles, as defined in (139)

CAFETYP = Diesel hybrid, diesel, and gas hybrid

and 11 represents region 11 = national sales

For each alternative fuel type, CAFETYP, new sales are computed up to a total of ten times, at increments of DEL_APSHR, or 0.5 percent. A new set of CAFE calculations are made for each increment and compared to the CAFE standard. Further sales stop after successfully passing the standard. New vehicle sales are computed as follows:

$$AVSALES_{vt,class,11,FuelType} = AVSALES_{vt,class,11,FuelType} + DEL\_SALES_{vt,class,FuelType} \tag{87}$$

$$AVSALES_{vt,class,11,GAS} = AVSALES_{vt,class,11,GAS} - DEL\_SALES_{vt,class,GAS} \tag{88}$$

where,

FuelType = Gas hybrids, diesels, and diesel hybrids, in that order

The new shares, APSHR55, are then re-calculated, as in (145). Total sales, AVSALEST, remain unchanged.

If at any time gasoline sales become negative, sales of gasoline engine vehicles are increased until sales reach zero, with a corresponding decrease in vehicle sales of diesel hybrids, diesels, and gas hybrids, respectively. There are constraints to new vehicle sales. For each CAFETYP, sales stop after ten failures to meet the standard, or after 5 percent of total sales. Also, a maximum of 500,000 new sales are allowed for each CAFETYP.

11. Combine Results Of Domestic And Imported Vehicles

In subsequent modules of the transportation model, domestic and imported vehicles are not treated separately. It is therefore necessary to construct an aggregate estimate of each vehicle characteristic for each class of car and light truck. Aggregate vehicle characteristics are determined by weighting each vehicle class, *class*, by their relative share of the market (PERGRP). These numbers are assumed to be constant across classes and time, and have been obtained from NHTSA data of the domestic, *dom*, and imported, *imp*, market shares:[6]

$$MPG_{vt,class} = \frac{1}{\frac{PERGRP_{dom,class}}{FE_{dom,class}} + \frac{PERGRP_{imp,class}}{FE_{imp,class}}} \qquad \textbf{(89)}$$

$$HPW_{vt,class} = HP_{dom,class} * PERGRP_{dom,class} + HP_{imp,class} * PERGRP_{imp,class} \qquad \textbf{(90)}$$

$$PRI_{vt,class} = PRICE_{dom,class} * PERGRP_{dom,class} + PRICE_{imp,class} * PERGRP_{imp,class} \qquad \textbf{(91)}$$

$$VRNG_{vt,class} = RNG_{vt,class} = RANGE_{dom,class} * PERGRP_{dom,class} + RANGE_{imp,class} * PERGRP_{imp,class} \qquad \textbf{(92)}$$

$$WGT_{vt,class} = WEIGHT_{dom,class} * PERGRP_{dom,class} + WEIGHT_{imp,class} * PERGRP_{imp,class} \qquad \textbf{(93)}$$

where,

MPG = Vehicle fuel economy

HPW = Vehicle horsepower

PRI = Vehicle price

VRNG = RNG = Vehicle range

WGT = Vehicle weight

PERGRP = Percent of vehicles import or domestic by market class

vt = 1 (cars, except minicompacts); 2 (light trucks, except standard pickups, standard vans, and standard utilities)

These numbers are then passed to the CVCS, and the overall fleet stock submodule to produce estimates of fleet efficiencies.

Regional Sales Submodule

The Regional Sales Submodule is a simple accounting mechanism, which uses exogenous estimates of new car and light truck sales and the results of the MTCS, to produce estimates of regional sales and the characteristics of light duty vehicles that are subsequently passed to the Light Duty Stock Submodule.

Nationwide estimates of total new vehicle sales come from the NEMS macroeconomic model.

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[6] Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 27*, ORNL-6973, 2008.
For Cars: Table 7.5, 2006 data. For Light Trucks: Table 7.6, 2006 data.

In order to comply with the NEMS requirement for regional fuel consumption estimates, the Regional Sales Submodule allocates new car and light truck sales among the nine Census divisions and permits regional variations in vehicle attributes. This also gives the transportation model the capability to analyze regional differences in alternative vehicle legislation. For example, California LEVII legislation requiring minimum percentages of vehicles sold be zero emissions vehicles, which are earned in part through credits obtained from the sales of advanced technology partial zero emission vehicles, have been adopted by Connecticut, Massachusetts, Maine, New York, New Jersey, Oregon, Rhode Island, Washington and Vermont.

This is not a separate submodule in itself, but rather a series of intermediate calculations used to generate several regional variables, which are used in subsequent steps in the transportation model. It comprises two subroutines, CGSHARE and TREG; the first calculates light vehicle market class shares and average horsepower and weight for cars and light trucks, and the second generates regional shares of fuel consumption, driving demand, and sales of vehicles by market class.

1. Redistribute MTCS Sale Shares Among Six Market classes

The first stage in this submodule involves the estimation of non-fleet sales of cars and light trucks for each of the six market classes and CAFE groups described in the MTCS. The fraction of car and truck sales attributed to fleets is assumed to vary over time across market classes and the estimation period. Although the fuel economies of domestic and imported vehicles have already been combined, the separate market shares are recorded and the calculations are performed separately for domestic and imported vehicles.

It is first necessary to estimate car and light truck sales after getting total sales from the macroeconomic model. Total sales of trucks are shared into the following gross vehicle weight rating (GVWR) categories: trucks less than 8,500 pounds, included in the LDV Module; trucks between 8,500 and 10,000 pounds, modeled separately in the Class 2b Vehicle Submodule; and trucks over 10,000 pounds, included in the Highway Freight Module. Additionally, the LDV Module estimates the allocation of LDV sales between cars and light trucks to capture the changing purchase patterns of consumers in recent years.

First, estimate the percent of total light vehicles < 8,500 pounds GVW that are cars, CARSHARE:

$$CARSHARE_{Year} = e^{\{\rho LOG(CARSHARE_{Year-1})+\beta_0(1-\rho)+\beta_1[LOG(INCOME00_{Year})-\rho LOG(INCOME00_{Year-1})]} * \\ e^{\{\beta_2[LOG(FUEL04_{Year})-\rho LOG(FUEL04_{Year-1})]+\beta_3[DUMM_{Year}-\rho DUMM_{Year-1}]\}} \quad \textbf{(94)}$$

where,

INCOME00 = Per capita income in 2000 dollars

FUEL04 = Fuel price in 2004 $ per gallon

DUMM = Dummy variable = 2003 – 1992 = 11, for all projected years

ρ = Lag factor for the difference equation

Calculate new car and light truck (class 1 and 2A, less than 8,500 pounds GVW) sales:

$$NEWCARS_{Year} = \left(MC\_SQTRCARS_{Year} + MC\_VEHICLES_{1,Year} + MC\_VEHICLES_{3,Year}\right) * CARSHARE_{Year}$$
$$and$$
$$NEWCLS12A_{Year} = \left(MC\_SQTRCARS_{Year} + MC\_VEHICLES_{1,Year} + MC\_VEHICLES_{3,Year}\right) * \left(1 - CARSHARE_{Year}\right) \quad \textbf{(95)}$$

where,

MPG NEWCARS = Total new car sales

NEWCLS12A = Total new light truck sales

MC_SQTRCARS = Total car sales, from the macroeconomic model

$MC\_VEHICLES_{1,Year}$ = Sales of light truck, 0 to 6,000 pounds GVW, from the macroeconomic model

$MC\_VEHICLES_{3,Year}$ = Sales of light trucks, 6,000 to 8,500 pounds GVW, from the macroeconomic model

CARSHARE = Share of light vehicles < 8,500 GVW that are cars

Calculate non-fleet, non-commercial sales of cars (*group=1,2*) and light trucks (*group=3,4*) in the 6 market classes:

$$NVS7SC_{group=1-2,classYear} = CLASS\_SHARE_{class,group=1-2,Year} * NEWCARS_{Year} * \left(1 - FLTCRAT_{Year}\right) * SALESHR_{group=1-2,Year}$$
$$and$$
$$NVS7SC_{group=3-4,classYear} = CLASS\_SHARE_{class,group=3-4,Year} * NEWCLS12A_{Year} * \left(1 - FLTTRAT_{Year}\right) * SALESHR_{group=3-4,Year} \quad \textbf{(96)}$$

where,

NVS7SC = Non-fleet, non-commercial sales

CLASS_SHARE = The market share for each car class, from MTCS

FLTCRAT = Fraction of new cars purchased by fleets by year

FLTTRAT = Fraction of new light trucks purchased by fleets by year

SALESHR = Fraction of vehicle sales that are domestic/imported by year

Sales are then combined for domestic and import groups, as follows:

$$NCSTSCF_{class,Year} = \sum_{group=1}^{2} NVS7SC_{group,class,Year}$$

$$and \qquad \textbf{(97)}$$

$$NLTSTSCF_{class,Year} = \sum_{group=3}^{4} NVS7SC_{group,class,Year}$$

where,

NCSTSCF = Sales of cars by 6 EPA market classes

NLTSTSCF = Sales of light trucks by 6 EPA market classes

The non-fleet market shares for cars and light trucks by market class starts at the last historic year and grows at the same rate as the non-fleet, non-commercial share of sales of cars and light trucks:

$$PASSHR_{class,Year} = PASSHR_{class,Year-1} * \frac{\left(\dfrac{NCSTSCF_{class,Year}}{\sum_{class=1}^{6} NCSTSCF_{class,Year}} \right)}{\left(\dfrac{NCSTSCF_{class,Year-1}}{\sum_{class=1}^{6} NCSTSCF_{class,Year-1}} \right)}$$

$$and$$

$$LTSHR_{class,Year} = LTSHR_{class,Year-1} * \frac{\left(\dfrac{NLTCSTSCF_{class,Year}}{\sum_{class=1}^{6} NLTSTSCF_{class,Year}} \right)}{\left(\dfrac{NLTSTSCF_{class,Year-1}}{\sum_{class=1}^{6} NLTSTSCF_{class,Year-1}} \right)} \qquad \textbf{(98)}$$

where,

PASSHR = The non-fleet market share for cars, and for the last historic year is the fraction of car sales as reported by the National Highway Traffic Safety Administration.

LTSHR = The non-fleet market share for light trucks and for the last historic year is the fraction of light truck sales as reported by the National Highway Traffic Safety Administration.

The weighted average horsepower of cars and light trucks, weighted by the normalizing of the non-fleet market shares, is then calculated:

$$AHPCAR_{Year} = \sum_{class=1}^{6} HPW_{car,class} * \frac{PASSSHR_{class,Year}}{\sum_{class=1}^{6} PASSHR_{class,Year}}$$

$$and \tag{99}$$

$$AHPTRUCK_{Year} = \sum_{class=1}^{6} HPW_{trk,class} * \frac{LTSHR_{class,Year}}{\sum_{class=1}^{6} LTSHR_{class,Year}}$$

A similar calculation occurs for the average weight of cars, AWTCAR, and light trucks, AWTTRUCK, weighted by the non-fleet market shares, as shown in the above equations.

2. Determine Regional Values of Fuel Demand and Vehicle Sales

Regional demand shares for each of eleven fuels, as defined by State Energy Data System (SEDS), are first initialized, ensuring that no region has a zero share in the preceding time period, then grown at the rate of personal income growth in each region, and renormalized so the shares add to 1.0:

$$SEDSHR_{FUEL,REG,Year} = \frac{SEDSHR_{FUEL,REG,Year-1} * \left(\frac{TMC\_YD_{REG,Year}}{TMC\_YD_{REG,Year-1}} \right)}{\sum_{REG=1}^{9} \left(SEDSHR_{FUEL,REG,Year-1} * \left(\frac{TMC\_YD_{REG,Year}}{TMC\_YD_{REG,Year-1}} \right) \right)} \tag{100}$$

where,

SEDSHR = Regional share of the consumption of a given fuel in period, Year.

TMC_YD = Estimated disposable personal income by region REG

REG = Index referring to Census region

These shares are passed to other modules in the transportation model, and used for the first year computation of VMT16R and VMTEER, in this case 1995.

The distribution of new car and light truck sales among regions is then addressed. This process takes several steps, and is based on the assumption that regional demand for new vehicles is proportional to regional travel demand. The calculation proceeds as follows:

Determine the regional cost of driving per mile:

$$COSTMIR_{REG,Year} = 0.1251 * \left(\frac{PMGTR_{REG,Year}}{MPGFLT_{Year}} \right) \tag{101}$$

where,

COSTMIR = The cost per mile of driving in region *REG*, in $/mile

PMGTR = The regional price of motor gasoline, in $/MMBTU

MPGFLT = The previous year's stock MPG for non-fleet vehicles

0.1251 = A conversion factor for gasoline, in MMBTU/gal, 5.253/42.0.

Calculate regional income:

$$INCOMER_{REG,Year} = \left(\frac{TMC\_YD_{REG,Year}}{MC\_N_{REG,Year}} \right) \tag{102}$$

where,

INCOMER = Regional per capita disposable income

TMC_YD = Total disposable income in region REG

MC_N = Total population in region REG

Estimate regional driving demand[7]:

$$VMTLDR_{REG,Year} = X * Y \tag{103}$$

where,

$$X = e^{\{\rho LOG(VMTLDR_{REG,Year-1}) + \beta_0(1-\rho) + \beta_1[LOG(VMTLDR_{REG,Year-1}) - \rho LOG(VMTLDR_{REG,Year-2})]\}}$$

$$Y = e^{\{\beta_2[LOG(INCOMER_{REG,Year}) - \rho LOG(INCOMER_{REG,Year-1})] + \beta_3[LOG(COSTMIR_{REG,Year}) - \rho LOG(COSTMIR_{REG,Year-1})]\}}$$

and,

$$VMTEER_{REG,Year} = VMTLDR_{REG,Year} * LICDRIVER_{REG,Year} \tag{104}$$

where,

VMTLDR = Regional vehicle-miles traveled per licensed driver

ρ = Lag factor for the difference equation

VMTEER = Total VMT in region REG

LICDRIVER = Total regional licensed drivers

[7] The development and estimation of the VMT equation is described in detail later, in the VMT Submodule (Section 3).

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,Year} = \frac{VMTEER_{REG,Year}}{\sum_{REG=1}^{9} VMTEER_{REG,Year}} \tag{105}$$

Divide non-fleet car and light truck sales according to regional VMT shares:

$$NCS_{REG,class,Year} = NCSTSC_{class,Year} * RSHR_{REG,Year} \tag{106}$$

and,

$$NLTS_{REG,class,Year} = NLTSTSC_{class,Year} * RSHR_{REG,Year} \tag{107}$$

where,

MPG = Vehicle fuel economy

NCS = New car sales, by market class and region

NLTS = New light truck sales, by market class and region

Consumer Vehicle Choice Submodule (CVCS)

The CVCS is a projection tool designed to support the LDV Module of the NEMS Transportation Sector Model. The objective of the CVCS is to estimate the market penetration (market shares) of conventional and alternative-fuel vehicles during the period 1995-2030. The submodule uses estimates of new car fuel economy obtained from the MTCS submodule of the LDV Module, and fuel price estimates generated by NEMS to project technology market shares. The submodule is useful both to assess the penetration of conventional and alternative-fuel vehicles and to allow analysis of policies that might impact their penetration.

The CVCS is derived using attribute-based discrete choice techniques and logit-type choice functions, which represent a demand function for vehicle sales in the United States. The demand function takes projections of the changes in vehicle and fuel attributes for the considered technologies to produce the market share penetration for the various technologies.

The demand function is a logit discrete choice model that can be represented as follows:

$$\log\left(\frac{P_k}{1-P_k}\right) = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_k X_k + \varepsilon_k \tag{108}$$

where P_k is the probability of a consumer choosing vehicle k, $ß_1$ is the constant, $ß_{1\ldots,}$ $ß_k$ are the coefficients of vehicle and fuel attributes and $X_i,\ldots X_k$ are vehicle and fuel attributes.

The basic structure of the projection component of the market share estimation for AFV sales is a three-dimensional matrix format. The matrix consists of *I* vehicle technology types, *K* attributes for each technology, and *T* number of years for the analysis. Each cell C_{ikt} in the *C* matrix contains a coefficient reflecting the value of attribute *k* of vehicle technology *i* for the given year *t*.

The calculation of the market share penetration of AFV sales is expressed in the following equation:

$$S_{it} = P_{it} = \sum_{n=1}^{N} \frac{P_{itn}}{N} \quad , \qquad P_{itn} = \frac{e^{V_{itn}}}{\sum_{i=1}^{I} e^{V_{itn}}} \tag{109}$$

where,

S_{it} = market share sales of vehicle type i in year t,

P_{it} = aggregate probability over population N of choosing type i in year t,

n = individual n from population N,

P_{itn} = probability of individual n choosing type i in year t,

V_{itn} = a function of the K elements of the vector of attributes (A) and coefficients (B), generally linear in parameters, i.e.:

$$V = ß_1X_1 + ß_2X_2 + \ldots + ß_kX_k$$

and V is specific to vehicle i, year t, and individual n.

The above equation asserts that the share of each technology is equivalent to the aggregate probability over the population of choosing that technology, which is produced by summing the individual probability functions. The individual probabilities are a function of the ratio of the *V*'s (taken as an exponential). The market share of each vehicle type is ultimately determined by its attributes relative to the attributes of all competing vehicles.

The coefficients of the vehicle attributes in the CVCS are assumed to remain constant over time. This enables the calculation of the *C* matrix to be less cumbersome; however, the methodology can utilize either changing or constant coefficient values for the vehicle attributes. The *C* matrix is replicated for each year of the analysis and for each target group incorporated in the study. A *V* value is produced for each of the vehicle technologies, and for each of the target regions, size and scenario during each year of the study.

The CVCS operates in three stages, using a bottom-up approach to determine the eventual market shares of conventional and alternative vehicles. Results from the lower stages are passed to the next higher stage in the sequence. As the prices of AFVs are functions of sales volume (estimated in the MTCS), the CVCS goes through two iterations; first, estimating sales volume using the previous year's volume-dependent prices, then re-estimating prices and consequent sales.

The submodule provides market shares for fourteen alternative-fuel technologies in addition to the conventional gasoline and diesel technologies. As stated above, there are three stages or levels to the “tree” structure of the CVCS-logit model. In the first stage, the shares of vehicle sales are determined among five vehicle groups: conventional, hybrid, dedicated alternative fuel, fuel cell, and electric. The second stage of the logit model subdivides each of the five groups into sales shares among the vehicle types within the each group. The conventional vehicles consist of gasoline, diesel, flex-fuel methanol and ethanol, and CNG and LPG bi-fuels. Hybrid electric vehicles contain gasoline, plug-in gasoline, and diesel hybrids. Dedicated ethanol, CNG and LPG comprise the dedicated AFV group. Fuel cell vehicles include gasoline and methanol reformers, and hydrogen based fuel cells. The fifth group is represented by electric vehicles, which may use lead-acid, Ni-MH, or Li-Ion batteries. The third level of the CVCS evaluates the value associated with the proportion of the travel in which flex or bi-fuel vehicles are using the alternative-fuel or gasoline fuel.

Several vehicle attributes are weighted and evaluated in the utility function. The following vehicle and fuel attributes are considered: vehicle price, fuel cost or cost of driving per mile (fuel price divided by fuel efficiency), vehicle range, fuel availability, battery replacement cost, acceleration from 0 to 60 miles per hour in seconds, home refueling capability, maintenance costs, luggage space, and make and model diversity or availability.

The vehicle attributes of vehicle purchase price, fuel cost, acceleration, maintenance and battery cost, and fuel availability are discussed in detail below.

Calculate vehicle purchase price in nominal dollars:

$$PSPR_{vt,FuelType,class} = PRI_{vt,FuelType,class} * TMC\_PGDP \qquad \textbf{(110)}$$

where,

vt = Index referring to vehicle type (car or light truck)

FuelType = Index referring to fuel type (1-16)

class = Index referring to vehicle market class (1-6)

PRI = Aggregate vehicle price, obtained from MTCS, and constrained not to drop below gasoline vehicle price plus the high volume differential between gasoline and ATV

TMC_PGDP = Implicit GDP price deflator from the macroeconomic model, used to convert 1990 dollars to nominal dollars

Calculate fuel costs:

$$FLCOST_{vt,FuelType,class,REG} = \frac{FPRICE_{FuelType,REG} * TMC\_PGDP}{MPG_{vt,FuelType,class}} \qquad \textbf{(111)}$$

where,

FLCOST = Fuel operating costs for each technology, in nominal $ per mile

FPRICE = Vehicle fuel price in nominal $ per gallon

REG = Index referring to 9 census regions

MPG = Aggregate vehicle fuel economy

Calculate acceleration (0-60 mph) in seconds:

$$ACCL_{vt,FuelType,class} = e^{-0.00275} * \left(\frac{HPW_{vt,FuelType,class}}{WGT_{vt,FuelType,class}} \right)^{-0.776} \quad \textbf{(112)}$$

Calculate maintenance and battery costs in nominal dollars:

$$MAINT_{1,FuelType,class,REG} = MAINTCAR_{FuelType,REG} * TMC\_PGDP$$
$$and \quad \textbf{(113)}$$
$$MAINT_{2,FuelType,class,REG} = MAINTTRK_{FuelType,REG} * TMC\_PGDP$$

where,

MAINTCAR = Car maintenance and battery costs in $ 96, from OTT Quality Metrics 99

MAINTTRK = Light truck maintenance and battery costs in $ 96, from OTT Quality Metrics 99

TMC_PGDP = conversion from 1996 dollars to nominal dollars

Calculate Fuel Availability (TALT2) Subroutine Methodology

The fuel availability variable attempts to capture the dynamic associated with the increasing number of refueling stations. The premise is that the number of refueling stations is proportional to the number of vehicles. Therefore, as vehicle stocks accumulate over time, the number of refueling stations will increase as a function of a historical relationship between the number of refueling stations and vehicle stocks. Fuel availability is used in the CVCS-Logit Submodule as an input in determining the proportion of travel associated with the use of alternative-fuels in a flex or bi-fuel vehicle. Fuel availability is also used in the utility function within the CVCS-Logit Submodule to determine the proportion of sales among various vehicle types or technology groups. The final fuel availability variable is configured as an index relative to the number of gasoline refueling stations.

Calculate the vehicle stocks by the highway fuel type to determine the number of refueling stations that might be using the fuel. The mapping from engine technology fuel type to highway fuel type is shown in Table 2.

Table 2. Engine Technology Fuel Type to Highway Fuel Type

Engine Technology Fuel Type	Highway Fuel Type
Gasoline	Gasoline
Gasoline, plug-in gasoline, and diesel hybrid	Gasoline/diesel/electricity
Flex-fuel and dedicated ethanol	Ethanol/gasoline[8]
Flex-fuel and fuel cell methanol	Methanol/gasoline[8]
Bi-fuel and dedicated CNG	CNG/gasoline[8]
Bi-fuel and dedicated LNG	LPG/gasoline[8]
Dedicated electricity	Electricity
Hydrogen fuel cell	Hydrogen

Estimate the vehicle stock used to calculate needed refueling stations:

$$PREDSTK_{hwy\_fuel,Year} = LDVSTK_{FuelType,Year-1} + W * LDVSTK_{FuelType=flex:bi-fuel,Year-1} \quad \textbf{(114)}$$

where,

PREDSTK = Predicted vehicle stock used to calculate needed refueling stations

LDVSTK = Vehicle stock, by engine technology fuel type, 1 ... 16, using above mapping

W = weight given to assumed proportion of flex or bi-fuel vehicle stock that refuel with alternative fuel

hwy_fuel = highway fuel type, 1...8

Calculate the number of new refueling stations needed to meet the requirements of the vehicle stock:

$$ALTSTAT_{hwy\_fuel,Year} = ALTSTAT_{hwy\_fuel,Year-1} + \frac{PREDSTK_{hwy\_fuel,Year} - PREDSTK_{hwy\_fuel,Year-1}}{STARAT_{hwy\_fuel}} \quad \textbf{(115)}$$

where,

ALTSTAT = Total national level alternative-fuel refueling stations

STARAT = Ratio of refueling stations to vehicle stock based on history

Regionalize the total refueling stations as a function of regional vehicle sales:

$$FUELVSAL_{REG,hwy\_fuel,Year} = NCSTECH_{REG,class,FuelType,Year-1} + NLTECH_{REG,class,FuelType,Year-1}$$

$$AFVSHREG_{REG,hwy\_fuel,Year} = \frac{FUELVSAL_{REG,hwy\_fuel,Year}}{\sum FUELVSAL_{REG,hwy\_fuel,Year}} \quad \textbf{(116)}$$

$$ALTSTA_{REG,hwy\_fuel,Year} = ALTSTAT_{hwy\_fuel,Year} * AFVSHREG_{REG,hwy\_fuel,Year}$$

where,

MPG = Vehicle fuel economy

NCSTECH = Regional car sales by engine technology fuel type

NLTECH = Regional light truck sales by engine technology fuel type

FUELVSAL = Regional vehicle sales within a highway fuel type

AFVSHREG = Regional vehicle sales shares within a highway fuel type

ALTSTA = Regional alternative-fuel refueling stations by highway fuel type

Calculate the fuel availability as an index relative to the number of gasoline refueling stations on a regional basis

$$FAVAIL_{hwy\_fuel,Year,REG} = \frac{ALTSTA_{REG,hwy\_fuel,Year}}{ALTSTA_{REG,Gasoline,Year}} \quad \textbf{(117)}$$

Re-align indices for fuel availability for engine technology fuel type

$$FAVL_{FuelType,REG,Year} = FAVAIL_{hwy\_fuel,Year,REG} \quad \textbf{(118)}$$

where, the fuel type mapping is described above.

Operation of the submodule begins at the third level and progresses to the first level, because the valuations at the lower levels are used as a part of the evaluation at the upper levels of the logit model. We start at Level three because it is the first set of calculations we make, namely, the value function for all vehicle technologies. We then calculate, at Level two, the share of technologies within each group, using the results of Level three. Next, at Level one, we compute the value function and the share of each group using the previous two level results. Finally, we calculate the market share of each vehicle technology using the shares computed in Level one and Level two.

a) Level Three

1) First, the CVCS calculates the share of fuel use between alternative-fuel and gasoline use within the flex and bi-fuel vehicles:

$$X3132 = X31_{vt,class} * \frac{X23_{vt,class}}{X22_{vt,class}}$$

$$BETAFA = X31_{vt,class} * \frac{BETAFA2_{vt,class}}{X22_{vt,class}} \qquad \textbf{(119)}$$

where,

X3132 = Coefficient for vehicle range; (X3132 = Flex methanol, X3142 = Flex ethanol,

X3152 = CNG Bi-fuel, and X3162 = LPG Bi-fuel)

X31 = Coefficient for level 3 multi-fuel generalized cost by vehicle type, *vt*, and market class, *class*

X23 = Coefficient for logit level 2 vehicle range

X22 = Coefficient for logit level 2 fuel cost

BETAFA = Coefficient for fuel availability linear component

BETAFA2 = Coefficient for fuel availability non-linear component

2) Utility values are estimated for the general cost function:

$$UISUM_{FuelType} = X31_{vt,class} * FLCOST_{vt,FuelType,class,REG} + X3132 * \frac{1}{VRNG_{vt,FuelType,class}} + BETAFA * e^{BETAFA2_{vt,class} * FAVL_{FuelType,REG}} \qquad \textbf{(120)}$$

where,

UISUM = Utility Value function for vehicle attributes at multi-fuel level for fuel type and region

FLCOST = Fuel cost of driving for Alternative Vehicle fuel technology, *FuelType*, in cents per mile

VRNG = Vehicle range in miles

FAVL = Fuel availability indexed relative to gasoline

FuelType = Fuel technologies, gasoline, flex-fuels ethanol and methanol, and bi-fuels CNG and LPG

3) Utility values are exponentiated and summed:

$$ESUM_{FuelType} = e^{UISUM_{FuelType}}$$

$$ETOT = \sum_{FuelType} ESUM_{FuelType} \tag{121}$$

where,

ESUM = Exponentiated utility of value

ETOT = Sum of ESUM across fuel types gasoline and alternative-fuel in flex and bi-fuel vehicles

4) ETOT is sent to the general cost function to estimate third level market share values.

$$GENCOST = \frac{1}{X31_{vt,class}} * \log(ETOT) \tag{122}$$

where,

GENCOST = General cost function or value from third level that is used as the value of fuel cost of driving at the second level of the logit

b) Level Two

The second level of the CVCS calculates the market shares among the AFV technologies within each of the five first level groups. The five groups consist of: 1) conventional vehicles (gasoline, diesel, flex-fuel methanol and ethanol, and bi-fuels CNG and LPG), 2) hybrid electric vehicles (gasoline, plug-in gasoline, and diesel fueled), 3) dedicated AFVs (ethanol, CNG, and LPG fueled), 4) fuel cell vehicles (gasoline, methanol, and hydrogen fueled), and 5) electric vehicles (using lead-acid , Ni-MH, and Li-Ion batteries). Second level market shares are estimated separately for flex and bi-fueled vehicles versus shares estimated for dedicated fuel vehicles.

1) Second level logit model calculations for the flex and bi-fuel vehicles determine their share

within the conventional vehicles, which represents the first of five groups at the first level as follows:

$$\begin{aligned}UISUM_{jt} &= X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * GENCOST \\ &+ X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\ &+ X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\ &+ X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log\left(MMAVAIL_{vt,FuelType,class,Year}\right) \\ &+ X210_{vt,FuelType}\end{aligned} \quad \textbf{(123)}$$

where,

$UISUM_{jt}$ = Utility value for the jt vehicle type at the second level within one of the five jg groups at the first level

X21 = Coefficient for vehicle price at the second level in dollars

X22 = Coefficient for fuel cost per mile at the second level in cents per mile

X24 = Coefficient for battery replacement cost at the second level

X25 = Coefficient for vehicle acceleration time from 0 to 60 miles per hour in seconds

X26 = Coefficient for electric vehicle and PHEV home refueling capability

X27 = Coefficient for maintenance cost in dollars

X28 = Coefficient for luggage space indexed to gasoline vehicle

X29 = Coefficient for vehicle make and model diversity availability relative to gasoline

X210 = Coefficient for calibration coefficient determined in trninput.wk1 input file

PSPR = Vehicle price at the second level in dollars

BRCOST25 = Battery replacement cost at the second level

ACCL = Vehicle acceleration time from 0 to 60 miles per hour in seconds

HFUEL = Electric vehicle and PHEV home refueling capability dummy variable (0,1 value)

MAINT = Maintenance cost in dollars

LUGG = Luggage space indexed to gasoline vehicle

MMAVAIL = Vehicle make and model diversity availability relative to gasoline exogenously determined in trninput.wk1

2) Second level logit model utility values for all vehicle types except the flex and bi-fuel vehicles are calculated. These values are used to determine their share within the five groups at the first level where: jg=2 for hybrid vehicles; jg=3 for dedicated alcohol and gaseous vehicles; jg= 4 for fuel cell vehicles; and jg=5 for electric vehicles.

$$\begin{aligned} UISUM_{jt} = {} & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * FLCOST \\ & + X23_{vt,class} * \left(\frac{1}{VRNG_{vt,FuelType,class,Year}} \right) \\ & + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\ & + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\ & + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log\left(MMAVAIL_{vt,FuelType,class,Year}\right) \\ & + X210_{vt,FuelType} + BETAFA2 * e^{BETAFA22_{vt,class} * FAVL_{FuelType,REG,Year}} \end{aligned} \tag{124}$$

Exponentiate the utility value for each vehicle technology and sum across all vehicle technologies within a given group.

$$\begin{aligned} ESUM_{jt} &= e^{UISUM_{jt}} \\ ETOT_{jg} &= \sum_{jt \subset jg} ESUM_{jt} \\ XSHARE_{jg,jt} &= \frac{ESUM_{jt}}{ETOT_{jg}} \end{aligned} \tag{125}$$

c) Level One

1) First, calculate the generalized cost function as a function of the sum of the exponentiated utility values for each group (jg)

$$GCOST_{jg} = \frac{1}{X21_{vt,class}} * \log(ETOT_{jg}) \tag{126}$$

where,

GCOST = Generalized cost function of the group (jg)

2) Calculate the utility value based on the generalized cost function, for jg=1,5.

$$UISUM_{jg} = X11_{vt,class} * GCOST_{jg} \tag{127}$$

3) Exponentiate the utility value, then sum up exponentiated utility values across the groups. The share of the each group is then estimated as exponentiated utility value divided by the sum of the values.

$$ESUM_{jg} = e^{UISUM_{jg}}$$

$$YSHARE_{jg} = \frac{ESUM_{jg}}{\sum_{jg=1}^{5} ESUM_{jg}} \tag{128}$$

$$APSHR44_{vt,class,REG,FuelType} = XSHARE_{jg,jt} * YSHARE_{jg}$$

where,

FuelType = the engine technology fuel type, jt, associated with the fuel group, jg.

Note, APSHR44 is used in equation (136), the vehicle sales equation in the LDV Fleet Submodule.

LDV Fleet Submodule

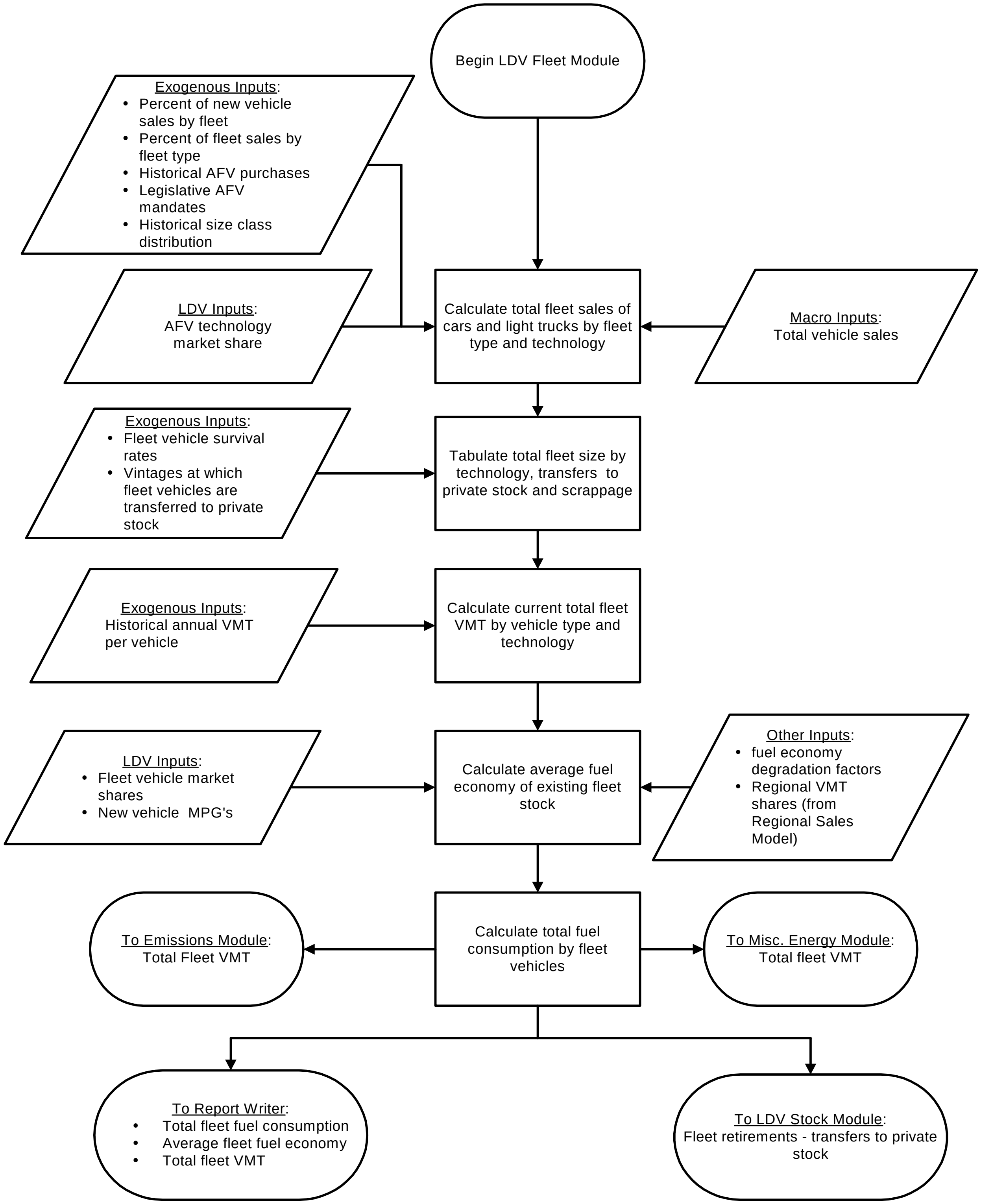
The Light Duty Vehicle Fleet Submodule generates estimates of the stock of cars and trucks used in business, government, and utility fleets, and subsequently estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined vintages. The LDV Fleet Submodule includes a characterization of Class 2b vehicles, which are used in business and trade and are not classifiable under either the LDV Module or the Highway Freight Submodule.

Fleet Vehicles are treated separately in the transportation model because of the special characteristics of fleet light duty vehicles. The LDV Fleet Submodule generates estimates of the stock of cars and light trucks that are used in three different types of fleets, as well as VMT, fuel efficiency, and energy consumption estimates that are distinct from those generated for personal light duty vehicles in the LDV Module and LDV Stock Submodule. The primary purpose for this is not only to simulate as accurately as possible the very different sets of characteristics one would expect to see in fleet as opposed to personal vehicles but also to allow for the greater opportunity for regulation and policy-making that fleet purchases represent. Legislative mandates for AFV purchases, fleet fuel efficiencies, etc. can be incorporated through the subroutine TLEGIS, which has been set up specifically for this purpose.

The submodule uses the same variable names for cars and light trucks, which are distinguished by the value of an index designating vehicle type. Vehicles are also distinguished by the type of fleet to which they are assigned. Business, government, and utility fleets are assumed to have different operating characteristics and retirement rates. This submodule includes three stages: 1) determine total vehicle purchases, surviving fleet stocks and travel demand, 2) calculate the fuel efficiency of fleet vehicles, and 3) estimate the consequent fuel consumption.

The flowchart for the LDV Fleet Submodule is presented in Figure 7. Additional flowcharts outlining major LDV Fleet calculations in more detail are presented throughout this section.

Figure 7. LDV Fleet Submodule



Note: the emissions module is currently inactive.

1. Calculate Fleet Sales and Stocks

Calculate fleet acquisitions of cars and light trucks, see Figure 8:

$$FLTSAL_{vt=1,\,flt,Year} = FLTCRAT_{Year} * NEWCARS_{Year} * FLTCSHR_{flt,Year}$$
$$and \qquad \textbf{(129)}$$
$$FLTSAL_{vt=2,\,flt,Year} = FLTTRAT_{Year} * NEWCLS12A_{Year} * FLTTSHR_{flt,Year}$$

where,

FLTSAL = Sales to fleets by vehicle and fleet type

FLTCRAT = Fraction of total car sales attributed to fleets

FLTTRAT = Fraction of total truck sales attributed to fleets

NEWCARS = Total new car sales in a given year

NEWCLS12A = Total new light truck sales in a given year

FLTCSHR = Fraction of fleet cars purchased by a given fleet type

FLTTSHR = Fraction of fleet trucks purchased by a given fleet type

vt = Index of vehicle type: 1 = cars, 2 = light trucks

flt = Index of fleet type: 1 = business, 2 = government, 3 = utility

A new variable is then established, FLTECHSAL, disaggregating AFV sales by engine technology fuel type, *engtech*, namely (fuels, 1 to 7) ethanol flex, methanol flex, electric, cng bifuel, lpg bifuel, cng, and lpg, and (conventional fuel, 8) gasoline.

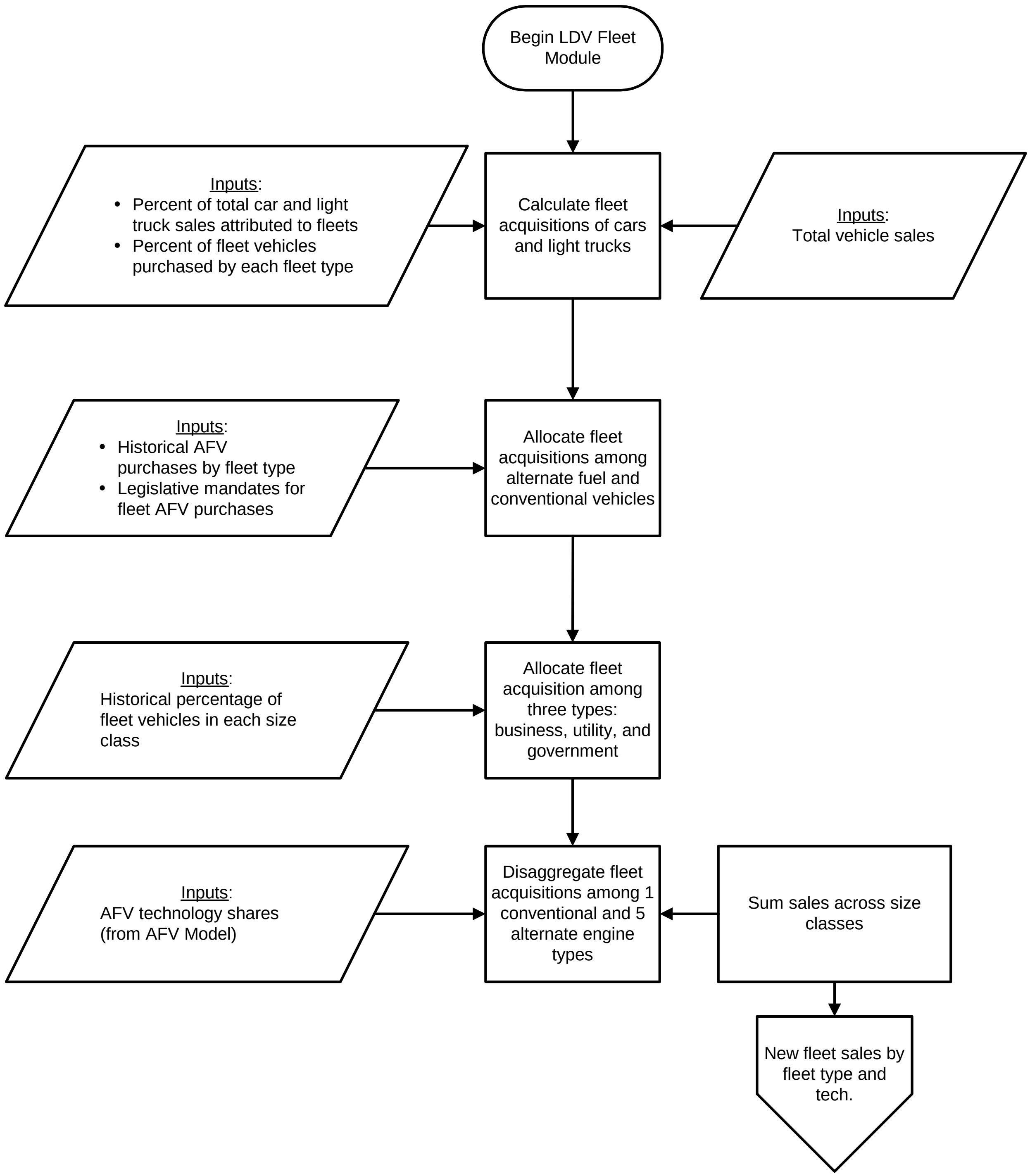
$$FLTECHSAL_{vt,flt,class,engtech<8} = FLTSAL_{vt,flt,Year} * FLTECHSHR_{engtech<8,flt} * FLTAFSHR_{flt,class,vt} * FLTSSHR_{flt,class,vt}$$
$$and \qquad \textbf{(130)}$$
$$FLTECHSAL_{vt,flt,class,engtech=8} = FLTSAL_{vt,flt,Year} * FLTECHSHR_{engtech=8,flt} * FLTSSHR_{flt,class,vt}$$

where, FLTECHSAL = Fleet sales by size, technology, and fleet type

FLTECHSHR = Alternative technology shares by fleet type

Engtech = Index of fuel types: 1-7 = alternative fuels (neat), 8 = gasoline

Figure 8. LDV New Fleet Acquisitions Submodule



Sales are then summed across market classes:

$$FLTECH_{vt,flt,engtech} = \sum_{class=1}^{6} FLTECHSAL_{vt,flt,class,engtech} \quad \textbf{(131)}$$

where,

FLTECH = Vehicle purchases by fleet type and technology

The next step is to modify the array of surviving fleet stocks from previous years, and to add these new acquisitions, see Figure 9. This is done by applying the appropriate survival factors to the current vintages and inserting FLTECH into the most recent vintage:

$$FLTSTKVN_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint-1,Year-1} * SURVFLTT_{vt,vint-1}$$
$$and \quad \textbf{(132)}$$
$$FLTSTKVN_{vt,flt,engtech,vint=1,Year} = FLTECH_{vt,flt,engtech}$$

where,

FLTSTKVN = Fleet stock by fleet type, technology, and vintage

SURVFLTT = Survival rate of a given vintage

vint = Index referring to vintage of fleet vehicles

The stocks of fleet vehicles of a given vintage are then identified, assigned to another variable, and removed from the fleet:

$$OLDFSTK_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint,Year} \quad \textbf{(133)}$$

where,

OLDFSTK = Old fleet stocks of given types and vintages, transferred to the private sector

The variable OLDFSTK is subsequently sent to the LDV Stock Submodule to augment the fleet of private vehicles. The vintages at which these transitions are made are dependent on the type of vehicle and the type of fleet, as shown in Table 3.

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{vt,flt,engtech,Year} = \sum_{vint=1}^{6} FLTSTKVN_{vt,flt,engtech,vint,Year} \quad \textbf{(134)}$$

where,

TFLTECHSTK = Total stock within each technology and fleet type

Figure 9. Determine Characteristics of Existing LDV Fleets

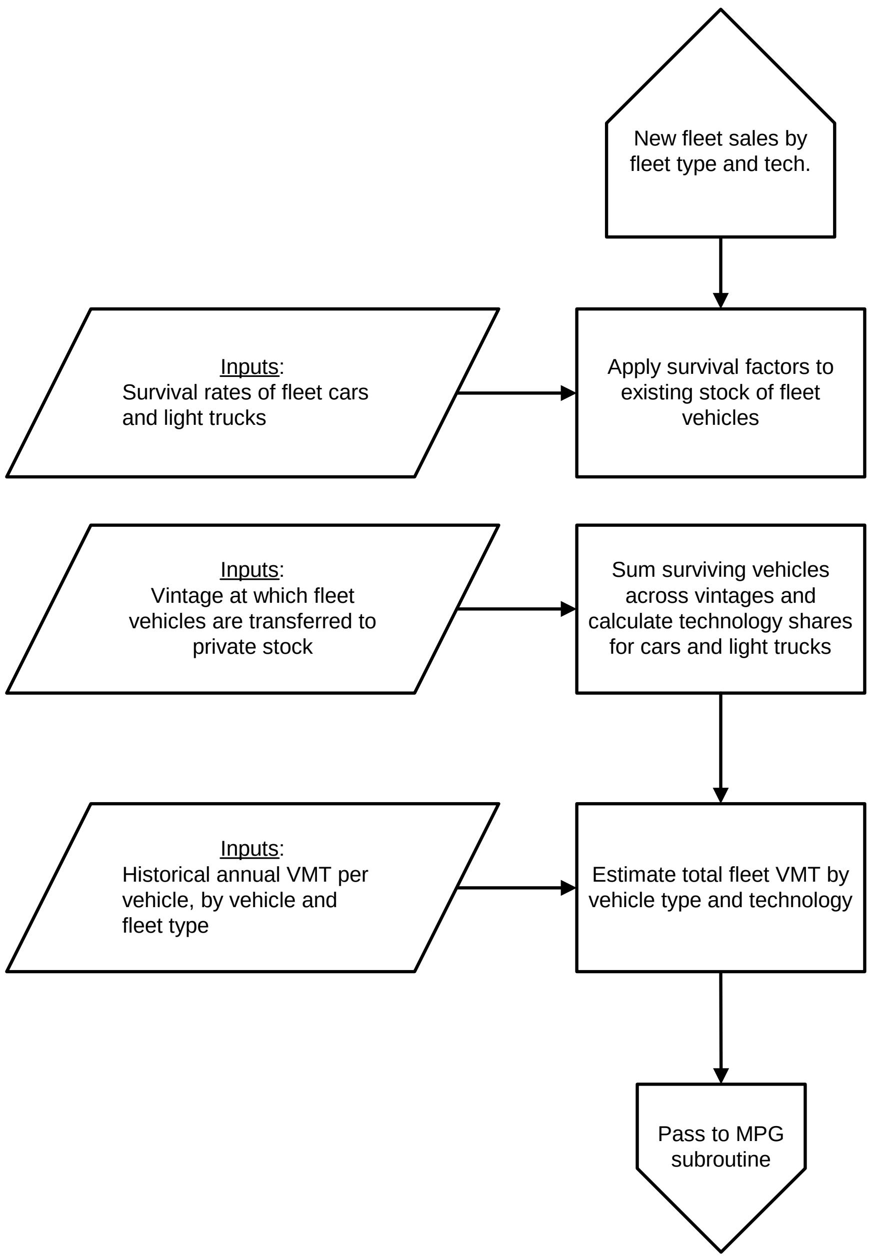


Table 3. Transfer Vintage of Fleet Vehicles

Vehicle Type (vt)	Fleet Type (flt)	Transfer Vintage (vint) (years)
Car (vt = 1)	Business (flt = 1)	5
Car	Government (flt = 2)	6
Car	Utility (flt = 3)	7
Light Truck (vt = 2)	Business	6
Light Truck	Government	7
Light Truck	Utility	6

The percentage of total fleet stock represented by each of the vehicle types and technologies is determined as follows, where the share of fleet stock is divided by the total of all surviving fleet vehicles in a given year:

$$VFSTKPF_{vt,flt,engtech,Year} = \frac{TFLTECHSTK_{vt,flt,engtech,Year}}{\sum_{vt=1}^{2}\sum_{flt=1}^{3}\sum_{engtech=1}^{6} TFLTECHSTK_{vt,flt,engtech,Year}} \qquad \textbf{(135)}$$

where,

VFSTKPF = Share of fleet stock by vehicle type and technology

Vehicle sales and market shares are then adjusted on a regional basis to reflect the legislatively mandated sales of vehicles that earn zero-emission vehicle (ZEV) credits, States that currently have these legislative requirements include California, Connecticut, Massachusetts, Maine, New York, New Jersey, Oregon, Rhode Island, Vermont, and Washington.

1) Calculate regional vehicle sales for cars and light trucks, by technology and market class:

$$VSALES_{vt=1,class,REG,FuelType,Year} = APSHR44_{vt=1,class,REG,FuelType,Year} * NCS_{REG,class,Year}$$
$$and \qquad \textbf{(136)}$$
$$VSALES_{vt=2,class,REG,FuelType,Year} = APSHR44_{vt=2,class,REG,FuelType,Year} * NLTS_{REG,class,Year}$$

where,

APSHR44 = Share calculated from equation 128

NCS = Regional non-fleet car sales by market class, calculated in equation 106.

NLTS = Regional non-fleet light truck sales by market class, calculated in equation 107.

FuelType = Index which matches technologies in the CVCS to corresponding *engtech* fuel type

vt = Index of vehicle type: 1 = cars, 2 = light trucks

2) Mandated sales of ZEV's by participating state are then calculated:

$$ZEVCD_{rg} = TTLZEV_{Year} * \left(COEF1_{rg} * NEWCARS_{Year} + COEF2_{rg} * NEWCLS12A_{Year} \right) \quad \textbf{(137)}$$

where,

ZEVCD = State-mandated sales of ZEV's, and ZEVST = ZEVMA, ZEVNY, ZEVCA

rg = region index of participating states:

= 1 = Maine, Massachusetts, and Vermont, Connecticut, and Rhode Island

= 2 = New York, New Jersey (2009)

= 9 = California, Oregon, and Washington (2009)

TTLZEV = Total percent of mandated sales of ZEV's, from input file, trninput.wk1

= ATPZEV + ZEV + ZFCV (found in equations 140, 141, and 142, respectively)

NEWCARS = Total new car sales

NEWCLS12A = Total new light truck sales

COEF1 = Fraction of total new car sales by participating state

COEF2 = Fraction of total new light truck sales by participating state

3) Sum all of the sales used for gasoline hybrid, methanol fuel cell and gasoline fuel cell vehicles, based on the sales that the advanced technology vehicle (ATV) submodule calculated from the logit model equations:

$$TOTCRED_{REG} = \sum_{vt=1}^{2} \left(VSALES\_EVGH_{vt,REG} + VSALES\_FCM_{vt,REG} + VSALES\_FCG_{vt,REG} \right) \quad \textbf{(138)}$$

where,

VSALES_EVGH = gasoline hybrid vehicle sales = $VSALES_{FuelType=16}$,summed over market classes

VSALES_FCM = methanol fuel cell vehicles sales = $VSALES_{FuelType=13}$, summed over market classes

VSALES_FCG = gasoline fuel cell vehicles sales = $VSALES_{FuelType=15}$, summed over market classes

TOTCRED = total ZEV sales for gasoline hybrid, methanol and gasoline fuel cell vehicles

REG = census region 1 (participating state MA), 2 (NY),and 9 (CA)

4) Regional vehicle sales, VSALES, are adjusted for gasoline hybrid, fuel cell, and electric vehicles, depending on meeting legislative mandates. First, set AVSALES = VSALES:

$$AVSALES_{vt,class,REG,Gasoline} = VSALES_{vt,class,REG,Gasoline} \quad \textbf{(139)}$$

a) If the total sale of gasoline hybrid, and fuel cell (excluding hydrogen) vehicles, TOTCRED, is less than the total maximum allowable Low Emission Vehicle Program (LEVP) sales, ZEVSALES*ATPZEV, then increase the vehicle sales to meet the mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSALES_{REG,Year} * ATPZEV_{Year}}{TOTCRED_{REG,Year} * VSALES\_EVGH_{vt,REG}} \right] \quad \textbf{(140)}$$

where,

AVSALES = total vehicle sales, adjusted for gasoline hybrid and fuel cell (excluding hydrogen) vehicles

ZEVSALES = total ZEV sales that are mandated in census region, REG=1,2, and 9

= ZEVCD

= ZEVR for REG=1 (states= ME, MA, VT, CT, and RI)

= ZEVNY for REG=2 (states=NJ and NY)

= ZEVCA for REG=9 (states=CA,OR, and WA)

ATPZEV = percent of total sales associated with sale of gasoline hybrid, methanol and gasoline fuel cell vehicles, from trninput.wk1

b) If the total sale of electric vehicles, TZEVSAL, is less than the total maximum allowable LEV Program sales, ZEVSALES * ZEV, then increase the resulting electric vehicle sales to meet these mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSALES_{REG,Year} * ZEV_{Year}}{TZEVSAL_{REG,Year}} \right] \quad \textbf{(141)}$$

where,

AVSALES = new total vehicle sales, adjusted for electric vehicles

TZEVSAL = total available ZEVsales of electric vehicles

= $VSALES\_EV_{vt=1,REG} + VSALES\_EV_{vt=2,REG}$

VSALES_EV = electric vehicle sales = $VSALES_{FuelType=7}$, summed over market classes

ZEV = percent of total sales associated with sale of electric vehicles, from trninput.wk1

c) If the total sale of hydrogen fuel cell vehicles, TZFCSAL, is less than the total maximum allowable LEV Program sales, ZEVSALES * ZFCV, then increase the resulting hydrogen fuel cell vehicle sales to meet these mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSALES_{REG,Year} * ZFCV_{Year}}{TZFCSAL_{REG,Year}} \right] \quad \textbf{(142)}$$

where,

AVSALES = new total vehicle sales, adjusted for hydrogen fuel cell vehicles

TZFCSAL = total available ZEV sales from hydrogen fuel cell vehicles

= $VSALES\_FCH_{vt=1,REG} + VSALES\_FCH_{vt=2,REG}$

VSALES_FCH = hydrogen fuel cell vehicle sales = $VSALES_{FuelType=14}$, summed over market classes

ZFCV = percent of total sales associated with the sale of hydrogen fuel cell vehicles, in trninput.wk1

5) The additional sale of vehicles resulting from increasing the above alternative fuel technology vehicle sales are subtracted from gasoline vehicle sales:

$$AVSALES_{vt,class,REG,Gasoline} = AVSALES_{vt,class,REG,Gasoline} - DEL\_TECH_{vt,class,REG,FuelType} \quad \textbf{(143)}$$

where,

DEL_TECH = the additional vehicle sales needed to meet the maximum

= $AVSALES_{vt,class,REG,FuelType}$ - $VSALES_{vt,class,REG,FuelType}$

FuelType = gasoline hybrid, fuel cell, and electric engine fuel technologies

Sum the adjusted vehicle sales across technologies:

$$AVSALEST_{vt,class,REG} = \sum_{FuelType=1}^{16} AVSALES_{vt,class,REG,FuelType} \qquad \textbf{(144)}$$

where,

AVSALEST = Total regional adjusted vehicle sales by market class

Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{vt,class,REG,FuelType} = \frac{AVSALES_{vt,class,REG,FuelType}}{AVSALEST_{vt,class,FuelType}} \qquad \textbf{(145)}$$

where,

APSHR55 = Absolute regional market shares of adjusted vehicle sales

6) Calculate new car and light truck sales using market shares:

$$NCSTECH_{REG,class,FuelType} = NCS_{REG,class} * APSHR55_{vt=1,class,REG,FuelType}$$
$$and \qquad \textbf{(146)}$$
$$NLTECH_{REG,class,FuelType} = NLTS_{REG,class} * APSHR55_{vt=2,class,REG,FuelType}$$

where,

NCSTECH = Regional new car sales by technology, within the six market classes

NLTECH = Regional light truck sales by technology, with the six market classes

<u>2. Calculate Fleet VMT</u>

Historical data on the amount of travel by fleet vehicles is now used to estimate total fleet VMT:

$$FLTVMT_{Year} = \sum_{vt=1}^{2} \sum_{flt=1}^{3} \sum_{engtech=1}^{6} \left(TFLTECHSTK_{vt,flt,engtech,Year} * FLTVMTYR_{flt,Year,vt} \right) \qquad \textbf{(147)}$$

where,

FLTVMT = Total VMT driven by fleet vehicles

FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type, from trninput.wk1

TFLTECHSTK = total stock within each technology and fleet type, calculated in equation 134

Total VMT is then disaggregated by vehicle type and technology:

$$FLTVMTECH_{vt,flt,engtech,Year} = FLTVMT_{Year} * VFSTKPF_{vt,flt,engtech,Year} \quad \textbf{(148)}$$

where,

FLTVMTECH = Fleet VMT by technology, vehicle type, and fleet type

VFSTKPF = Share of fleet stock, calculated in equation 135

3. Calculate Fleet Stock MPG

The average efficiencies of the five non-gasoline technologies (ethanol, methanol, electric, CNG, and LPG) and conventional gasoline ICE technology are calculated as follows (see Figure 10):

$$FLTMPG_{vt,flt,engtech} = \left[\frac{\sum_{class=1}^{6} FLTECHSAL_{vt,flt,class,engtech}}{\sum_{class=1}^{6} \frac{FLTECHSAL_{vt,flt,class,engtech}}{MPG_{vt,FuelType,class}}} \right] \quad \textbf{(149)}$$

where,

FLTMPG = New fleet vehicle fuel efficiency, by fleet type and engine technology fuel type, *engtech*

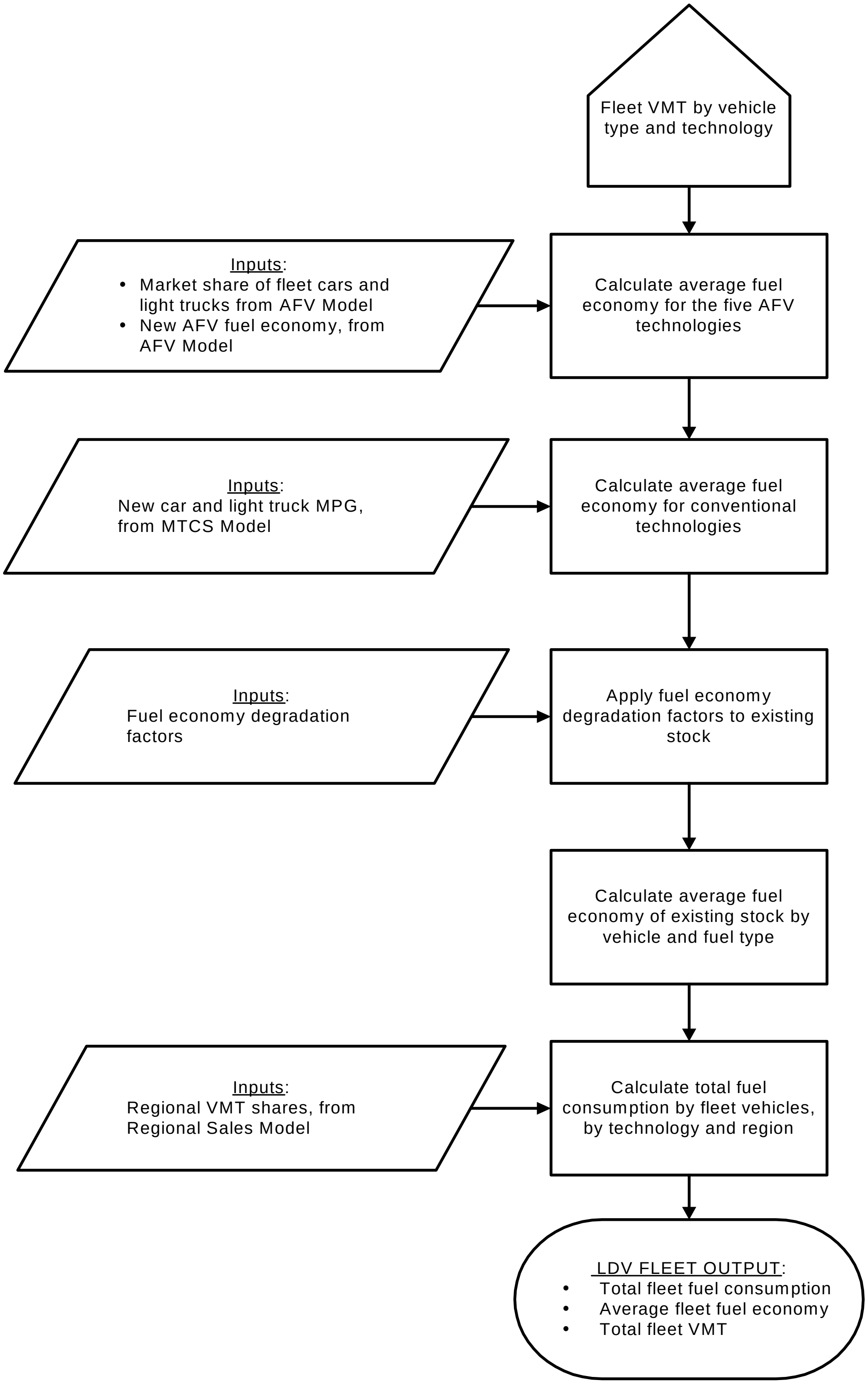
Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{vt} = \left[\frac{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} FLTECH_{vt,flt,engtech}}{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} \frac{FLTECH_{vt,flt,engtech}}{FLTMPG_{vt,flt,engtech}}} \right] \quad \textbf{(150)}$$

where,

FLTMPGTOT = Overall fuel efficiency of new fleet cars and light trucks

Figure 10. Determine Fuel Economy and Consumption for LDV Fleets



The fuel efficiency of new vehicles is then added to an array of fleet stock efficiencies by vintage, which is adjusted to reflect the passage of time, for vintage, *vint = 1,2,…,7*.

For vint=1:

$$CMPGFSTK_{flt,engtech,vint,Year} = FLTMPG_{vt=1,flt,engtech,Year}$$
$$and \qquad \textbf{(151)}$$
$$TMPGFSTK_{flt,engtech,vint,Year} = FLTMPG_{vt=2,flt,engtech,Year}$$

where,

CMPGFSTK = Car fleet MPG fleet type, technology, and vintage

TMPGFSTK = Light truck fleet MPG by fleet type, technology, and vintage

For vint=2,3,…,7:

$$CMPGFSTK_{flt,engtech,vint,Year} = CMPGFSTK_{flt,engtech,vint-1,Year-1}$$
$$and \qquad \textbf{(152)}$$
$$TMPGFSTK_{flt,engtech,vint,Year} = TMPGFSTK_{flt,engtech,vint-1,Year-1}$$

Average fuel efficiency by vehicle and fleet type is then calculated:

$$MPGFLTSTK_{vt=1,flt,engtech} = \left[\frac{\sum_{vint=1}^{maxvint} FLTSTKVN_{vt=1,flt,engtech,vint}}{\sum_{vint=1}^{maxvint} \frac{FLTSTKVN_{vt=1,flt,engtech,vint}}{CMPGFSTK_{flt,engtech,vint} * CDFRFG}} \right]$$
$$and \qquad \textbf{(153)}$$
$$MPGFLTSTK_{vt=2,flt,engtech} = \left[\frac{\sum_{vint=1}^{maxvint} FLTSTKVN_{vt=2,flt,engtech,vint}}{\sum_{vint=1}^{maxvint} \frac{FLTSTKVN_{vt=2,flt,engtech,vint}}{TMPGFSTK_{flt,engtech,vint} * LTDFRFG}} \right]$$

where,

MPGFLTSTK = Fleet MPG by vehicle and fleet type, and technology, across vintages

Maxvint = Maximum vintage index, *vint*, associated with a given vehicle and fleet type

CDFRFG = degradation factor for cars

LTDFRFG = degradation factor for light trucks

The overall fleet average MPG is finally calculated for cars and light trucks:

$$FLTTOTMPG_{vt} = \left[\frac{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} TFLTECHSTK_{vt,flt,engtech}}{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} \frac{TFLTECHSTK_{vt,flt,engtech}}{MPGFLTSTK_{vt,flt,engtech}}} \right] \qquad \textbf{(154)}$$

where,

FLTTOTMPG = Fleet vehicle average fuel efficiency for cars and light trucks

4. Calculate Fuel Consumption by Fleet Vehicles

Fuel consumption is simply the quotient of fleet travel demand and fuel efficiency, which have been addressed above:

$$FLTLDVC_{vt,flt,engtech} = \frac{FLTVMTECH_{vt,flt,engtech,Year}}{MPGFLTSTK_{vt,flt,engtech}} * QBTU_{engtech} \qquad \textbf{(155)}$$

where,

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

QBTU = Energy content, in Btu/Gal, of the fuel associated with each technology

Consumption is then summed across fleet types, and converted to Btu values:

$$FLTFCLDVBTU_{vt,flt,engtech,Year} = \frac{FLTVMTECH_{vt,flt,engtech,Year}}{MPGFLTSTK_{vt,flt,engtech}} \qquad \textbf{(156)}$$

where,

FLTFCLDVBTU = Fuel consumption, in Btu, by vehicle type and technology

Consumption by trucks and cars are added, and total consumption is subsequently distributed among regions:

$$FLTFCLDVBTUR_{REG,engtech,Year} = \sum_{vt=1}^{2} FLTFCLDVBTU_{vt,engtech,Year} * RSHR_{REG} \qquad \textbf{(157)}$$

where,

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology

RSHR = Regional VMT shares, from the Regional Sales Submodule

REG = Index of census regions

Class 2b Vehicle Submodule

The Class 2b Vehicle Submodule provides an accounting of sales, stocks, fuel economy, and energy use for vehicles weighting 8,500 to 10,000 pounds GVWR.[8] The submodule tracks travel and fuel efficiency for twenty vehicle vintages. The primary purpose of this submodule is to provide a mechanism to allocate the stock and new sales of Class 2b vehicles among the various major-use groups considered in this submodule, which includes five industrial categories (e.g., agriculture, mining, construction, total manufacturing, and utility) and one household segment (e.g., personal travel or personal VMT). Historical stock numbers are derived from the Oak Ridge National Laboratory study using Polk data,[9] and new sales are obtained from the macroeconomic model. The shares used for allocating the stock and new sales information are derived from the 1997 Vehicle Inventory and Use Survey (VIUS). VIUS provides data to use in distributing the VMT by major use group that allows estimation of the total annual miles traveled within each category.

Calculate the new Class 2b vehicle sales:

$$NEWCLS2B_{Year} = MC\_VEHICLES_{4,Year} * 1000 \tag{158}$$

where,

$MC\_VEHICLES_{4,Year}$ = Sales of light trucks 8,500 to 10,000 pounds GVW, from the macroeconomic model

Update Class 2b vehicle stocks to reflect survival curve and sales by vintage, for 20 vintages, where the 20th vintage represents the stock of vehicles 20 years and older:

$$\begin{gathered} CLTSTK_{vint=1,Year} = NEWCLS2B_{Year} \\ and \\ CLTSTK_{vint,Year} = CLTSTK_{vint-1,Year-1} * CLTSURV_{vint-1} \end{gathered} \tag{159}$$

where,

CLTSTK = Class 2b vehicle stock, by vintage

CLTSURV = Percentage of previous year's stock that gets carried over

vint = vintage or age of vehicle = 2,.., 20;

Estimate the VMT demand for Class 2b vehicles, by vintage:

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8 As defined in NEMS, light commercial trucks are a subset of Class 2 vehicles (vehicles weighting 6,001 to 10,000 pounds GVW) and are often referred to as Class 2b vehicles (8,500 to 10,000 pounds GVW). Class 2a vehicles (6,001 to 8,500 pounds GVW) are addressed in the Light Vehicle Module.

9 Oak Ridge National Lab, *Memorandum on the Distribution of Trucks by Age and Weight: 2000 Truck Population*, Stacy C. Davis, November 2001.

$$CLTVMT_{vint,Year} = CLTSTK_{vint,Year} * CLTVMTV_{vint,1995} * \left(\frac{growth2_{Year}}{growth1_{Year}}\right)^{Year-1995} \quad \textbf{(160)}$$

where,

CLTVMTV = Class 2b vehicle miles traveled per truck for 1995, from trninput.wk1

growth1 = annual growth in Class 2b vehicle miles traveled

= $\sum_{vint=1,20}(cltvmt_{vint,Year}) / \sum_{vint=1,20}(cltvmt_{vint,Year-1})$

growth2 = annual growth in industry sector output weighted by Class 2b vehicle travel distribution by industry, for industry groups: 1 = Agriculture; 2 = Mining; 3 = Construction; 4 = Trade; 5 = Utilities; 6 = Personal

Estimate Class 2b vehicle fuel economy by vintage:

$$CLTMPG_{vint,Year} = CLTMPGV_{vint}, vint = 1,\cdots,20, Year = 1995$$
$$and$$
$$CLTMPG_{vint,Year} = CLTMPG_{vint,Year-1}, vint = 1, Year \geq 1996 \quad \textbf{(161)}$$
$$and$$
$$CLTMPG_{vint,Year} = CLTMPG_{vint-1,Year-1} * \left[\frac{MPGT_{Gasoline,Year}}{MPGT_{Gasoline,Year-1}}\right], vint \geq 2, Year \geq 1996$$

where,

MPGT = Light-duty truck mpg (gasoline technology), from the LDV Stock Module

CLTMPGV = Base year light-duty truck mpg (gasoline technology)

Calculate fuel consumption in gallons and Btu's for Class 2b vehicles.

$$CLTGAL_{Year} = \sum_{vint=1}^{20} \frac{CLTVMT_{vint,Year}}{CLTMPG_{vint,Year}}$$
$$and \quad \textbf{(162)}$$
$$CLTBTU_{Year} = CLTGAL_{Year} * \frac{5.253}{42}$$

Calculate average fuel economy, mpg, by summing over the vintages:

$$CLTMPGT_{Year} = \frac{\sum_{vint=1}^{20} CLTVMT_{vint,Year}}{CLTGAL_{Year}} \quad \textbf{(163)}$$

LDV Stock Submodule

The LDV Stock Submodule takes sales and efficiency estimates for new cars and light trucks from the LDV Module, and returns the number and characteristics of the total surviving fleet of light-duty vehicles, along with regional estimates of LDV fuel consumption. The LDV Stock Submodule flowchart is presented in Figure 11.

The LDV Stock Submodule uses vintage-dependent constants such as vehicle survival and relative driving rates, and fuel economy degradation factors to obtain estimates of stock efficiency.

The LDV Stock Submodule is perhaps the most important transportation sector submodule, since the largest portion of transportation energy consumption is accounted for by light duty vehicles that are at least a year old. The LDV Stock Submodule takes the results of the LDV Module (i.e., the number and characteristics of newly purchased cars and light trucks) and integrates those into the existing stock of vehicles, taking into account vehicle retirements and vehicles that are transferred from fleets to private ownership. The result is a snapshot of the "average" car for each region.

These characteristics are passed to the VMT Submodule, which determines the average number of miles driven by each vehicle in the current year. The product then becomes the regional fuel consumption estimate.

The first step is to calculate total vehicle sales by technology for the current time period:

$$TECHNCS_{FuelType} = \sum_{class=1}^{6} \sum_{REG=1}^{9} NCSTECH_{REG,class,FuelType}$$
$$and \qquad \textbf{(164)}$$
$$TECHNLT_{FuelType} = \sum_{class=1}^{6} \sum_{REG=1}^{9} NLTECH_{REG,class,FuelType}$$

where,

TECHNCS = Total new car sales, by engine technology fuel type

TECHNLT = Total new light truck sales, by engine technology fuel type

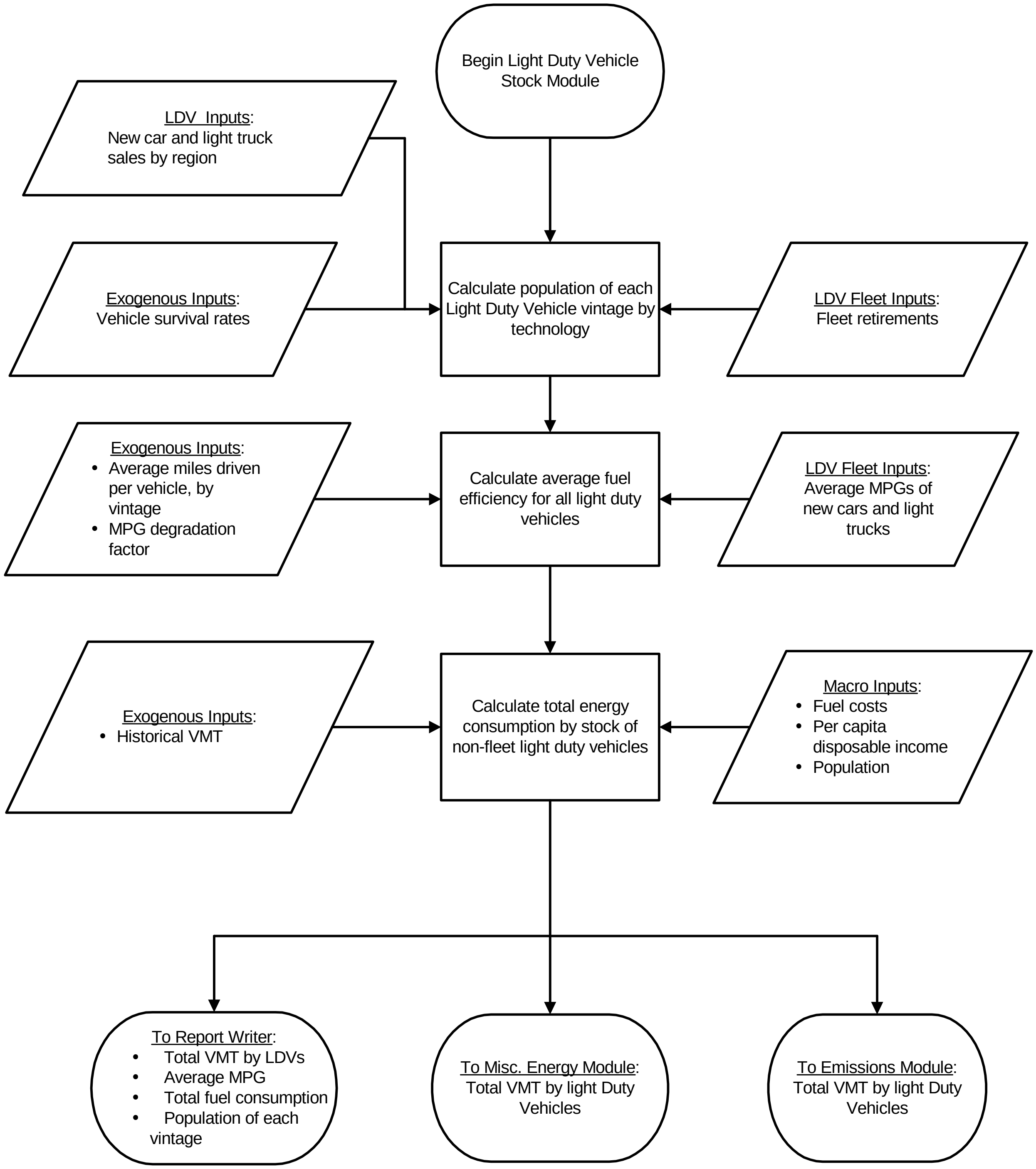
NCSTECH = New car sales, by region, market class, and technology, from the CVCS

NLTECH = New light truck sales, by region, market class, and technology, from the CVCS

FuelType = Engine technology fuel types (1to16)

These variables are assigned to the first vintages of the car and light truck stock arrays, and the population of subsequent vintages is calculated:

Figure 11. LDV Stock Submodule



Note: the emissions module is currently inactive.

For *vint* = 2,3,…,19:

$$PASSTK_{FuelType,vint,Year} = PASSTK_{FuelType,vint-1,Year-1} * SSURVP_{vint-1}$$
$$and \qquad \textbf{(165)}$$
$$LTSTK_{FuelType,vint,Year} = LTSTK_{FuelType,vint-1,Year-1} * SSURVLT_{vint-1}$$

For *vint* = 20:

$$PASSTK_{FuelType,vint=20,Year} = A * B * C$$
$$and \qquad \textbf{(166)}$$
$$LTSTK_{FuelType,nint=20,Year} = X * Y * Z$$

where,

$$A = PASSTK_{FuelType,vint=19,Year-1}$$

$$B = SSURVP_{vint=19} + PASSTK_{FuelType,vint=20,Year-1}$$

$$C = SSURVP_{vint=20}$$

$$X = LTSTK_{FuelType,vint=19,Year-1}$$

$$Y = SSURVP_{vint=19} + LTSTK_{FuelType,vint=20,Year-1}$$

$$Z = SSURVP_{vint=20}$$

PASSTK = Surviving car stock, by technology and vintage

LTSTK = Surviving light truck stock, by technology and vintage

SSURVP = Fraction of a given vintage's cars that survive

SSURVLT = Fraction of a given vintage's light trucks that survive

The submodule encompasses twenty vintages, with the twentieth being an aggregation of all vehicles 20 years old or older. SSURVP and SSURVLT thus each contain twenty values measuring the percentage of vehicles of each vintage that survive into the next year. These values are taken from the Alan Greenspan and Darrel Cohen study,[10] which lists scrappage and survival rates for 25 vintages. Survival rates for vintages 20 through 25 were simply averaged to collapse Oak Ridge National Laboratory's 25 vintages into the 20 used by the transportation

[10] *Motor Vehicle Stocks, Scrappage, and Sales,* Alan Greenspan and Darrel Cohen, October 30, 1996, published by the Federal Reserve System.

model. The stock of selected vintages and technologies calculated above is then augmented by a number of fleet vehicles that are assumed to roll over into the non-fleet population after a number of years of fleet service:

The stock of selected vintages and technologies calculated above is then augmented by a number of fleet vehicles that are assumed to roll over into the non-fleet population after a number of years of fleet service:

$$PASSTK_{FuelType,vint,Year} = PASSTK_{FuelType,vint,Year} + OLDFSTK_{car,flt,FuelType,vint,Year}$$
$$and \tag{167}$$
$$LTSTK_{FuelType,vint,Year} = LTSTK_{FuelType,vint,Year} + OLDFSTK_{truck,flt,FuelType,vint,Year}$$

where,

OLTFSTK = Number of fleet vehicles rolled over into corresponding private categories

vint = Transition vintage: vintage at which vehicles of a given type are transferred

Total stocks of cars and trucks are then determined by summing over vintages and technologies:

$$STKCAR_{Year} = \sum_{vint=1}^{20} \sum_{FuelType=1}^{16} PASSTK_{FuelType,vint,Year}$$
$$and \tag{168}$$
$$STKTR_{Year} = \sum_{vint=1}^{20} \sum_{FuelType=1}^{16} LTSTK_{FuelType,vint,Year}$$

where,

STKCAR = Total stock of non-fleet cars

STKTR = Total stock of non-fleet light trucks

The share of each technology in the total LDV stock is finally calculated:

$$VSPLDV_{FuelType,Year} = \frac{\sum_{vint=1}^{20} \left(PASSTK_{FuelType,vint,Year} + LTSTK_{FuelType,vint,Year} \right)}{STKCAR_{Year} + STKTR_{Year}} \tag{169}$$

where,

VSPLDV = The light duty vehicle shares of each of the sixteen vehicle technologies

The above variables are then used to determine average fuel efficiencies of the current year's stock of non-fleet vehicles.

1. Calculate Stock Efficiencies for Cars and Light Trucks

Overall fuel efficiency is calculated as the weighted average of the efficiencies of new vehicles and the efficiencies of the surviving vintages.

Sum new car and light truck sales across regions:

$$NVSALES_{vt=1,class,FuelType,Year} = \sum_{REG=1}^{9} NCSTECH_{REG,class,FuelType,Year}$$
$$and \tag{170}$$
$$NVSALES_{vt=2,class,FuelType,Year} = \sum_{REG=1}^{9} NLTECH_{REG,class,FuelType,Year}$$

The average efficiencies using the harmonic mean of the fifteen non-gasoline technologies are calculated as follows:

$$MPGC_{FuelType,Year} = \left[\frac{\sum_{class=1}^{6} \frac{NVSALES_{vt=1,class,FuelType,Year}}{MPG_{vt=1,FuelType,class}}}{\sum_{class=1}^{6} NVSALES_{vt=1,class,FuelType,Year}} \right]^{-1}$$
$$and \tag{171}$$
$$MPGT_{FuelType,Year} = \left[\frac{\sum_{class=1}^{6} \frac{NVSALES_{vt=2,class,FuelType,Year}}{MPG_{vt=2,FuelType,class}}}{\sum_{class=1}^{6} NVSALES_{vt=2,class,FuelType,Year}} \right]^{-1}$$

where,

MPGC = New car fuel efficiency, by engine technology fuel type

MPGT = New light truck fuel efficiency, by engine technology fuel type

The overall fuel efficiency of cars and light trucks is then calculated across the twenty vintages addressed in the submodule.[11] Since older vehicles are driven less than newer vehicles, it is necessary to weight the fuel efficiencies of each vintage according to the average number of miles driven. This is done by summing the total number of miles driven across all vintages and technologies:[12]

[11] Initial (2003) values for on-road car and light truck fleet MPG are obtained from the Federal Highway Administration, *Highway Statistics, 2006,* U.S. Department of Transportation (2007).

[12] Vehicle-miles calculated in this step are used to establish relative driving rates for the various technologies. Actual travel demand is generated by the model in a subsequent step.

$$TOTMICT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{20} PASSTK_{FuelType,vint,Year} * PVMT_{vint}$$

and **(172)**

$$TOTMITT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{20} LTSTK_{FuelType,vint,Year} * LVMT_{vint}$$

where,

TOTMICT = Total miles driven by cars

TOTMITT = Total miles driven by light trucks

PVMT = Average miles driven by each vintage of car, from RTECS

LVMT = Average miles driven by each vintage of light truck, from RTECS

The next step is to calculate the total energy consumed across all vintages and technologies of cars and light trucks. Since the on-road fuel efficiency of cars and trucks degrades over time, vintage fuel efficiencies must be adjusted using degradation factors:

$$CMPGT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{20} \frac{PASSTK_{FuelType,vint,Year} * PVMT_{vint}}{CMPGSTK_{FuelType,vint,Year} * CDFRFG}$$

and **(173)**

$$TMPGT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{20} \frac{LTSTK_{FuelType,vint,Year} * LVMT_{vint}}{TTMPGSTK_{FuelType,vint,Year} * LTDFRFG}$$

where,

CMPGT = Car stock MPG

TMPGT = Light truck stock MPG

CDFRFG = Car fuel efficiency degradation factor

LTDFRFG = Light truck fuel efficiency degradation factor

Stock fuel efficiency for car and light truck is then simply the ratio of total travel to total consumption for cars and light trucks:

$$SCMPG_{Year} = \frac{TOTMICT_{Year}}{CMPGT_{Year}}$$

and **(174)**

$$STMPG_{Year} = \frac{TOTMITT_{Year}}{TMPGT_{Year}}$$

Combining the results for cars and trucks provides the average fuel efficiency for all light duty vehicles:

$$MPGFLT_{Year} = \frac{TOTMICT_{Year} + TOTMITT_{Year}}{CMPGT_{Year} + TMPGT_{Year}} \quad \textbf{(175)}$$

Calculate the average fuel efficiency for car and light truck by technology:

$$CMPG\_IT_{FuelType,Year} = \left[\frac{\sum_{vint=1}^{20} \frac{PASSTK_{FuelType,vint,Year} * PVMT_{vint}}{CMPGSTK_{FuelType,vint,Year} * CDFRFG}}{\sum_{vint=1}^{20} PASSTK_{FuelType,vint,Year} * PVMT_{vint}} \right]^{-1}$$

$$and \quad \textbf{(176)}$$

$$TMPG\_IT_{FuelType,Year} = \left[\frac{\sum_{vint=1}^{20} \frac{LTSTK_{FuelType,vint,Year} * LVMT_{vint}}{TTMPGSTK_{FuelType,vint,Year} * LTDFRFG}}{\sum_{vint=1}^{20} LTSTK_{FuelType,vint,Year} * LVMT_{vint}} \right]^{-1}$$

These fuel efficiency figures are combined with the results of the subsequent VMT Submodule to determine the actual fuel consumption by light duty vehicles.

VMT Submodule

The travel demand module of the NEMS transportation model is a submodule of the LDV Stock Module that uses NEMS estimates of fuel price and personal income, along with population projections to generate a projection of the demand for personal travel, expressed in vehicle-miles traveled per driver. This is subsequently combined with projections of car fleet efficiency to estimate fuel consumption.

The primary concern in projecting VMT per licensed driver in the mid to long term is to address those effects that alter historical growth trends. The factors affecting future VMT trends are the fuel cost of driving, disposable personal income, and past VMT trends.

Annual vehicle stock, VMT, and fuel consumption data is available from the Federal Highway Administration (FHWA). All macroeconomic inputs are calculated based on a chain-weighted average. This data is used to estimate the generalized difference equations in the NEMS VMT Submodule:

$$LOG(VMTLD_{Year}) - \rho LOG(VMTLD_{Year-1}) = \alpha(1-\rho) + \sum_{N=1}^{3} \beta_N \left[LOG(X_{N,Year}) - \rho LOG(X_{N,Year-1}) \right] \quad \textbf{(177)}$$

where,

VMTLD = per licensed driver travel demand for the driving age population

X_N, N = 1,2, and 3, are the input variables.

Of greater significance is the historical VMT and stock inputs provided by FHWA. In the past, FHWA's estimate of the number and driving patterns of 2-axle, 4-tire trucks has been interpreted as representing that of Light Duty Trucks, defined as having a weight of less than 8,500 pounds, and thus properly within the purview of the LDV Module. To further refine the submodule, a category of truck has been defined: Class 2b vehicles, which comprise all single-unit trucks in the 8,500 to 10,000 pound range. The travel demands of these trucks are now modeled separately, based on aggregate measures of industrial output from the macroeconomic model.

The generalized difference equation used to estimate the VMT per driver is given below:

$$VMTLD_{Year} = e^{\{\rho LOG(VMTLD_{Year-1}) + \beta_0(1-\rho) + \beta_1[LOG(VMTLD_{Year-1}) - \rho LOG(VMTLD_{Year-2})]\}} * e^{\{\beta_2[LOG(INCOME16_{Year}) - \rho LOG(INCOME16_{Year-1})] + \beta_3[LOG(COSTMI_{Year}) - \rho LOG(COSTMI_{Year-1})]\}} \quad \textbf{(178)}$$

where,

VMTLD = the vehicle miles traveled per licensed driver

COSTMI = the fuel cost of driving a mile, expressed in 1996 dollars.

INCOME16 = the per capita income for age 16+, expressed in 1996 dollars.

ρ = the lag factor is estimated using the Cochrane-Orcutt iterative procedure and ρ and β are defined locally.

Air Travel Module

The air travel component of the NEMS transportation model comprises two separate submodules: the Air Travel Demand Submodule and the Aircraft Fleet Efficiency Submodule. These submodules use NEMS projections of fuel price, macroeconomic activity, and population growth, as well as assumptions about aircraft retirement rates and technological improvements to generate projections of passenger and freight travel demand and the fuel required to meet that demand. The Air Travel Module receives exogenous estimates of aircraft load factors, new technology characteristics, and aircraft specifications that determine the average number of available seat-miles each plane will supply in a year.

Air Travel Demand Submodule

The Air Travel Demand Submodule produces projections of domestic, international, and Non U.S. passenger travel demand, expressed in revenue passenger-miles (RPMD, RPMI, and RPMN), and U.S. and Non U.S. air freight demand, measured in revenue ton-miles (RTM). Domestic travel means takeoff and landing are both in the U.S. (states and territories), while International travel means either takeoff or landing is in the U.S (exactly one). Non U.S. travel means both takeoff and landing are outside the U.S. RPMD and RPMI are combined into a single U.S. demand for seat-miles, and passed to the Aircraft Fleet Efficiency Submodule, which adjusts aircraft stocks to meet that demand. Aircraft stock is made up of three types of aircraft, wide body, narrow body, and regional jets.

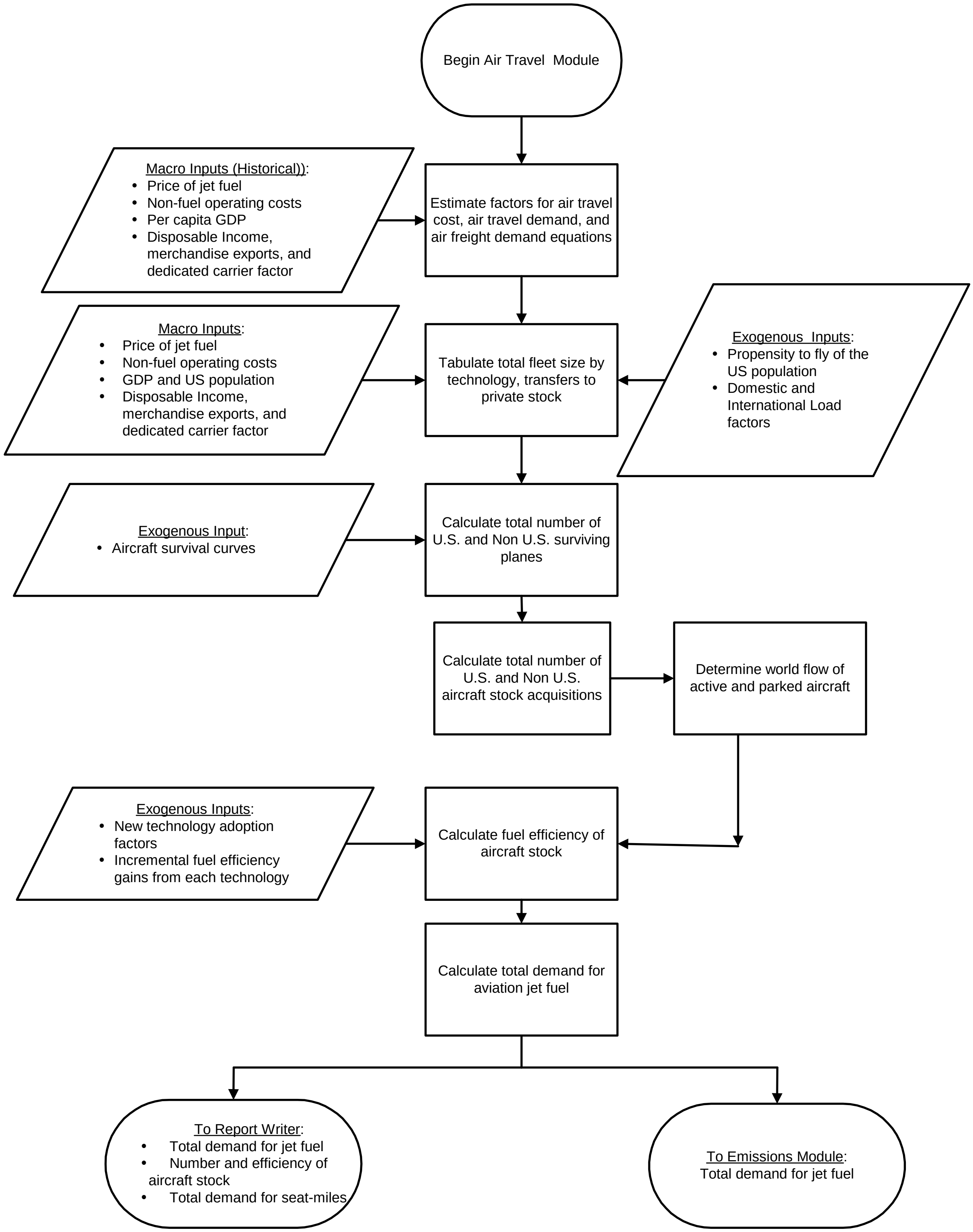
The Air Travel Demand Submodule is based on several assumptions about consumer behavior and the structure of the airline industry. Of greatest significance is the assumption that the deregulation of the industry has substantially altered the dynamics of passenger travel; model parameters have therefore been estimated using only post-deregulation data. It is further assumed that travel demand is influenced by economic conditions.

The Air Travel Demand Submodule, as implemented in NEMS, is a series of linear equations estimated over the period 1980 to 2007. As noted above, it is assumed that domestic and international travel is motivated by economic measures and ticket prices. Key model relationships are presented below. Where numbers appear in place of variable names, parameters have been estimated statistically from historical trends. Also presented in Figure 12 is the flowchart for the Air Travel Module. The steps involved in calculating Air Travel Demand are listed below:

1) Calculate the cost of flying for domestic and international travel:

$$\begin{aligned} YIELD_{Dom,Year} = {} & ALPHAYD * (1 - RHOYD) + RHOYD * YIELD_{Dom,Year-1} + BETAFUELD * \left(PJFTR_{Year} - RHOYD * PJFTR_{Year-1}\right) \\ & - BETATIMED * \left(YEAR + 11 - RHOYD * (Year + 10)\right) \\ & \textit{and} \\ YIELD_{Intl,Year} = {} & ALPHAYI * (1 - RHOYI) + RHOYI * YIELD_{Intl,Year-1} + BETAFUELI * \left(PJFTR_{Year} - RHOYI * PJFTR_{Year-1}\right) \\ & - BETATIMEI * \left(YEAR + 11 - RHOYI * (Year + 10)\right) \end{aligned} \tag{179}$$

Figure 12. Air Travel Module



Note: the emissions module is currently inactive.

where,

YIELD = Cost of air travel, domestic(Dom) and International(Intl), expressed in cents per RPM.

PJFTR = Price of jet fuel, in 1996 dollars per million Btu.

2) Calculate total revenue passenger-miles for domestic, international, and Non U.S. travel:

<u>*Domestic:*</u>

$$\begin{aligned}\text{RPMTD}_{wreg,\ Year} &= ALPHARD * (1 - RHORD) + RHORD * \text{RPMTD}_{wreg,\ Year-1} \\ &+ BETARPMD * \left(\text{RPMTD}_{wreg,\ Year-1} - RHORD * \text{RPMTD}_{wreg,\ Year-2}\right) \\ &+ BETAINCD * \left(\text{MC\_YPDR}_{Year} - RHORD * MC\_YPDR_{Year-1}\right) + BETAYLDD * \left(\text{YIELD}_{Dom,\ Year} - RHORD * YIELD_{Dom,\ Year-1}\right) \\ &+ BETADMYD * \left(\text{DUMMYD}_{Year} - RHORD * DUMMYD_{Year-1}\right)\end{aligned} \quad \textbf{(180)}$$

where,

RPMTD = Total revenue passenger-miles for domestic travel.

MC_YPDR = Personal Disposable Income in 2000 dollars.

DUMMYD = Dummy Variable to reflect the impact of 9/11 and industry restructuring.

WREG = World region; 1 implies U.S., 2 implies Non U.S.

<u>*International*</u>*:*

$$\begin{aligned}\text{RPMTI}_{wreg,\ Year} &= ALPHARI * (1 - RHORI) + RHORI * \text{RPMTI}_{wreg,\ Year-1} \\ &+ BETARMPI * \left(\text{RPMTI}_{wreg,\ Year-1} - RHORI * \text{RPMTI}_{wreg,\ Year-2}\right) \\ &+ BETAINCI * \left(\text{MC\_YPDR}_{Year} - RHORI * MC\_YPDR_{Year-1}\right) + BETAYLDI * \left(\text{YIELD}_{Intl,\ Year} - RHORI * YIELD_{Intl,\ Year-1}\right) \\ &+ BETADMYI * \left(\text{DUMMYI}_{Year} - RHORI * DUMMYI_{Year-1}\right)\end{aligned} \quad \textbf{(181)}$$

where,

RPMTI = Total revenue passenger-miles for international travel.

DUMMYI = Dummy Variable to reflect the impact of 9/11 and industry re-structuring.

<u>*Non U.S.:*</u>

$$\begin{aligned}\text{RPMTN}_{wreg,\ Year} &= ALPHARN * (1 - RHORN) + RHORN * \text{RPMTN}_{wreg,\ Year-1} \\ &+ BETARMPN * \left(\text{RPMTN}_{wreg,\ Year-1} - RHORN * \text{RPMTN}_{wreg,\ Year-2}\right) \\ &+ BETAINCN * \left(\text{GDPNUS}_{Year} - RHORN * GDPNUS_{Year-1}\right) + BETAYLDN * \left(\text{YIELD}_{Intl,\ Year} - RHORN * YIELD_{Intl,\ Year-1}\right) \\ &+ BETADMYN * \left(\text{DUMMYN}_{Year} - RHORI * DUMMYN_{Year-1}\right)\end{aligned} \quad \textbf{(182)}$$

where,

RPMTN = Total revenue passenger-miles for international travel.

DUMMYN = Dummy Variable to reflect the impact of 9/11 and industry re-structuring.

GDPNUS = Non U.S. GDP in billion 2000 dollars.

2A) Calculate domestic, international, and Non U.S. revenue-passenger miles by aircraft type

$$RPMD_{atyp,Year} = RPMTD_{Year} * SRPMD_{atyp,Year}$$
$$and$$
$$RPMI_{atyp,Year} = RPMTI_{Year} * SRPMI_{atyp,Year} \qquad \textbf{(183)}$$
$$and$$
$$RPMN_{atyp,Year} = RPMTN_{Year} * SRPMN_{atyp,Year}$$

where,

RPMD = Revenue passenger-miles for domestic travel by aircraft type.

SRPMD = Share of domestic travel performed by aircraft type.

RPMI = Revenue passenger-miles for international travel by aircraft type.

SRPMI = Share of international travel performed by aircraft type.

RPMD = Revenue passenger-miles for Non U.S. travel by aircraft type.

SRPMD = Share of Non U.S. travel performed by aircraft type.

3) Calculate the dedicated U.S. and Non U.S. RTM of air freight:

$$RTM_{us,Year} = ALPHARTM - BETAPJFR * PJFTR_{Year} + BETAXIM * MC\_XGR_{Year}$$
$$and \qquad \textbf{(184)}$$
$$RTM_{nus,Year} = RTM_{us,Year} * PCT\_RTM\_NUS$$

where,

MC_XGR = Value of merchandise exports, in 1996 dollars

PCT_RTM_NUS = Non U.S. RTM based on the Current Market Outlook, 2007-2027, Boeing Commercial Services

4) Calculate the total demand for available seat-miles, incorporating the estimated load factors of domestic and international travel:

$$ASMDEMD_{atyp,Year} = \frac{RPMD_{atyp,Year}}{LFDOM_{atyp,Year}} + \frac{RPMI_{atyp,Year}}{LFINTER_{atyp,Year}} + \frac{RPMN_{atyp,Year}}{LFINTER_{atyp,Year}}$$

$$and \qquad \textbf{(185)}$$

$$SMDEMD_{Year} = \sum_{atyp=1}^{3} ASMDEMD_{atyp,Year}$$

where,

ASMDEMD = Demand for available seat-miles, by aircraft type

SMDEMD = Total demand for available seat-miles.

LFDOM = Exogenously determined load factor for domestic travel by aircraft type.

LFINTER = Exogenously determined load factor for international travel by aircraft type.

Aircraft Fleet Efficiency Submodule

The Aircraft Fleet Efficiency Submodule is a structured accounting mechanism that provides estimates of the number of narrow, wide-body, and regional jet aircraft available to meet passenger and freight travel demand subject to user-specified parameters. This mechanism also permits the estimation of fleet efficiency using a weighted average of the characteristics of surviving aircraft and those acquired to meet demand.

The intent of this submodule is to provide a quantitative approach for estimating aircraft fleet energy efficiency. To this end, the submodule estimates surviving aircraft stocks and average characteristics at a level of disaggregation that is supportable by available data, and projects the fuel efficiencies of new acquisitions under different sets of economic and technological scenarios. The resulting fleet average efficiencies are returned to the Air Travel Demand Submodule to support the projection of commercial passenger and freight carriers' jet fuel consumption to the year 2030.

Although the air module estimates fuel use from all types of aircraft, only commercial aircraft efficiencies are explicitly modeled. Efficiencies of general aviation aircraft and military planes are not addressed. General aviation fuel use, including jet fuel, is directly estimated, and aviation gasoline demand is projected using a time-dependent extrapolation. Military jet fuel use is estimated in another module using projections of military budgets.

Total fleet efficiency is based on separate estimates of the stock and efficiency of the three types of aircraft considered by the submodule: narrow body, wide body, and regional jets.[13] The

[13] Narrow body aircraft, such as the Airbus 320 and Boeing 737, have seating for approximately 120-180 passengers, and are characterized by two banks of seats separated by a center aisle. Wide body aircraft, such as the Boeing 747, carry from 200-500 passengers in three banks of seats. Regional Jets, such as the Canadair RJ-100, have seating for approximately 50-110 passengers.

development of the hub and spoke system has lead airlines to invest in smaller aircraft. In 1991, narrow body aircraft accounted for approximately 54 percent of total available seat-miles, and wide body aircraft accounted for 41 percent, with regional jets accounting for the remaining 5 percent. By 2000, narrow body aircraft accounted for approximately 60 percent of total available seat-miles, and wide body aircraft accounted for 33 percent, with regional jets accounting for the remaining 7 percent.

The submodule operates in six stages: 1) estimates the sales of new U.S. and Non-U.S. aircraft; 2) determines the total stock of aircraft by aircraft type; 3) determines the demand for commercial aircraft; 4) computes the flow of aircraft, active and parked, between US and Non-US regions to satisfy demand, supply balance; 5) calculates the fleet efficiency improvements of newly acquired aircraft; and 6) estimates fuel consumption.

__1. Sales of New U.S. and Non U.S. Aircraft__

First determine the sales of new aircraft, based on the growth of travel demand and economic growth. Travel demand, expressed as a demand for revenue passenger-miles, is obtained from the Air Travel Demand Submodule. New aircraft sales estimates the aircraft delivered in the current year, however there is a two to three year lag between when aircraft are ordered and delivered. Hence, sales in the current year show a strong correlation with the lagged demand for travel:

$$\begin{aligned}&STKPASS\_SALES_{us,Year} = ALPHASALUS + BETARPMSUS * RPMTOT\_US_{Year}\\&+ BETAGDPSUS * LOG(MC\_GDPR_{Year}) + BETATIMSUS * (Year + 9)\\&and\\&STKPASS\_SALES_{nus,Year} = ALPHASALN + BETARPMSN * RPMTOTN_{Year}\\&+ BETAGDPSN * LOG(GDPNUS_{Year}) + BETATIMSN * (Year + 9)\end{aligned} \quad \mathbf{(186)}$$

where,

$STKPASS\_SALES_{us,Year}$ = Total U.S. Sales of New Passenger Aircraft

$STKPASS\ SALES_{nus,Year}$ = Total Non U.S. Sales of New Passenger Aircraft

us = index representing U.S. region = 1

nus = index representing Non U.S. region = 2

Sales of new passenger aircraft are then allocated between the three aircraft types considered by the submodule. The fraction of sales attributable to each aircraft type is based on an analysis of historic trends.

$$STK\_PASS_{wreg,atyp,age=1,Year} = STKPASS\_SALES_{wreg,Year} * SHR\_NEW\_STK_{wreg,atyp,Year} \quad \mathbf{(187)}$$

where,

STK_PASS = U.S. and Non U.S. Stock of new passenger aircraft, age=1, by the three aircraft types.

SHR_NEW_STK = Fraction of total sales attributable to each aircraft type

The rate of new aircraft acquisition significantly affects the average energy intensity of the fleet, and, subsequently, the projection of energy demand. This submodule differs from other stock models in that retirements are not assumed to take place abruptly once the aircraft have reached a specified age. Instead, a logistic survival function estimates the fraction of originally delivered aircraft that survive after a given number of years.

2. Stock Estimation

The aircraft stock submodule provides an accounting for aircraft stocks and sales. The submodule tracks all passenger and cargo aircraft, and calculates the number of aircraft required to meet demand. The first step is to determine the initial stock of aircraft available. The aircraft stock in the current year is determined as equal to the previous year's stock, plus new sales, less those aircraft that have been scrapped less initial parked aircraft.

It is important to provide an accurate portrayal of the age distribution of airplanes because of the relatively small size of the U.S. commercial fleet, in 2007, slightly fewer than eight thousand two hundred aircraft.[14] This distribution determines the number of aircraft retired from service each year, and consequently has a strong influence on the number of new aircraft acquired to meet air travel demand. Due to the international nature of the market for aircraft, constructing a survival algorithm using only domestic deliveries and stocks is not feasible because aircraft of different vintages are regularly bought and sold on the international market and the surviving domestic stock of a given vintage may exceed the number of aircraft of that vintage that had originally been delivered domestically. The problem is mitigated by assuming that the scrappage rate of aircraft on a worldwide basis also characterizes that of domestic aircraft. The available aircraft capacity is calculated once the number of surviving aircraft by type is established. Historical data on aircraft stocks are taken from the World Jet Inventory Year publication.[15] The stock of surviving passenger aircraft is subsequently estimated with the following equation:

$$STK\_PASS_{wreg,atyp,age,Year} = STK\_PASS_{wreg,atyp,age-1,Year-1} * SURVAC_{atyp,age} \quad \textbf{(188)}$$

where,

STK_PASS = U.S. and Non U.S. stock of surviving passenger aircraft by aircraft type, of a given age.

SURVAC = Survival rate (1-scrappage rate) of aircraft of a given age.

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[14] Bureau of Transportation Statistics, *National Transportation Statistics*, U.S. Department of Transportation (2007), June 2008, Table 1-11.

[15] Jet Inventories Inc., *World Jet Inventory: Year-End 2007*, (March 2008).

The stock submodule also accounts for the stock of cargo aircraft and cargo plane retirement. The scrappage rates of cargo aircraft are derived from historical data using the following equation:

$$STK\_CARGO_{wreg,atyp,age,Year} = STK\_CARGO_{wreg,atyp,age-1,Year-1} * SURVAC_{wreg,atyp,age} \quad \textbf{(189)}$$

where,

STK_CARGO = U.S. and Non U.S. stock of surviving cargo aircraft by aircraft type

Older passenger planes are often converted for use in cargo service. Starting with passenger aircraft of vintage 25 years, the aircraft stock submodule moves aircraft into cargo service, first parked, then activated when needed. Reflecting this, the stock of cargo aircraft is defined by:

$$\begin{aligned} &STK\_CARGO_{wreg,atyp,age,Year} = STK\_CARGO_{wreg,atyp,age-1,Year-1} \\ &+ STK\_PASS_{wreg,atyp,age,Year} * CARGO\_PCT_{age} \end{aligned} \quad \textbf{(190)}$$

where,

CARGO_PCT = Percent of passenger planes, aged 25 years or older, shifted to cargo service

The stock of passenger aircraft is then adjusted for the older planes moved into cargo service as shown in the following equation:

$$STK\_PASS_{wreg,atyp,age,Year} = STK\_PASS_{wreg,atyp,age,Year} * \left(1 - CARGO\_PCT_{age}\right) \quad \textbf{(191)}$$

The total stock of passenger aircraft is then computed as follows:

$$STK\_SUP\_TOT_{wreg,atyp,Year} = \sum_{age} STK\_PASS_{wreg,atyp,age,Year} \quad \textbf{(192)}$$

where,

STK_SUP_TOT = Total U.S. and Non U.S. stock of passenger aircraft by aircraft type.

3. Demand for Commercial Aircraft

The demand for commercial aircraft is then calculated. The demand for commercial aircraft is based on the growth of travel demand. The seat miles flown per aircraft have historically grown slowly. Available seat-miles demanded data are obtained from the Air Travel Demand Submodule, and the passenger demand for aircraft is:

$$STKPASS\_DMD_{wreg,atyp,Year} = \frac{ASMDEMD_{wreg,atyp,Year}}{ASMAC_{atyp,Year}} \quad \textbf{(193)}$$

where,

STKPASS_DMD = U.S. and Non U.S. passenger stock of aircraft demanded to meet travel demand, by aircraft type.

ASMAC = Available seat-miles flown per aircraft

The initial supply of active passenger aircraft, $STKPASS\_ACTIVE_{wreg,atyp,age,Year}$, consists of the total stock of aircraft less aircraft that are parked, and is defined as:

$$STKPASS\_ACTIVE_{wreg,atyp,age,Year} = STK\_PASS_{wreg,atyp,age,Year} - STKPASS\_PARKED_{wreg,atyp,age,Year} \quad \textbf{(194)}$$

where,

STKPASS_ACTIVE = U.S. and Non U.S. Active stock of passenger aircraft, by aircraft type and age.

The total supply of active passenger aircraft, STKPASS_ACTIVE_TOT, is then calculated:

$$STKPASS\_ACTIVE\_TOT_{wreg,atyp,Year} = \sum_{age} STKPASS\_ACTIVE_{wreg,atyp,age,Year} \quad \textbf{(195)}$$

4. Movement of U.S. and Non U.S. Aircraft

After calculating the initial demand for active world aircraft and the initial supply of active world aircraft, the difference between supply and demand for active aircraft, DEL_STKPASS, is calculated.

$$DEL\_STKPASS_{wreg,atyp,Year} = STKPASS\_DMD_{wreg,atyp,Year} - STKPASS\_ACTIVE\_TOT_{wreg,atyp,Year} \quad \textbf{(196)}$$

Test the Difference

If the demand for U,S, aircraft is greater than the supply of U.S. aircraft then more U.S. supply is needed. Do the following.

First, consider U.S. aircraft and unpark U.S. aircraft. Keep unparking U.S. aircraft until ten percent of the stock is left or until all aircraft demanded is available. If more aircraft is needed, then import Non U.S. aircraft.

Next, consider Non U.S. aircraft. If Non U.S. supply is greater than Non U.S. demand, import active Non U.S. aircraft into the U.S. until either no more U.S. aircraft is needed or no more Non U.S. active aircraft is available. After active Non U.S. aircraft is used, and if still more U.S. aircraft is needed, unpark Non U.S. aircraft and import to U.S. until no more is needed or is available.

If supply of U.S. aircraft is greater than demand, then less U.S. supply of active aircraft is needed. Do the following.

First, check if there is a Non U.S. need for aircraft. If so, export active U.S. aircraft until either all aircraft needed is supplied or all available active U.S. aircraft is used.

Next, if no more active U.S. aircraft is available, but aircraft is still needed, then unpark U.S. aircraft and export to fulfill Non U.S. demand. If the U.S. runs out of parked aircraft and still more is needed, unpark Non U.S. aircraft.

Finally, park the remaining U.S. and Non U.S. aircraft. That is, if supply of U.S. aircraft is greater than the demand for U.S. aircraft, park the remaining U.S. aircraft. If the supply of Non U.S. aircraft is greater than the demand for Non U.S. aircraft, park the remaining Non U.S. aircraft.

5. Fleet Efficiency Improvements

Efficiency improvements of newly acquired aircraft are determined by technology choice that is dependent on the year acquired, the type of aircraft and the price of fuel. There are six advanced technologies, *ifx = 1,2,…,6*, to choose from, including four engine related improvements, advanced aerodynamics, and weight-reducing composite materials. In order to model a smooth transition from old to new technologies, the efficiencies of the four engine technologies are based on TRIGYEAR, or the year the technology is introduced, and the improved efficiency gains of each technology over the previous generation of technology. Each generation replaces the previous one, and the penetrations are based on a logistic function. The efficiencies of the aerodynamic and weight reducing technologies are additive and are based on several logistic functions that reflect the commercial viability of each technology. The two arguments, the time effect (TIMEFX) and the price effect (COSTFX), are based on the assumption that the rate of technology incorporation is determined not only by the length of time the technology has been commercially viable, but also by the magnitude of a given technology's price advantage as shown in the following:

$$TIMEFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year-1} + \left(TIMECONST_{atyp} * TPN_{ifx,atyp} * TYRN_{ifx,atyp}\right) \quad \textbf{(197)}$$

where,

TIMEFX = Factor reflecting the length of time an aircraft technology improvement has been commercially viable, by aircraft type.

TIMECONST = User-specified scaling constant, reflecting the importance of the passage of time.

TPN = Binary variable (0,1) that tests whether current fuel price exceeds the considered technology’s trigger price.

TYRN = Binary variable that tests whether current year exceeds the considered technology's year of introduction.

ifx = Index of technology improvements (1-6).

The cost effect is now calculated:

$$COSTFX_{ifx,atyp,Year} = \left[\frac{TPJFGAL_{Year} - TRIGPRICE_{ifx,atyp}}{TPJFGAL_{Year}}\right] * TPN_{ifx,atyp} * TYRN_{ifx,atyp} * TPZ_{ifx,atyp} \quad \textbf{(198)}$$

where,

COSTFX = Factor reflecting the magnitude of the difference between the price of jet fuel and the trigger price of the considered technology, by aircraft type.

TPJFGAL = Price of jet fuel.

TRIGPRICE = Price of jet fuel above which the considered technology is assumed to be commercially viable.

TPZ = Binary variable that tests whether implementation of the considered technology is dependent on fuel price.

Thus the overall effect of time and fuel price on implementing technology improvements is defined by the equation:

$$TOTALFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year} + COSTFX_{ifx,atyp,Year} - BASECONST \quad \textbf{(199)}$$

where,

BASECONST = Adjustment that anchors the logistic curve, thus ensuring that technologies are not incorporated prior to their commercial viability.

For each technology, a technology penetration function is defined as:

$$TECHPEN_{ifx,atyp,Year} = \left[1 + e^{-TOTALFX_{ifx,atyp,Year}}\right]^{-1} \quad \textbf{(200)}$$

The fractional fuel efficiency improvement is calculated for each aircraft type using the following equation:

$$FRACIMP_{atyp,Year} = 1.0 + EFFIMP_{ifx=1} * \left(TECHPEN_{ifx=1,atyp,Year} - TECHPEN_{ifx=2,Year}\right) + \sum_{ifx=2}^{6} EFFIMP_{ifx} * TECHPEN_{ifx,atyp,Year}$$

$$and$$

$$FRACIMP_{WB,Year} = 1.0 + \sum_{ifx=1}^{6} EFFIMP_{ifx} * TECHPEN_{ifx,WB,Year}\ ; ifx \neq 2$$

(201)

where,

FRACIMP = Fractional efficiency improvement for the three aircraft types.

EFFIMP = Fractional improvement associated with a given technology, ifx.

$atyp$ = Narrow Body and Regional Jet Aircraft.

WB = Wide Body Aircraft.

Given the variety of non-exclusive technologies, some assumptions must be made: 1) technologies enter the mix as they become viable and cost competitive; 2) the inclusion of a technology with a higher trigger price is dependent on the prior use of those technologies with lower trigger prices; and 3) efficiency gains attributable to each technology are directly proportional to the level of penetration of that technology.

Fleet efficiency in seat-mpg is estimated using a series of simplifying assumptions. First, the new stock efficiency is determined for each type of aircraft and for domestic and international travel, using the following equation:

$$\begin{aligned} ASMPGD_{atyp,age=1,Year} &= ASMPGD_{atyp,age=1,Year=2005} * FRACIMP_{atyp,Year} \\ &\textit{and} \\ ASMPGI_{atyp,age=1,Year} &= ASMPGI_{atyp,age=1,Year=2005} * FRACIMP_{atyp,Year} \end{aligned} \qquad \textbf{(202)}$$

where,

ASMPGD = Domestic aircraft fuel efficiency in available seat-mpg.

ASMPGI = International aircraft fuel efficiency in available seat-mpg.

Second, stock efficiency is assumed to remain unchanged over time and is defined as:

$$\begin{aligned} ASMPGD_{atyp,age,Year} &= ASMPGD_{atyp,age-1,Year-1} \\ &\textit{and} \\ ASMPGI_{atyp,age,Year} &= ASMPGI_{atyp,age-1,Year-1} \end{aligned} \qquad \textbf{(203)}$$

Total available seat mpg, $ASMPGT_{Year}$, is computed as the harmonic average of domestic fuel efficiency and international fuel efficiency, weighted by domestic and international available seat-miles.

<u>5. Estimating Fuel Consumption</u>

The total seat-miles demanded is estimated by combining the demand for passenger seat miles and the revenue ton-miles which is converted to seat miles as follows:

$$SMD\_TOT_{Year} = SMDEMD_{Year} + RTM_{Year} * EQSM \qquad \textbf{(204)}$$

where,

SMD_TOT = Total seat-miles demanded

EQSM = Factor that converts Revenue Ton Miles to Seat-miles

The demand for jet fuel is then defined by:

$$JFGAL_{Year} = \frac{SMDTOT_{Year}}{ASMPGT_{Year}} \tag{205}$$

The demand for aviation gasoline is defined as:

$$AGD_{Year} = BASEAGD + GAMMA * e^{-KAPPA*(Year-1979)} \tag{206}$$

where,

AGD = Demand for aviation gasoline, in gallons

BASEAGD = Baseline demand for aviation gasoline

GAMMA = Baseline adjustment factor

KAPPA = Exogenously-specified decay constant

Jet fuel demand is converted from gallons into Btu using the following relationships:

$$\begin{gathered} JFBTU_{Year} = JFGAL_{Year} * \frac{5.670 MMBtu/bbl}{42 gal/bbl} \\ and \\ AGDBTU_{Year} = AGD_{Year} * \frac{5.048 MMBtu/bbl}{42 gal/bbl} \end{gathered} \tag{207}$$

Jet fuel and aviation gasoline demand by region is estimated by the following:

$$\begin{gathered} QJETR_{REG,Year} = JFBTU_{Year} * SEDSHR_{JetFuel,REG,Year} \\ and \\ QAGR_{REG,Year} = AGDBTU_{Year} * SEDSHR_{AvGas,REG,Year} \end{gathered} \tag{208}$$

where,

SEDSHR = Regional shares of fuel (jet fuel or aviation gasoline) demand, from the State Energy Data System.

Freight Transport Module

The freight module of the NEMS transportation model addresses the three primary modes of freight transport: truck, rail, and marine. This module uses NEMS projections of real fuel prices, trade indices, coal production, and projections of selected industries' output from the macroeconomic model to estimate travel demand for each freight mode, and the fuel required to meet that demand. The carriers in each of these modes are characterized, with the possible exception of trucks, by very long operational lifetimes, and the ability to extend these lifetimes through retrofitting. This results in a low turnover of capital stock and the consequent dampening of improvement in average energy efficiency. Given the long projection horizon, however, this module will provide estimates of modal efficiency growth, driven by assumptions about systemic improvements modulated by fuel price projections.

Projections are made for each of the modes of freight transport: trucks, rail, and ships. In each case, travel projections are based on the industrial output of specific industries, travel growth in most cases being directly proportional to increases in value of goods produced. Rail additionally uses NEMS coal projections to account for part of the travel. This is then converted to energy demand using the average energy intensity for the mode in question. Total energy demand is subsequently shared out to the various types of fuel used for freight transport, under the assumption that relative shares remain constant. As each mode, except trucks, is considered in the aggregate, no distinction is drawn between classes of carriers.

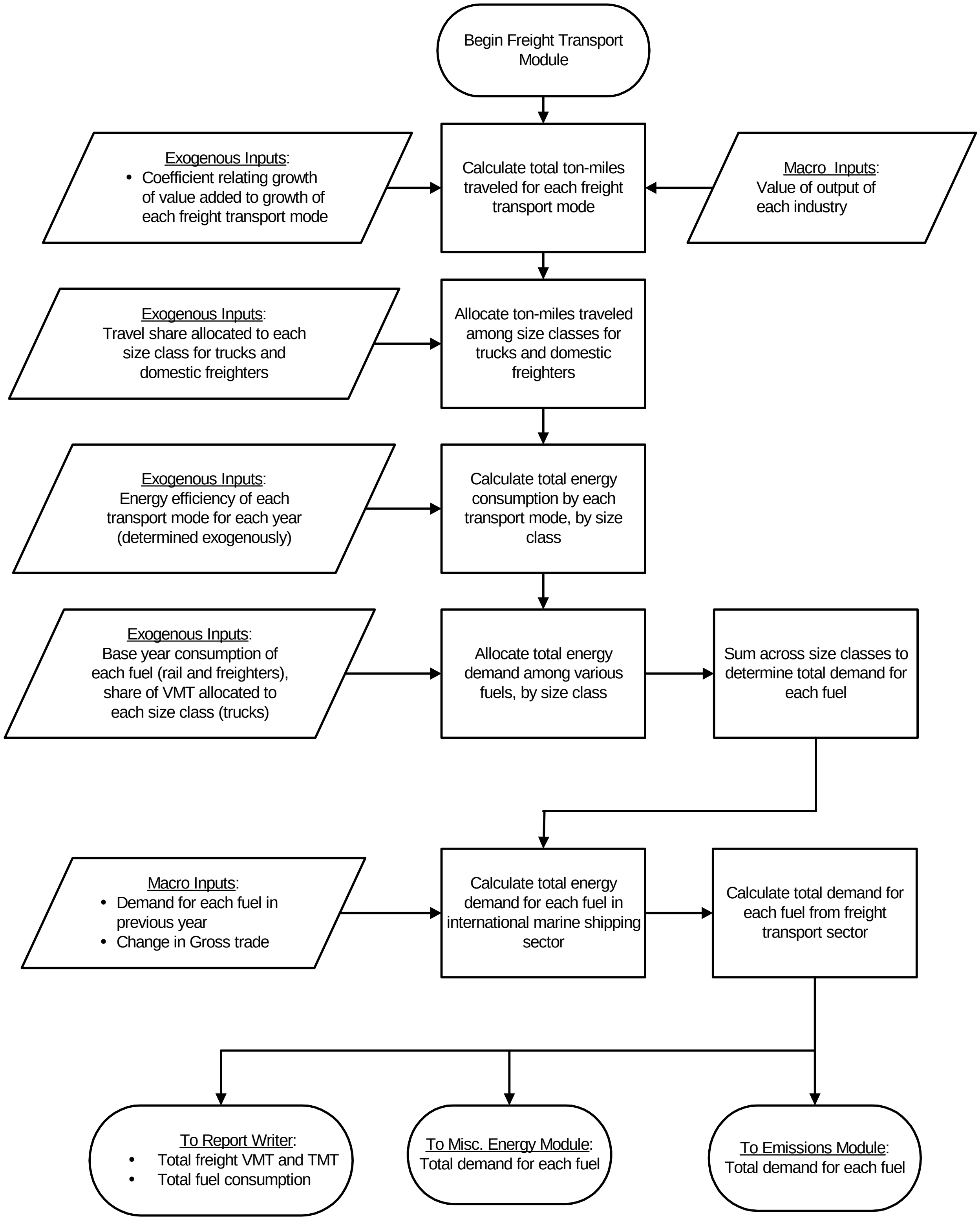
The Freight Transport Module developed for NEMS incorporates additional levels of detail. This is accomplished by stratifying the trucking sector according to market class and developing a stock adjustment model for each market class and fuel type. Parameters relating industrial output tonnage to changes in value of goods produced have been explicitly incorporated.

The NEMS Freight Transport Module aggregates the value of output from various industries into a reduced classification scheme, relating the demand for transport to the growth in the value of output of each industrial category. The relationships used for truck, rail, and waterborne freight are presented in sequence below. The flowchart for the Freight Transport Module is presented in Figure 13.

Freight Truck Stock Adjustment Submodule (FTSAS)

This section describes the methodology of the FTSAS that has been integrated into the Transportation Demand Sector Model of the NEMS. The FTSAS allows for manipulation of a number of important parameters, including the market penetration of existing and future fuel-saving technologies as well as alternatively-fueled heavy-duty vehicles. The FTSAS uses NEMS projections of real fuel prices and selected industries’ output from the macroeconomic model to estimate freight truck travel demand, and purchases. Projections of retirements of freight trucks, important truck stock characteristics such as fuel technology market share and fuel economy, and fuel consumption come from the transportation model.

Figure 13. Freight Transport Module



Projections are made for three modes of freight transport: trucks, rail, and ships. In each case, travel projections are based on the industrial output of specific industries, travel growth in most cases being directly proportional to increases in value of goods produced. Rail additionally uses NEMS coal projections to account for part of the travel. The Rail and Ship submodules then convert ton miles traveled to energy demand using the average energy intensity for the mode in question. Total energy demand is subsequently shared out to the various types of fuel used for freight transport. The FTSAS utilizes vintage, market class, sector, and fuel technology-specific freight truck fuel economies to derive energy demand.

The FTSAS projects the consumption of diesel fuel, motor gasoline, liquefied petroleum gas (LPG), and CNG accounted for by freight trucks in each of twelve industrial sectors. Twenty truck vintages, three truck market classes and two fleet types are tracked throughout the submodule, each having its own average fuel economy and average number of miles driven per year. The three truck market classes are defined as follows: Class 3 trucks 10,001 to 14,000 pounds GVWR, Classes 4-6 trucks 14,001 to 26,000 pounds GVWR, and Classes 7-8 trucks > 26,000 pounds GVWR. This section presents and describes the methodology used by the submodule to project each of these important variables. See Figure 14 for the flow chart of the Highway Freight Submodule.

There are six main procedures that are executed during each year of the model run to produce estimates of fuel consumption. In the first, fuel economies of the incoming class of new trucks are estimated through market penetration of existing and new fuel-saving technologies. Relative fuel economies are used in the second routine to determine the market share of each fuel technology in the current year's truck purchases. The third routine determines the composition of the existing truck population, utilizing the characteristics of the current year's class of new trucks along with exogenously estimated vehicle scrappage and fleet transfer rates. New truck sales data from the macroeconomic model are used to determine new truck purchases in the fourth routine. In the fifth routine, VMT demand is allocated among truck types and divided by fuel economy to determine fuel consumption. Finally, the truck stocks are rolled over into the next vintage, and the module is prepared for the next year's run.

1. Estimate New Truck Fuel Economies

The first step in the FTSAS is to determine the characteristics of the incoming class of truck purchases. Estimates of new light, medium heavy, and heavy truck fuel economies are generated endogenously and depend on the market penetration of specific fuel-saving technologies. Currently existing fuel-saving technologies are based on the report, *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory[16] and include drag reduction and advanced tires. Currently existing technologies gain market share via time-dependent exponential decay functions with exogenously determined maxima and minima, based on historical trends.

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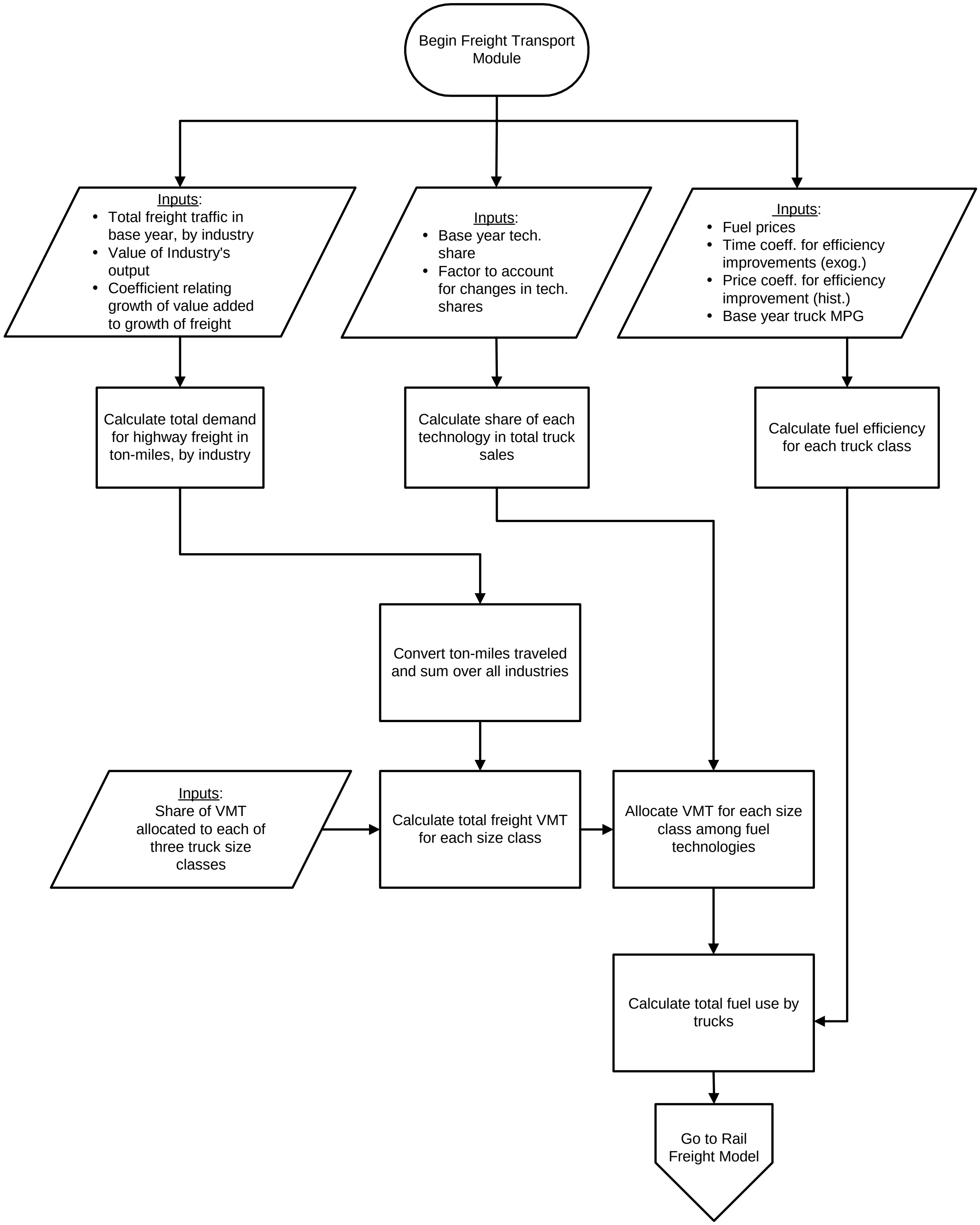
[16] *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August, 1999.

Figure 14. Highway Freight Submodule



Future technologies are adapted from *The Potential Effect of Future Energy Efficiency and Emissions Improving Technologies on Fuel Consumption of Heavy Trucks*, Argonne National Laboratory,[17] and include advanced transmissions, lightweight materials, synthetic gear lube, advanced drag reduction, advanced tires, electronic engine controls, turbo-compounding, hybrid power trains, and port-injection. Place holders allow for the introduction of four additional technologies. Future technologies can enter the market at various times throughout the submodule run depending on the year in which they become commercially available and on the level of fuel prices relative to a calculated cost-effective fuel price (based on capital costs) at which the technology becomes economically viable. Because prices vary by fuel type, the market shares of fuel-saving technologies are specified separately for diesel, gasoline, LPG and CNG trucks.

EPA has adopted strict new emission standards for on-road heavy-duty vehicles that take effect beginning in 2007. Under these new standards, both NO_x and PM emissions must be ten times lower than current (2004) levels, and the 2007 standards represent a 25-fold reduction compared to emission standards in the early 1990s. Thus, emissions from 2007 model year and later trucks will be dramatically lower than most trucks currently in use today. To meet these standards, truck engine manufacturers will need to use exhaust after-treatment devices for the first time, much like the catalytic converters currently found on automobiles. Note, however, that the emission standards apply only to new vehicles in the year of their manufacture; there are no emission standards that apply to in-use vehicles, other than some state regulations on exhaust smoke opacity.

The emission control devices that will allow engine manufacturers to meet these new standards typically cannot tolerate high sulfur levels in fuel. EPA has adopted companion standards for diesel fuel sulfur levels. Since late last year, on-road diesel fuel must have no more than 0.15 parts per million (ppm) sulfur (ultra-low sulfur), compared to the old standard of 500 ppm. This ultra-low sulfur diesel (ULSD) will be required for off-road applications (such as locomotives and port cargo handling equipment) by 2010.

The first step the submodule executes in each year is to calculate the average fuel price over the previous three years:

$$CFAVPC_{Year,Frt\_Fuel} = \frac{PRICE_{Year,Frt\_Fuel} + PRICE_{Year-1,Frt\_Fuel} + PRICE_{Year-2,Frt\_Fuel}}{3} \quad \textbf{(209)}$$

where,

Frt_Fuel = Index referring to fuel type, where *Frt_Fuel*=1 refers to diesel, *Frt_Fuel*=2 refers to gasoline, *Frt_Fuel*=3 refers to LPG and *Frt_Fuel*=4 refers to CNG

CFAVPC = Average price of fuel over three year period, in $ per MBtu

PRICE = Price of each fuel, in $ per MBtu

[17] *The Potential Effect of Future Energy Efficiency and Emissions Improving Technologies on Fuel Consumption of Heavy Trucks*, Argonne National Laboratory, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August, 2002.

The next step is to calculate the fuel trigger price at which the technology becomes economically viable:

$$TGPRCXG_{SC,Frt\_Fuel,Frt\_Tech} = \frac{CAPCXG_{SC,Frt\_Fuel,Frt\_Tech}}{\sum_{IP=1}^{PAYBKXG_{SC,Frt\_Tech}} \frac{MBTUTKXG_{SC} * MPGIPXG_{SC,Frt\_Fuel,Frt\_Tech}}{1+\left(0.01 * DISCRTXG\right)^{IP}}} \qquad \textbf{(210)}$$

where,

PAYBKXG = Exogenous payback period for a given technology and market class, in years

TGPRCXG = Fuel trigger price at which a technology, Frt_Tech, becomes economically viable

CAPCXG = Capital cost of a technology

MBTUTKXG = Exogenously determined fuel usage

MPGIPXG = Exogenously determined incremental fuel improvement

DISCRTXG = Exogenously determined discount rate

IP = Index for payback periods

Frt_Tech = Freight truck technologies

SC = Market class

Whether a future technology enters the market during a particular year depends on the cost effective price of that technology relative to the average price of each fuel over the past three years.

Technology market penetration depends on the level of fuel prices relative to the technology's cost effective price. For each technology that has entered the market, and for existing technologies, the effect of fuel prices on market penetration is determined for the current year by the equation:

$$PREFF_{Year,SC,Frt\_Fuel,Frt\_Tech} = 1 + PRVRXG_{SC,Frt\_Fuel,Frt\_Tech} * \left[\frac{CFAVPC_{Year,Frt\_Fuel}}{TGPRCXG_{SC,Frt\_Fuel,Frt\_Tech}} - 1\right] \qquad \textbf{(211)}$$

where,

PREFF = Effect of fuel price on market penetration rates for each freight technology

PRVRXG = Exogenously determined fuel price sensitivity parameter for each freight technology, representing the percent increase in technology market share if fuel price exceeds cost effective price by 100 percent

For each available technology, including existing technologies, each market class, and each fuel the submodule determines its share of the available market in the current year.

For each market class and technology, the market penetration over time is calculated, as an S-shaped logistical equation defined as follows:

$$PEN_{Year} = MINP + (MAXP - MINP) * \frac{1}{1 + e^{-\frac{Year - STYEAR - MIDPT}{COEFF}}} \qquad \textbf{(212)}$$

where,

PEN = Market penetration, by year

MAXP = Exogenously determined market penetration parameter: final market share of freight technology

MINP = Exogenously determined market penetration parameter: market share of technology in 1992

MIDPT = Exogenous parameter for existing technologies

COEFF = Market penetration curve for existing technologies

STYEAR = First year technology is available

If this is an emission control technology, or if the fuel price has reached the trigger price, then the technology share is as defined by the following:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = PREFF_{Year,SC,Frt\_Fuel,Frt\_Tech} * PEN_{Year} \qquad \textbf{(213)}$$

where,

TECHSHR = Market share of fuel-saving technology, Frt_Tech, for market class, SC, and fuel type, Frt_Fuel

However, if this is a fuel efficiency technology, and if the fuel price has not reached the trigger price, but the previous year’s technology market share is non-zero, then the current year’s market share grows at the same rate as the market penetration price sensitivity multiplier as follows:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = TECHSHR_{Year-1,SC,Frt\_Fuel,Frt\_Tech} * \frac{PREFF_{Year,Frt\_Fuel,Frt\_Tech}}{PREFF_{Year-1,Frt\_Fuel,Frt\_Tech}} \qquad \textbf{(214)}$$

Finally, if this is a fuel efficiency technology, and if the fuel price has not reached the trigger price, and the previous year's technology market share is zero, then the current year's market share is as follows:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = MINP \qquad \textbf{(215)}$$

If technology A is superseded by another mutually exclusive technology B at any time during the submodule run, technology A's market share must be adjusted to reflect the smaller pool of vehicles in its base market according to the relationship:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} * \left(1 - SPRSDEFF_{Year,SC,Frt\_Fuel,Frt\_Tech}\right) \qquad \textbf{(216)}$$

where,

SPRSDEFF = Superseding effect, equal to the market share of the superseding technology

Once the market shares in a given year are established, the effects of the technologies on the base fuel cost are tallied and combined to form a vector of "MPG Effects", which is used to augment the base fuel economy of new trucks of each market class and fuel type as defined by:

$$MPGEFF_{Year,SC,Frt\_Fuel} = \prod_{Frt\_Tech=1}^{40} \left(1 - MPGIPXG_{SC,Frt\_Fuel,Frt\_Tech} * TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech}\right) \qquad \textbf{(217)}$$

where,

MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in a given year

MPGIPXG = Exogenous factor representing percent improvement in fuel economy due to each technology

Fuel economy of new vintage, AGE = 1, freight trucks by market class can finally be determined as:

$$CFMPG_{Year,SC,AGE=1,Frt\_Fuel} = \frac{BSMPGXG_{SC,Frt\_Fuel}}{MPGEFF_{Year,SC,Frt\_Fuel}} \qquad \textbf{(218)}$$

where,

BSMPGXG = Fuel economy of new freight trucks with no fuel-saving technologies

2. Determine the Share of Each Fuel Type in Current Year's Class of New Trucks

Another major characteristic of the current year's class of new trucks, the market share of each fuel type, is calculated in the second FTSAS routine. Market penetration of alternative fuel freight trucks is more likely to be driven by legislative and/or regulatory action than by strict economics. For this reason, separate trends are incorporated for fleet vehicles, which are assumed to be more likely targets of future legislation, and non-fleet vehicles. The fuel technology routine described below is intended to simulate economic competition among fuel types after the creation of a market for alternative fuel trucks by government action. The user specifies the market share alternative fuel trucks are likely to achieve if they have no cost advantage over conventional technologies. The inherent sensitivity of each fuel technology to the cost of driving is also specified exogenously. The latter parameter represents the commercial potential of each fuel technology over and above what is mandated by government, and serves to modify the exogenous trend based on relative fuel prices and fuel economies. Additional user-specified parameters include the year in which the market penetration curves are initiated and the length of the market penetration cycle.

The first step in this process is to calculate the fuel cost for new trucks of each market class and fuel type that is defined as:

$$FCOST_{Year,SC,Frt\_Fuel} = \frac{CFAVPC_{Year,Frt\_Fuel}}{CFMPG_{Year,SC,Frt\_Fuel}} * HTRATE \tag{219}$$

where,

FCOST = Fuel cost of driving a truck of fuel type Frt_Fuel, in dollars per mile

HTRATE = Heat rate of gasoline, in million Btu per gallon

Frt_Fuel = 1, 3, 4 = non-gasoline trucks

a) Market Share of AFVs

The fuel cost of driving diesel trucks (Frt_Fuel=1) relative to AFVs (LPG and CNG vehicles) is then calculated as:

$$DCOST_{Year,SC,Frt\_Fuel} = 1 - PRAFDFXG_{SC,Frt\_Fuel} * \left[\frac{FCOST_{Year,SC,Frt\_Fuel}}{FCOST_{Year,SC,Frt\_Fuel=1}} - 1 \right] \tag{220}$$

where,

DCOST = Fuel cost per mile of diesel relative to LPG and CNG

PRAFDFXG = Exogenously determined parameter representing inherent variation in AFV market share due to difference in fuel prices

= 1, for LPG and CNG vehicles

Frt_Fuel = 3, 4

The market penetration curve parameters are determined during a user-specified trigger year and determined by the equations:

$$SLOPE_{SC,Frt\_Fuel,FLT} = \frac{\ln(0.01)}{0.5 * CYAFVXG_{SC,Frt\_Fuel,FLT}}$$

$$and \tag{221}$$

$$MIDYR_{SC,Frt\_Fuel,FLT} = TRGSHXG_{SC,Frt\_Fuel,FLT} + 0.5 * CYAFVXG_{SC,Frt\_Fuel,FLT}$$

where,

FLT = Index referring to fleet type, where *FLT* = 1 refers to non-fleet trucks and *FLT* = 2 refers to fleet trucks

SLOPE = Endogenously determined logistic market penetration curve parameter

CYAFVXG = Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration

MIDYR = Logistic market penetration curve parameter representing "halfway point" to maximum market penetration

TRGSHXG = Exogenously determined year in which each alternative fuel begins to increase in market share, due to EPACT1992 or other factors

Frt_Fuel = 3, 4

After the market penetration of alternative fuel trucks has been triggered, the AFV market trend is determined through a logistic function as follows:

$$MPATH_{Year,SC,Frt\_Fuel,Flt} = X * Y \tag{222}$$

where,

$$X = DCOST_{Year,SC,Frt\_Fuel}$$

$$Y = \left[BFSHXG_{SC,Frt\_Fuel,Flt} + \frac{EFSHXG_{SC,Frt\_Fuel,Flt} - BFSHXG_{SC,Frt\_Fuel,Flt}}{1 + e^{SLOPE_{SC,Frt\_Fuel,Flt} * (Year - MIDYR_{SC,Frt\_Fuel,Flt})}} \right]$$

BFSHXG = Base year (1997) market share of each fuel type

EFSHXG = Exogenously determined final market share of each fuel type

Frt_Fuel = 3, 4

The market share of alternative fuel trucks is assumed never to dip below the historical level in each sector. The actual AFV market share is thus calculated as the maximum of historical and projected shares as follows:

$$FSHFLT_{Year,SC,Frt\_Fuel,FLT} = \max\left[BAFSHXG_{SC,Frt\_Fuel,FLT}, MPATH_{Year,SC,Frt\_Fuel,FLT}\right] \tag{223}$$

where,

BAFSHXG = Exogenously determined base year (1997) share of alternative fuels in truck purchases

Frt_Fuel = 3, 4

b) Market Share of Diesel Trucks

The share of diesel, *Frt_Fuel* = 1, in conventional truck sales is projected through a time-dependent exponential decay function based on historical data that is defined by:

$$MPATH_{Year,SC,Frt\_Fuel=1,Flt} = BFSHXG_{SC,Frt\_Fuel=1,FLT} + \left[EFSHXG_{SC,Frt\_Fuel=1,Flt} - BFSHXG_{SC,Frt\_Fuel=1,FLT}\right] * \left[1 - e^{CSTDXG_{SC,FLT} + CSTDVXG_{SC,FLT} * Year}\right] \quad \textbf{(224)}$$

where,

CSTDXG,CSTDVXG = Exogenously determined market penetration curve parameters for diesel trucks

Because of the potential for any fuel type to exceed the user-specified “maximum” due to cost advantages over other technologies, market penetration must be capped at one hundred percent.

Diesel market share is calculated as the projected share of diesel in conventional truck sales multiplied by the share occupied by conventional trucks:

$$FSHFLT_{Year,SC,Frt\_Fuel=1,FLT} = \min\left[1, \left(1 - \sum_{Frt\_Fuel=3}^{4} FSHFLT_{Year,SC,Frt\_Fuel,FLT}\right) * MPATH_{Year,SC,Frt\_Fuel=1,FLT}\right] \quad \textbf{(225)}$$

The remainder of truck purchases is assumed to be gasoline, *Frt_Fuel*=2 and are defined by:

$$FSHFLT_{Year,SC,Frt\_Fuel=2,FLT} = 1 - \sum_{Frt\_Fuel=1,3,4} FSHFLT_{Year,SC,Frt\_Fuel,FLT} \quad \textbf{(226)}$$

3. Determine Composition of Existing Truck Stock

Once the characteristics of the incoming class of new trucks are determined, the next step is to determine the composition of the stock of existing trucks. Scrappage rates are applied to the current truck population based on:

$$TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT} = TRKSTK_{Year-1,SC,AGE-1,Frt\_Fuel,FLT} * \left(1 - SCRAP_{SC,AGE-1}\right) \quad \textbf{(227)}$$

where,

TRKSTK = Existing stock of trucks

SCRAP = Exogenously determined factor which consists of the percentage of trucks of each vintage that are scrapped each year

AGE = 2, 20; AGE = 1 refers to new truck sales

A number of trucks are transferred in each year from fleet to non-fleet ownership. Note, only gasoline and diesel fuel vehicles are transferred. Transfers of conventional trucks are based on exogenously determined transfer rates that are defined as:

$$TRF_{Year,SC,AGE,Frt\_Fuel} = TFFXGRT_{SC,AGE} * TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=2} \quad \textbf{(228)}$$

where,

TRF = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks

TFFXGRT = Exogenously determined percentage of trucks of each vintage to be transferred from fleets to non-fleets

The new existing population of trucks is simply the existing population (after scrappage) modified by fleet transfers:

$$\begin{gathered} TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=2} = TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=2} - TRF_{Year,SC,AGE,Frt\_Fuel} \\ and \\ TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=1} = TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=1} - TRF_{Year,SC,AGE,Frt\_Fuel} \end{gathered} \quad \textbf{(229)}$$

4. Calculate Purchases of New Trucks

New truck purchases are based on class 3 truck sales and on the macroeconomic models projections of classes 4-8 truck sales that is split between truck classes 4-6 and classes 7-8 as defined at the beginning of this section on the FTSAS:

$$\begin{aligned} NEWTRUCKS_{SC=1} &= MC\_VEHICLES_{5,Year} * 1000 \\ NEWTRUCKS_{SC=2} &= NEWCLS46_{Year} * NEWTRUCKS\_TOT_{Year} \\ NEWTRUCKS_{SC=3} &= (1 - NEWCLS46_{Year}) * NEWTRUCKS\_TOT_{Year} \end{aligned} \quad \textbf{(230)}$$

where,

NEWTRUCKS_TOT = Total new truck sales for classes 4-8, from the macroeconomic model.

NEWCLS46 = Truck classes 4-6 share of total truck sales.

$MC\_VEHICLES_{5,Year}$ = Sales of class 3 trucks from the macroeconomic model

SC = 1 refers to class 3; SC = 2 refers to class 4-6; SC = 3 refers to class 7-8

The next step is to calculate the new truck sales, *AGE* = 1, as:

$$TRKSTK_{Year,SC,AGE=1,Frt\_Fuel} = NEWTRUCKS_{SC} * FSHFLT_{Year,SC,Frt\_Fuel,FLT} \tag{231}$$

5. Calculate Fuel Consumption

The next stage of the submodule takes the total miles driven by trucks of each market class, fuel type and age and divides by fuel economy to determine fuel consumption.

The aggregate VMT growth by economic sector, *SEC*, is estimated. First, calculate Freight Adjustment coefficient, FOUT, which represents the relationship between the value of industrial output and freight demand in terms of VMT. It is used to factor industry growth to get VMT growth. FOUT is defined by:

$$FOUT_{SEC} = FAC\_T0_{SEC} + \frac{1 - FAC\_T0_{SEC}}{1 + e^{FAC\_K*(FAC\_T5 - Year)}} \tag{232}$$

where,

FAC_T0 = Base year freight adjustment coefficient, by sector, exogenously determined

FAC_K = log(9.0) / (FAC_T9 - FAC_T5)

FAC_T5 = Year of 50 percent freight adjustment coefficient decay = 2002

FAC_T9 = Year of 90 percent freight adjustment coefficient decay = 2007

Now calculate the adjustment VMT per truck as:

$$VMTADJ_{Year} = \frac{\sum_{SEC=1}^{12} VMTDMD_{Year-1,SEC} * \left(1 + OUTPUT_{Year,SEC}\right) * FOUT_{SEC}}{\sum_{SC,AGE,Frt\_Fuel,FLT} ANNVMT_{SC,AGE,Frt\_Fuel} * TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT}} \tag{233}$$

where,

VMTDMD = Annual sectoral VMT based on base year FHWA estimates of VMT

ANNVMT = Base year VMT per truck by 3 freight market classes.

Finally, adjust VMT to obtain VMT across all sectors using the equation:

$$VMTFLT_{Year,SC,AGE,Frt\_Fuel,FLT} = ANNVMT_{SC,AGE,Frt\_Fuel} * VMTADJ_{Year} * TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT} \tag{234}$$

Fuel consumption, in gallons of gasoline equivalent, is finally calculated by dividing VMT by on-road fuel economy:

$$FUELDMD_{Year,SC,Frt\_Fuel,FLT} = \sum_{AGE=1}^{20} \frac{VMTFLT_{Year,SC,AGE,Frt\_Fuel,FLT}}{CFMPG_{Year,SC,AGE,Frt\_Fuel}} \quad \textbf{(235)}$$

where,

FUELDMD = Total freight truck fuel consumption by market class and fuel type, in gallons of gasoline equivalent

CFMPG = Fuel economy of freight trucks, by market class, fuel, and vintage

Converting from gasoline equivalent to trillion Btu only requires multiplying by the heat rate of gasoline as shown here:

$$FUELBTU_{Year,SC,Frt\_Fuel,FLT} = FUELDMD_{Year,SC,Frt\_Fuel,FLT} * HEATRATE * 10^{-12} \quad \textbf{(236)}$$

where,

FUELBTU = Total fleet truck fuel consumption by market class and fuel type, trillion Btu

Rail Freight Submodule

Rail projections represent a simplification of the freight truck approach, in that only one class of freight rail and vehicle technology is considered. Projections of energy use by rail are driven by projections of coal production and of ton-miles traveled for each of the industrial categories used in the trucking sector. See Figure 15. The algorithm used to estimate energy consumption of rail freight is similar to the one used for trucks and is calculated in the following steps.

First, calculate ton-miles traveled for coal as follows:

$$COALT_{Year} = \sum_{Coal\_Reg=1}^{2} COALP_{Coal\_Reg,Year} * COALD_{Coal\_Reg} \quad \textbf{(237)}$$

where,

COALT = Total ton-miles traveled for coal in region, Coal_Reg, (east/west) in a given year

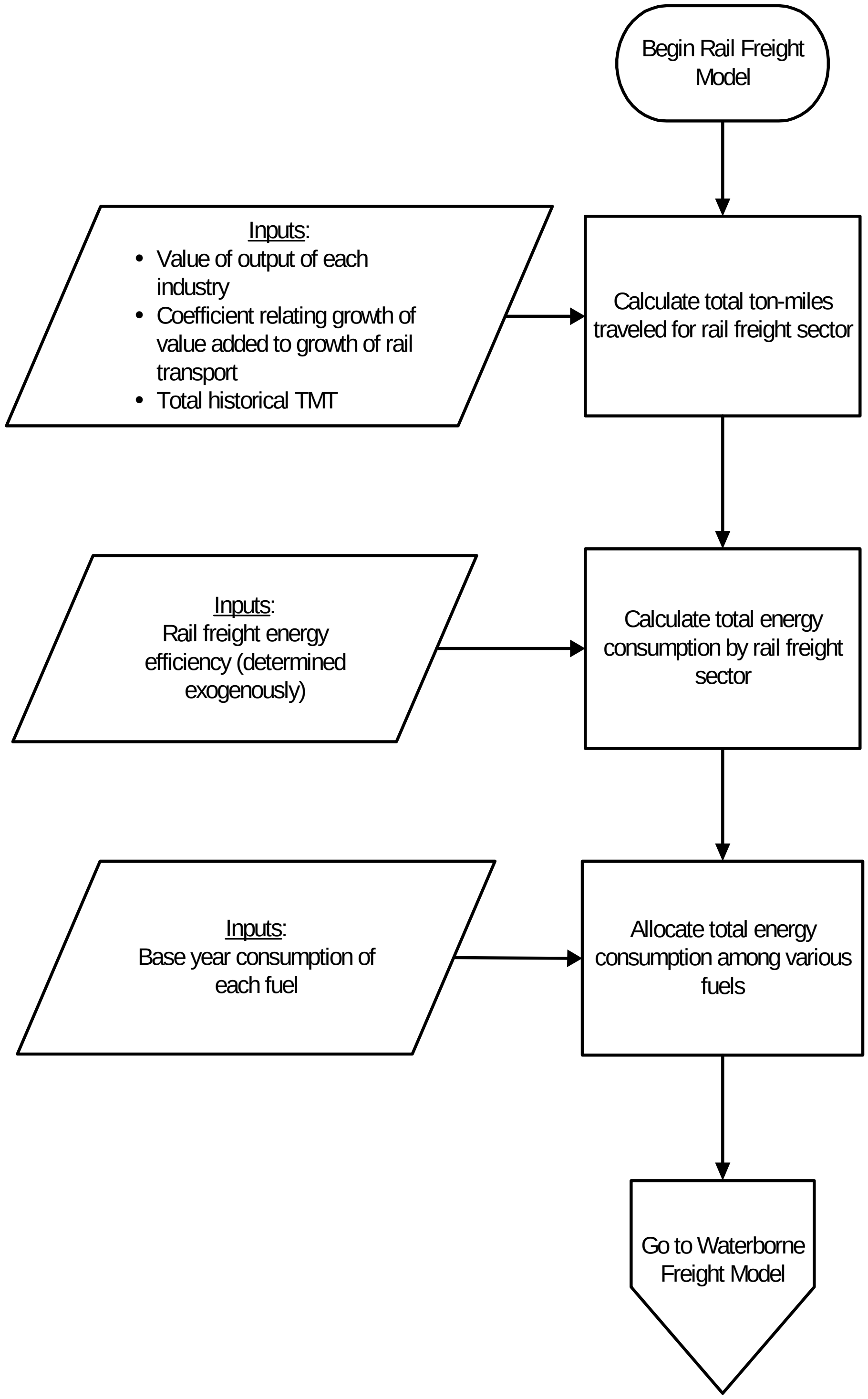
COALP = The production of coal in region, Coal_Reg, in a given year in tons

COALD = Distance coal has to travel in region, Coal_Reg.

Ton-miles traveled are calculated as follows:

$$RTMT_{ISIC,Year} = RTMT_{ISIC,Year_0} * FACR_{ISIC} * \frac{OUTPUT_{ISIC,Year}}{OUTPUT_{ISIC,Year_0}} \quad \textbf{(238)}$$

Figure 15. Rail Freight Submodule



where,

RTMT = Total rail ton-miles traveled for industry, *ISIC=1,10,* in year, *Year*

OUTPUT = Value of output of industry *ISIC*, in base year, $Year_0$, dollars

FACR = Coefficient relating growth of value of goods produced with growth of rail transport.

Calculate aggregated rail ton-miles traveled, RTMTT, as follows:

$$RTMT\_C_{ISIC=10,Year} = 0.1 * RTMT_{ISIC=10,Year_0} + 0.9 * RTMT_{ISIC=10,Year} * \frac{COALT_{Year}}{COALT_{Year_0}} \quad \textbf{(239)}$$

$$RTMTT_{Year} = RTMT\_C_{ISIC=10,Year} + \sum_{ISIC=1}^{10} RTMT_{ISIC,Year} \quad \textbf{(240)}$$

Energy consumption is then estimated using the projected rail energy efficiency as follows:

$$TQRAILT_{Year} = FERAIL_{Year} * RTMTT_{Year} \quad \textbf{(241)}$$

where,

TQRAILT = Total energy consumption by freight trains

FERAIL = Exogenously determined rail energy efficiency

Rail efficiency gains resulting from technological development and increased system efficiency are based on an exogenous analysis of trends.

This aggregate energy demand is used to estimate the demand for the various fuels used for rail transport, adjusting the previous year's demand for a given fuel by the fractional increase in overall energy requirements. This is defined by the following:

$$TQRAIL_{Rail\_Fuel,Year} = TQRAIL_{Rail\_Fuel,Year-1} * \frac{TQRAILT_{Year}}{TQRAILT_{Year-1}} \quad \textbf{(242)}$$

where,

TQRAIL = Total demand for each fuel by rail freight sector in year*, Year*

This approach is based on the assumption that the relative shares of each fuel remain constant across the projection horizon, and that there is little or no room for fuel substitution as prices vary.

Fuel consumption is then allocated to each region by:

$$TQRAILR_{Rail\_Fuel,REG,Year} = TQRAIL_{Rail\_Fuel,Year} * SEDSHRXX_{REG,Year} \quad \textbf{(243)}$$

where,

TQRAILR = Total regional fuel consumption for each technology

SEDSHRXX = Regional share of rail freight fuel consumption, from SEDS, by fuel, XX=DS (distillate), XX=RS (residual), XX=EL(electricity)

The submodule then calculates the fractional change in fuel efficiency as follows:

$$XRAILEFF_{Year} = \frac{FERAIL_{Year}}{FERAIL_{Year_0}} \quad \textbf{(244)}$$

where,

XRAILEFF = Growth in rail efficiency from base year, $Year_0$

Waterborne Freight Submodule

Two classes of waterborne transit are considered in this submodule: domestic marine traffic and freighters conducting foreign trade. This is justified on the grounds that vessels that comprise freighter traffic on rivers and in coastal regions have different characteristics than those which ply international waters. See Figure 16.

Domestic Marine

The estimate of total domestic waterborne travel demand is driven by projections of industrial output as defined by:

$$STMTT_{Year} = \sum_{ISIC=1}^{10} \left[STMT_{ISIC,Year_D} * FACS_{ISIC} \frac{OUTPUT_{ISIC,Year}}{OUTPUT_{ISIC,Year_D}} \right] \quad \textbf{(245)}$$

where,

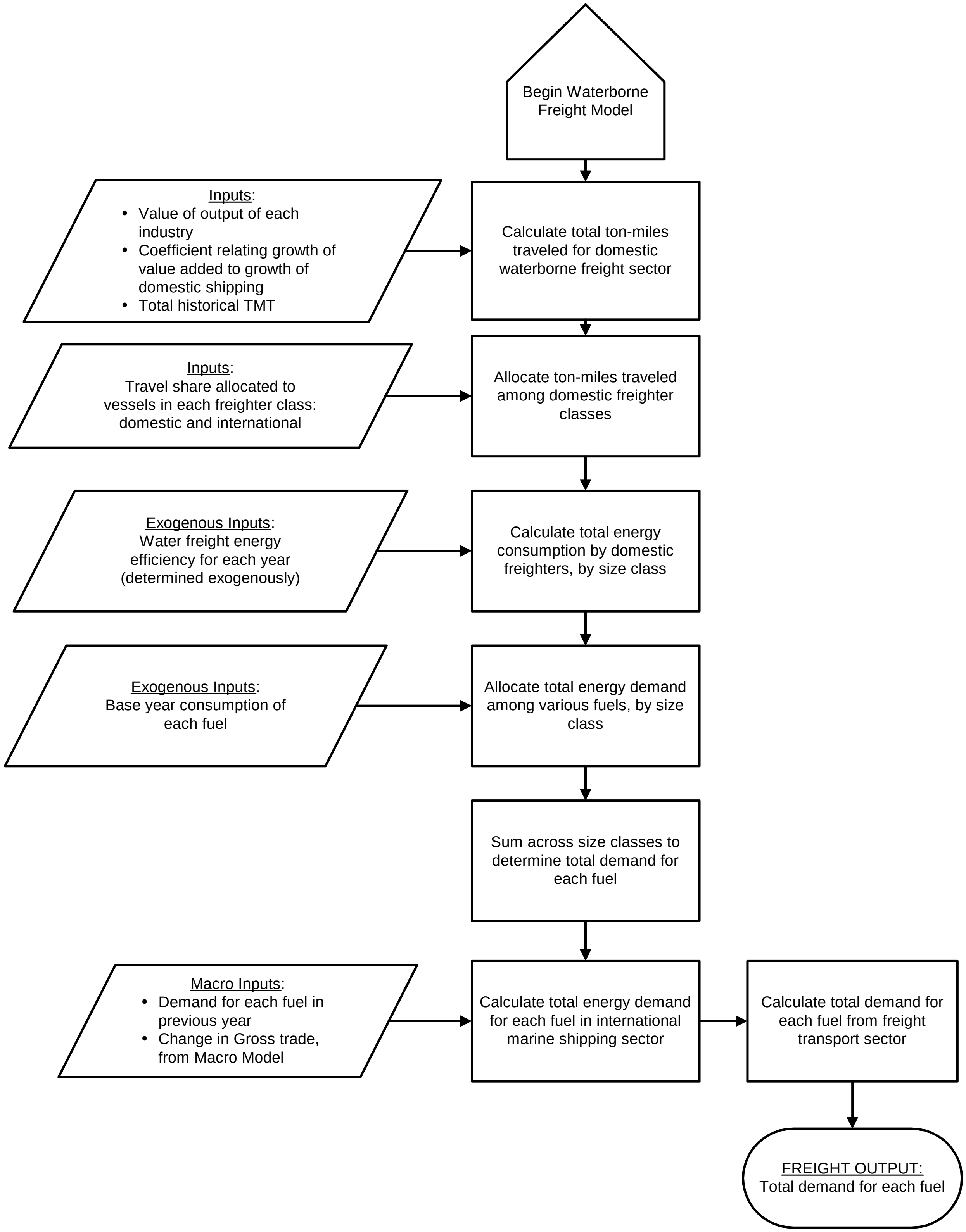
STMT = Total ton-miles of waterborne freight for industry, ISIC, in year, Year.

OUTPUT = Value of output of industry, ISIC, in base year dollars

FACS = Exogenous determined coefficient relating growth of value added with growth of shipping transport

$Year_D$ = Year of most recent data update

Figure 16. Waterborne Freight Submodule



Fuel use is subsequently estimated, using average energy efficiency as defined by:

$$SFDT_{Year} = FESHIP_{Year} * STMTT_{Year} \qquad \textbf{(246)}$$

where,

SFDT = Domestic ship energy demand

FESHIP = Average fuel efficiency

Estimated changes in energy efficiency are exogenous. The next step the submodule takes is allocating total energy consumption among three fuel types (distillate fuel, residual fuel oil and gasoline), which is defined by:

$$SFD_{Ship\_Fuel,Year} = SFDT_{Year} * SFSHARE_{Ship\_Fuel,Year} \qquad \textbf{(247)}$$

where,

SFD = Domestic ship energy demand, by fuel

SFSHARE = Domestic shipping fuel allocation factor

Ship_Fuel = Index referring to the three shipping fuel types

The factor that allocates energy consumption among the three fuel types is based on 2004 data[18] and is held constant throughout the run period.

Total energy demand is then regionalized as follows:

$$TQSHIPR_{Ship\_Fuel,REG,Year} = SFD_{Ship\_Fuel,Year} * SEDSHR_{Ship\_Fuel,REG,Year} \qquad \textbf{(248)}$$

where,

TQSHIPR = Total regional energy demand by domestic freighters

SEDSHR = Regional shares of fuel demand, from SEDS

The fractional change in domestic ship travel and fuel efficiency is then calculated as:

$$XSHIPEFF_{Year} = \frac{FESHIP_{Year}}{FESHIP_{Year_0}} \qquad \textbf{(249)}$$

where,

[18] Oak Ridge National Laboratory, Transportation Energy Data Book Edition 26, June 2007.

XSHIPEFF = Growth in ship efficiency from base year, $Year_0$

International Marine

Fuel demand in international marine shipping is directly estimated, linking the level of international trade with the lagged consumption of the fuel in question as follows:

$$ISFDT_{Year} = ISFDT_{Year-1} + 0.5 * ISFDT_{Year-1} * \left[\frac{GROSST_{Year}}{GROSST_{Year-1}} - 1 \right] \qquad \textbf{(250)}$$

where,

ISFDT = Total international shipping energy demand in year, *Year*

GROSST = Value of Gross Trade (imports + exports), from macroeconomic model

Total energy demand is then allocated among the various fuels by the following:

$$ISFD_{Ship\_Fuel,Year} = ISFDT_{Year} * ISFSHARE_{Ship\_Fuel,Year} \qquad \textbf{(251)}$$

where,

ISFD = International freighter energy demand, by fuel

ISFSHARE = International shipping fuel allocation factor

Regional fuel consumption is then calculated as:

$$TQISHIPR_{Ship\_Fuel,REG,Year} = ISFD_{Ship\_Fuel,Year} * SEDSHR_{Ship\_Fuel,REG,Year} \qquad \textbf{(252)}$$

where,

TQISHIPR = Total regional energy demand by international freighters

SEDSHR = Regional shares of fuel demand, from SEDS.

Miscellaneous Energy Demand Module

The Miscellaneous Energy Demand (MED) module addresses the projection of demand for several transportation fuels and sums total energy demand from all end-use categories. These categories include military operations, mass transit (passenger rail and buses), recreational boating, and lubricants used in all modes of transportation. Figure 17 presents the flowchart for the MED Module.

Military Demand Submodule

See Figure 18 for flowchart of Military Demand Submodule. Fuel demand for military operations is considered to be proportional to the projected military budget. The fractional change in the military budget is first calculated as follows:

$$MILTARGR_{Year} = \frac{TMC\_GFML_{Year}}{TMC\_GFML_{Year-1}} \quad \textbf{(253)}$$

where,

MILTARGR = The growth in the military budget from the previous year

TMC_GFML = Total defense budget in year, *Year*, from the macroeconomic model in NEMS

Total consumption of each of four fuel types is then determined by:

$$MFD_{Mil\_Fuel,Year} = MFD_{Mil\_Fuel,Year-1} * MILTARGR_{Year} \quad \textbf{(254)}$$

where,

MFD = Total military consumption of the considered fuel in year, Year

Mil_Fuel = Index of military fuel type: 1=Distillate, 2=Jet Fuel(Naptha), 3=Residual, 4=Jet Fuel(Kerosene)

Consumption is finally distributed among the nine census regions by the following equation:

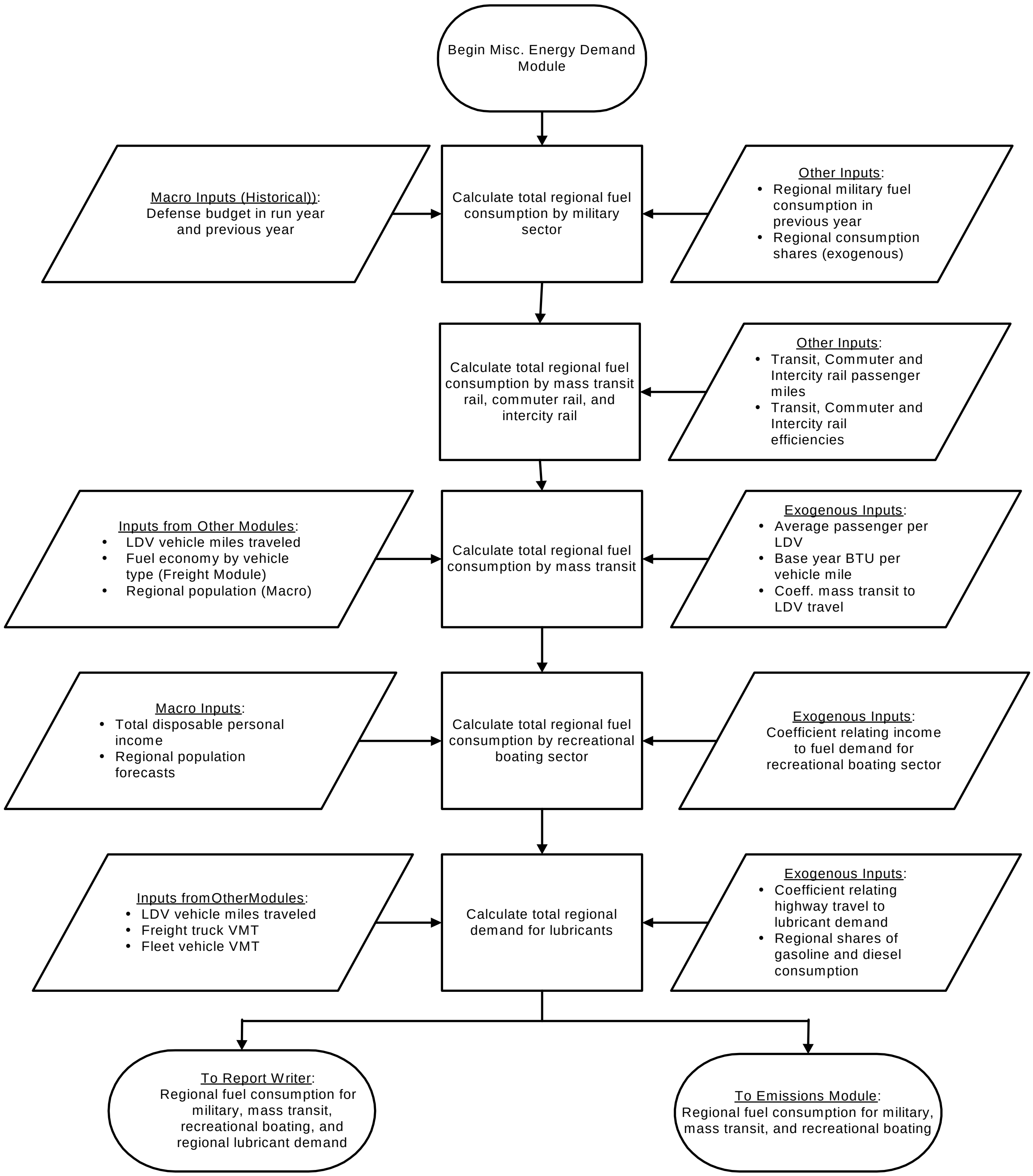
$$QMILTR_{Mil\_Fuel,REG,Year} = MFD_{Mil\_Fuel,Year} * MILTRSHR_{Mil\_Fuel,REG} \quad \textbf{(255)}$$

where,

QMILTR = Regional fuel consumption, by fuel type, in Btu

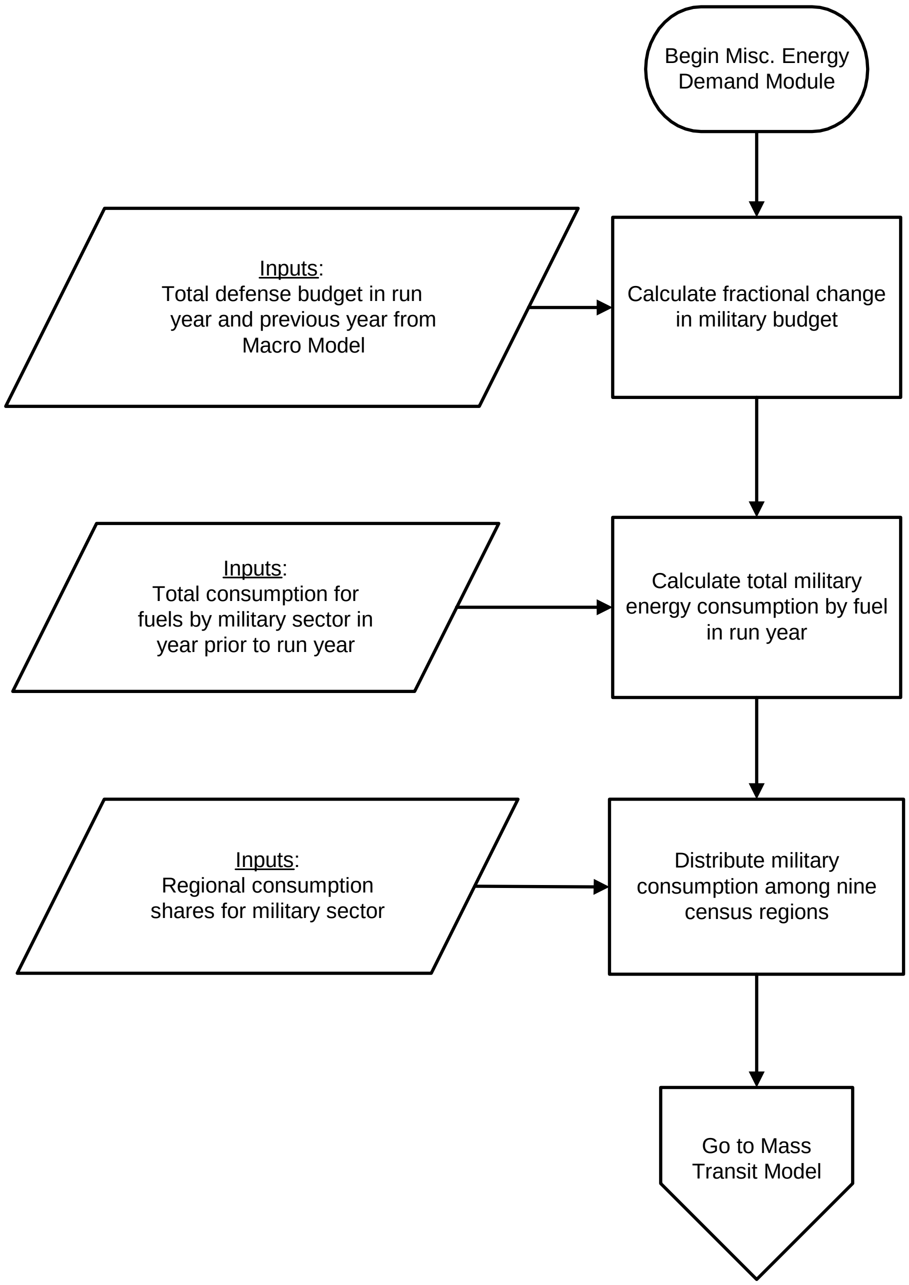
MILTRSHR = Regional consumption shares, from 1991 data, held constant

Figure 17. Miscellaneous Energy Demand Module



Note: the emissions module is currently inactive

Figure 18. Military Demand Submodule



Mass Transit Demand Submodule

See Figure 19 for flowchart of Mass Transit Demand Submodule. The growth of passenger-miles in each mode of mass transit is assumed to be proportional to the growth of passenger-miles in light duty vehicles. This is determined from the output of the VMT submodule and the load factor for LDV's, held constant at 1989 levels. Changes have been made to the Mass Transit Model to reflect passenger travel and energy demand by Census Division in the regional transit rail, regional commuter rail, and the regional intercity rail models. For each of these rail transit modes, the passenger miles traveled, historic efficiencies, travel demand log of income are read in. The sum of the three rail modes is captured by the following equation:

$$QMTRR_{Ifuel,Region,Year} = TRED_{Region,Year} + CREDE_{Region,Year} + IREDER_{Region,Year} \quad \textbf{(256)}$$

where,

QMTRR = Passenger rail energy demand by fuel by region

TRED = Transit Rail Energy Demand by census division

CREDE = Commuter Rail Energy Demand by census division

IREDER = Intercity Rail Energy Demand by census division

The following equations describe the bus segment of the model:

$$TMOD_{IM,Year} = TMOD_{IM,Year-1} * \left[\frac{VMTEE_{Year}}{VMTEE_{Year-1}}\right]^{BETAMS} \quad \textbf{(257)}$$

where,

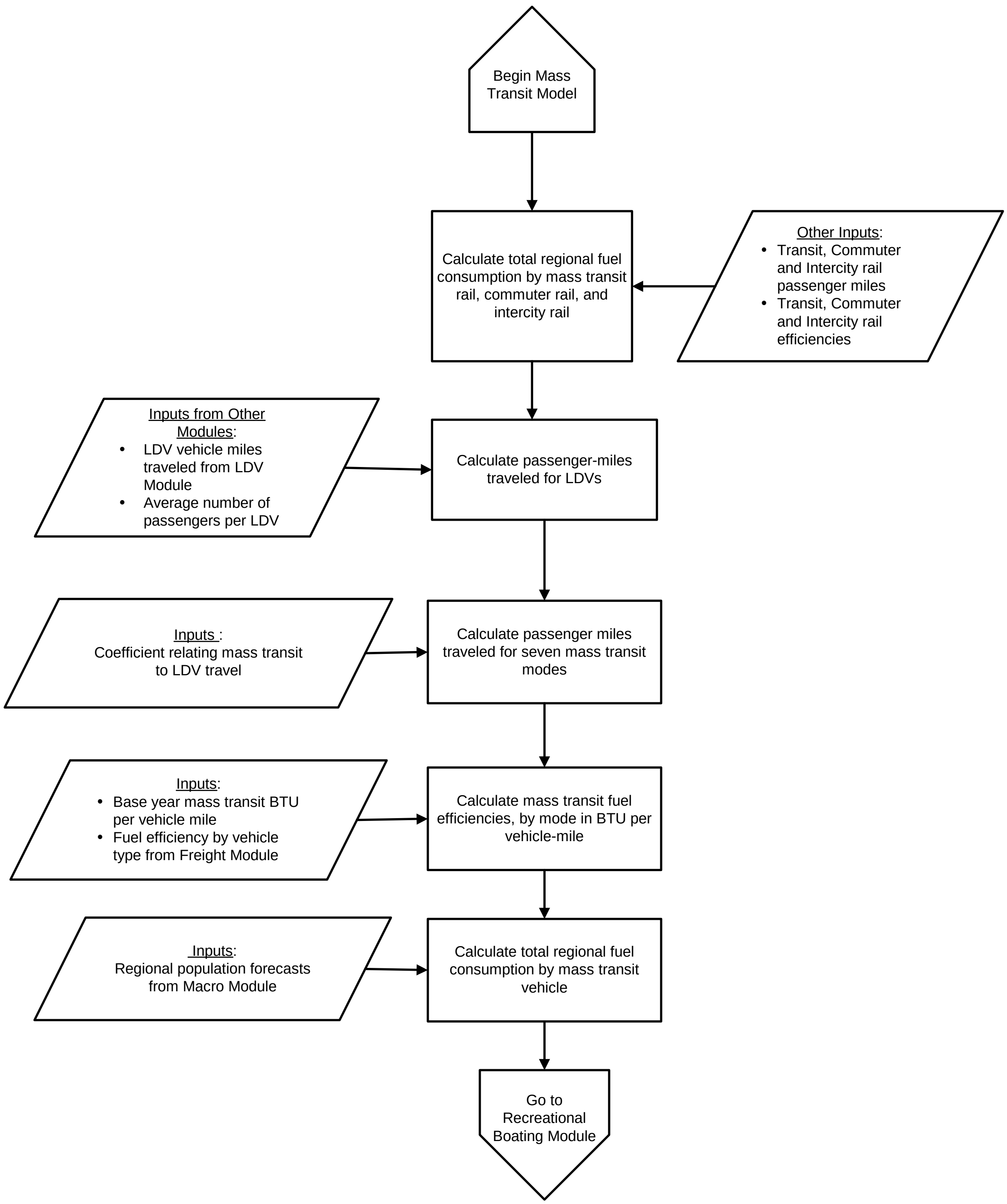
TMOD = Passenger-miles traveled, by mode

VMTEE = LDV vehicle-miles traveled, from the VMT submodule

BETAMS = Coefficient of proportionality, relating mass transit to LDV travel

IM = Index of transportation mode: 1 = Transit bus, 2 = Intercity Bus, 3 = School bus

Figure 19. Mass Transit Demand Submodule



Fuel efficiencies, in Btu per vehicle-mile, are obtained from the Freight Module for buses and rail; and mass transit efficiencies, in Btu per passenger-mile, are calculated as:

$$TMEFF_{IM,Year} = TMEFF_{IM,Year-1} * \frac{FTMPG_{IM,Year-1}}{FTMPG_{IM,Year}} \quad \textbf{(258)}$$

where,

TMEFF = Btu per passenger-mile, by mass transit mode

FTMPG = Freight mpg, by vehicle type, from the Freight Module

Total fuel consumption is calculated and distributed among regions according to their populations based on the following:

$$QMODR_{IM,REG,Year} = TMOD_{IM,Year} * TMEFF_{IM,Year} * \frac{MC\_NP_{REG,Year}}{\sum_{REG=1}^{9} MC\_NP_{REG,Year}} \quad \textbf{(259)}$$

where,

QMODR = Regional consumption of fuel, by mode

MC_NP = Regional population projections, from the macroeconomic model

Recreational Boating Demand Submodule

See Figure 20 for flowchart of Recreational Boating Demand Submodule. The growth in fuel use by recreational boats is related to the growth in disposable personal income. Initially the recreational boating fuel consumption per capita is estimated for all years and is used subsequently to determine the national and regional fuel consumption for this activity. The following equations describe the model used:

$$RBEDPC_{Fuel,Year} = X1_{Fuel} + X2_{Fuel} * LOG(INCOME00_{Year}) + X3_{Fuel} * PRICE04_{Fuel} \quad \textbf{(260)}$$

where,

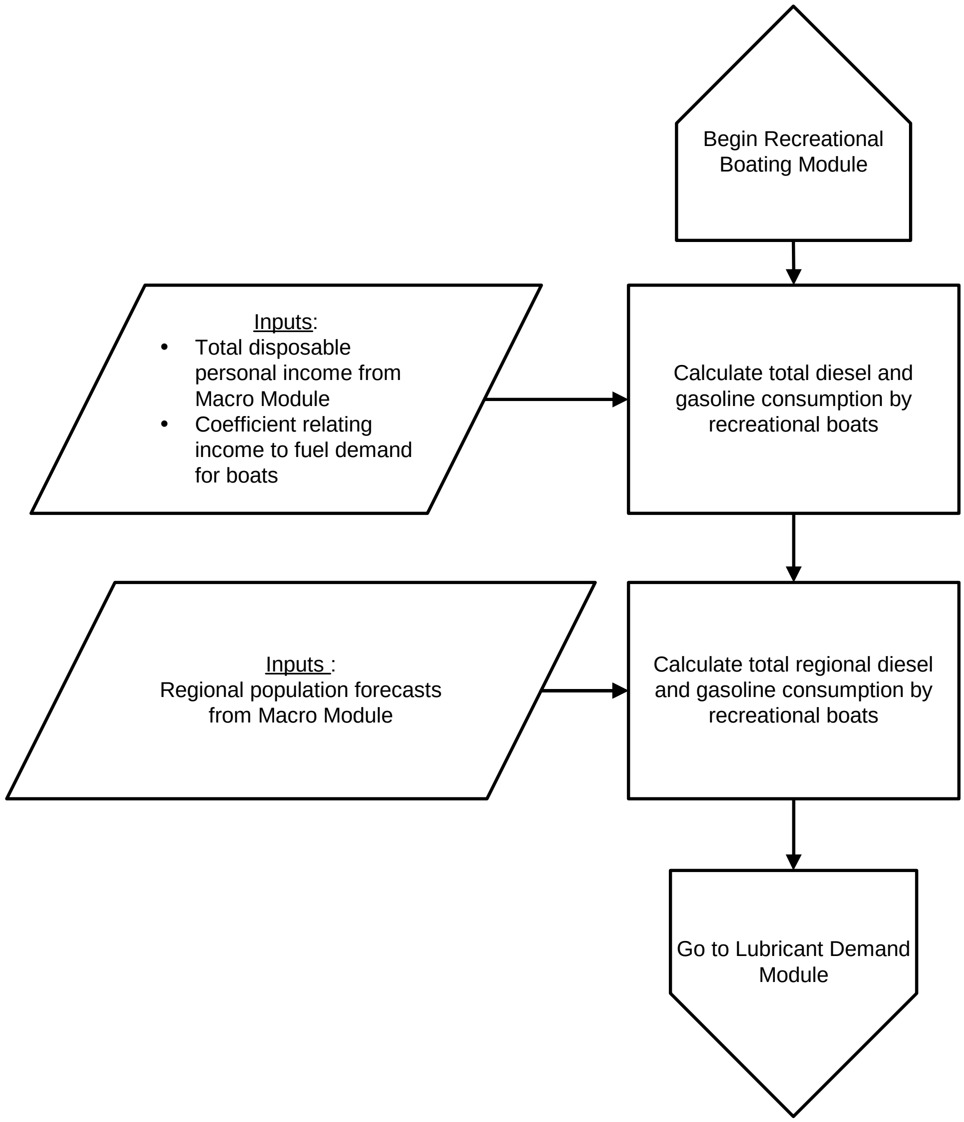
RBEDPC = Recreational fuel consumption per capita in year, Year, Fuel (where 1= Gasoline and 2 = Diesel)

X1 = Energy demand constant term for the above fuel types

X2 = Energy demand log of income for the above fuel types

X3 = Energy demand fuel cost in 2004 dollars for the above fuel types

Figure 20. Recreational Boating Demand Submodule



INCOME00 = Per capita income in 2000 dollars

PRICE04 = Fuel price in 2004 dollars for the above fuel types

This value is then used to estimate the national recreational fuel consumption for each year with the following equation:

$$RECFD_{Fuel,Year} = RBEDPC_{Fuel,Year-1} * \sum_{REG=1}^{9} MC\_NP_{REG,Year} \qquad \textbf{(261)}$$

where,

RECFD = National recreational fuel consumption in year, Year, Fuel (where 1=Gasoline and 2 = Diesel)

Following this the regional consumption is calculated according to population, as with mass transit. It is defined by:

$$QRECR_{Fuel,REG,Year} = RECFD_{Fuel,Year} * \frac{MC\_NP_{REG,Year}}{\sum_{REG=1}^{9} MC\_NP_{REG,Year}} \qquad \textbf{(262)}$$

where,

QRECR = Regional fuel consumption by recreational boats in year, Year, Fuel where 1=Gasoline and 2 = Diesel

Lubricant Demand Submodule

See Figure 21 for flowchart of Lubricant Demand Submodule. The growth in demand for lubricants is considered to be proportional to the growth in highway travel by all types of vehicles. Total highway travel is first determined as:

$$HYWAY_{Year} = VMTEE_{Year} + FTVMT_{Year} + FLTVMT_{Year} \qquad \textbf{(263)}$$

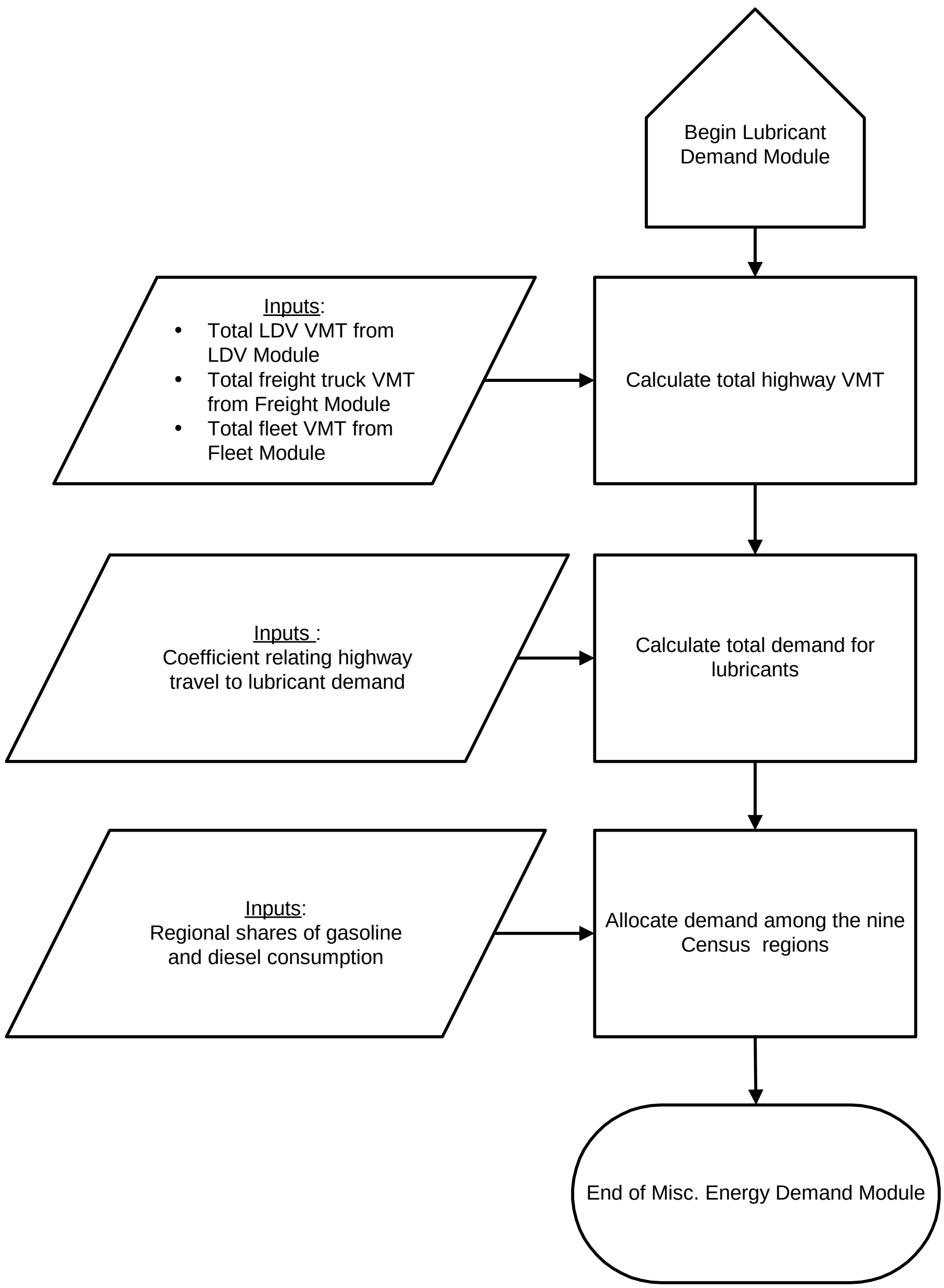
where,

HYWAY = Total highway VMT

FTVMT= Total freight truck VMT, from the Freight Module

FLTVMT = Total fleet vehicle VMT, from the Fleet Submodule

Figure 21. Lubricant Demand Submodule



Lubricant demand is then estimated based on the following:

$$LUBFD_{Year} = LUBFD_{Year-1} * \left[\frac{HYWAY_{Year}}{HYWAY_{Year-1}} \right]^{BETALUB} \quad \textbf{(264)}$$

where,

LUBFD = Total demand for lubricants in year, Year

BETALUB = Constant of proportionality, relating highway travel to lubricant demand

The lubricant demand is allocated to regions by a regional weighting of all types of highway travel as shown in the following:

$$QLUBR_{REG,Year} = LUBFD_{Year} * \left[\frac{(VMTEE_{Year} + FLTVMT_{Year}) * SHRMG_{REG,Year} + FTVMT_{Year} * SHRDS_{Year}}{HYWAY_{Year}} \right] \quad \textbf{(265)}$$

where,

QLUBR = Regional demand for lubricants in year, *Year*, in Btu

SHRMG = Regional share of motor gasoline consumption, from SEDS

SHRDS = Regional share of diesel consumption, from SEDS

Appendix A. Model Abstract

Model Name

Transportation Sector Module

Model Acronym

TRAN

Description

The Transportation Sector Module is part of the NEMS and incorporates an integrated modular design that is based upon economic, engineering, and demographic relationships that model transportation sector energy consumption at the nine Census Division level of detail. It comprises the following modules: Light Duty Vehicles, (including Light Duty Fleet Vehicles, Light Duty Stock, and Commercial Light Trucks), Air Travel, Freight Transport (truck, rail, and marine), and Miscellaneous Energy (military, mass transit, and recreational boats). The model provides sales estimates of 2 conventional and 14 alternative-fuel light duty vehicles, and consumption estimates of 12 fuel types.

Purpose of the Model

As a component of the National Energy Modeling System, the transportation model generates projections (through 2030) of transportation sector energy consumption. The transportation model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact transportation sector energy consumption.

Most Recent Model Update

October, 2006

Model Interfaces

Receives inputs from the Electricity Market Model, Petroleum Market Model, Natural Gas Transmission and Distribution Model, and the Macroeconomic Activity Mode

Documentation

Model Documentation Report: *Transportation Sector Model of the National Energy Modeling System*, DOE/EIA-M070(2007), November 2007.

Energy System Described

Domestic transportation sector energy consumption.

Coverage

- Geographic: Nine Census Divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific.

- Time Unit/Frequency: Annual, 1995 through 2030.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants, pipeline fuel, and natural gas.
- Economic Sectors: Projections are produced for personal and commercial travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Independent Expert Reviews Conducted

Independent Expert Review of Transportation Sector Component Design Report, June, 1992, conducted by David L. Greene, Oak Ridge National Laboratory.

Report of Findings on the NEMS Freight Transport Model, April 3, 2001, by David L. Greene, Oak Ridge National Laboratory.

Report of Findings, NEMS Freight Transport Model Review, April 4, 2001, by Mike Lawrence, Laurence O'Rourke, Jack Faucett Associates

Independent Evaluation of EIA's Freight Transportation Model, Draft Report, April 11, 2001, by James S. Moore, Jr. P.E. TA Engineering, Inc.

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- State Energy Data 2005 (SEDS), June 2007, http://www.eia.doe.gov/emeu/states/_use_multistate.html.
- Short Term Energy Outlook, Jan. 2008, http://www.eia.doe.gov/emeu/steo/pub/contents.html
- Macroeconomic Model Inputs: New vehicle sales, economic and demographic indicators, and defense spending.
- NEMS Supply Models: Fuel prices.

Non-DOE Input Sources:

- National Energy Accounts
- U.S. Department of Transportation, Federal Aviation Administration: Airport Capacity Benchmark Report, 2004
- U.S. Department of Transportation, Bureau of Transportation Statistics: Air Carrier Summary Data, 2007
- Jet Information Services Inc., World Jet Inventory: Year-End 2006, December 2006.
- Federal Highway Administration, Highway Statistics, FHWA-PL-01-1011, 2006
- National Highway Traffic and Safety Administration, Final Model Year Fuel Economy Report, March 2008
- Oak Ridge National Laboratory, Transportation Energy Data Book Ed. 27, ORNL-6973, 2008
- Oak Ridge National Laboratory, Stacy C. Davis and Lorena F. Truett, Fleet Characteristics and Data Issues, January 2003
- Department of Commerce, Bureau of the Census, Vehicle Inventory and Use Survey 1997, Oct 1999
- State of California, California Air Resources Board, California LEV Regulations with amendments effective August 14, 2004

- U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004, EPA420-S-04-002, April 2004

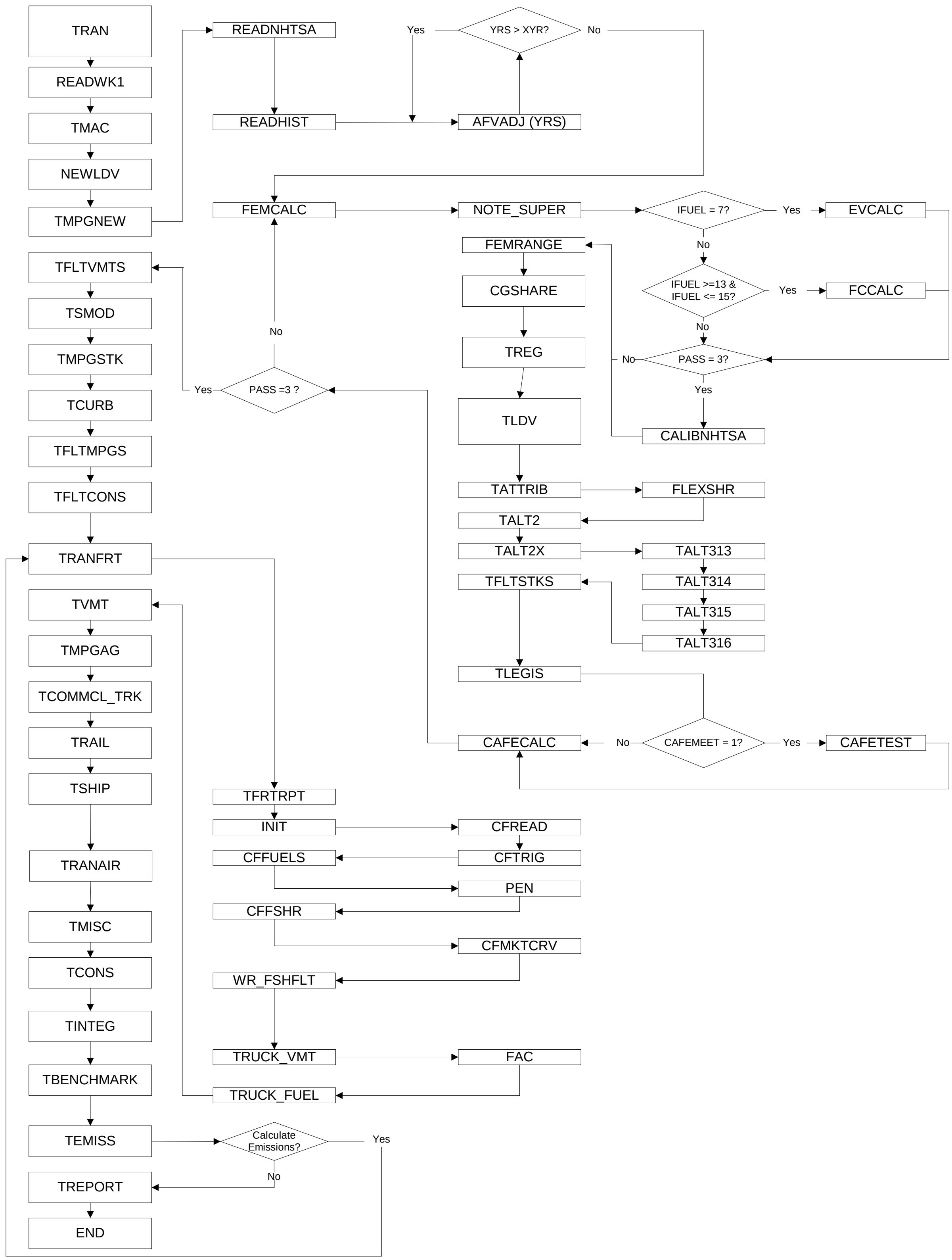
Appendix B. Acronyms

Acronym	Definition
ATV	Advanced Technology Vehicle
AFV	Alternative Fuel Vehicle
AFVADJ	Alternative Fuel Vehicle Adjustment Subroutine
ASM	Available Seat Miles
AEO2007	Annual Energy Outlook 2007
CNG	Compressed Natural Gas
CVCS	Consumer Vehicle Choice Submodule
CAFE	Corporate Average Fuel Economy
RPMD	Domestic Revenue Passenger Miles
EPACT1992	Energy Policy Act of 1992
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FTSAS	Freight Truck Stock Adjustment Submodule
GDP	Gross Domestic Product
GVWR	Gross Vehicle Weight Rating
ICE	Internal Combustion Engine
RPMI	International Revenue Passenger Miles
LDV	Light-Duty Vehicle
LPG	Liquefied Petroleum Gas
LEV	Low Emission Vehicle
MTCS	Manufacturers Technology Choice Submodule
MPG	Miles Per Gallon
MEDM	Miscellaneous Energy Demand Module
NEMS	National Energy Modeling System
Ni-MH	Nickel Metal Hydride
RPM	Revenue Passenger Miles
RTM	Revenue Ton-Miles
SMD	Seat Miles Demanded
SUV	Sport Utility Vehicle
SEDS	State Energy Data System
TMT	Ton Miles Traveled
ULEV	Ultra Low Emission Vehicle
VIUS	Vehicle and Inventory Use Survey
VMT	Vehicle-Miles Traveled
VMTS	Vehicle Miles Traveled Submodule
ZEV	Zero Emission Vehicle

Appendix C. Details of Subroutines used in the Model

A flowchart of the calls made by the Transportation Demand Model (TRAN) is provided Figure 22. The figure shows the first level subroutines on the left side and the subsequent calls made by the first level subroutine in the second, third, and fourth levels. A description of each of these subroutines, in the order presented in Figure 22, is also provided in this section. TRAN is a subroutine that is called by the NEMS main module several times. To optimize the convergence time for the solution some of the subroutines that provide data for TRAN module are only called once. These include subroutines such as READNHTSA and READHIST.

Figure 22. Flowchart of Calls made by TRAN Subroutine



SUBROUTINE: TRAN

Description: The NEMS transportation model encompasses a series of semi-independent models that address different aspects of the transportation sector. Projections are generated through separate consideration of energy consumption within the various modes of transport, including: private and fleet light-duty vehicles; aircraft; marine, rail, and truck freight; and various modes with minor overall impacts, such as mass transit and recreational boating. The model also provides projections of selected intermediate values that are generated in order to determine energy consumption. These elements include estimates of passenger travel demand by light vehicle, air, or mass transit; estimates of the efficiency with which that demand is met; projections of vehicle stocks and the penetration of new technologies; and estimates of the demand for freight transport that are linked to projections of industrial output. The NEMS transportation model consists of four modules developed to represent a variety of travel modes that are very different in design and utilization, save for their intended purpose of conveying passengers and/or freight. The four modules include: Light-Duty Vehicle, Air Travel, Freight Transport (Heavy Truck, Rail, and Marine), and Miscellaneous Energy Use.

Called by: NEMS Main Module; Emissions Module

Calls: TRANLBLS; READWK1; TMAC; NEWLDV; TMPGNEW; TFLTVMTS; TSMOD; TMPGSTK; TCURB; TFLTMPGS; TFLTCONS; TRANFRT; TVMT; TMPGAG;TCOMMCL_TRK; TRAIL; TSHIP; TAIRT; TAIREFF; TMISC; TCONS; TINTEG; TBENCHMARK; TEMISS;TREPORT; TOUTPUT

Equations: 1- 275

SUBROUTINE: READWK1

Description: Reads the spreadsheet input file TRNINPUT.WK1.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: TMAC

Description: Reassigns MACRO data to TRAN model local variables.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: NEWLDV

Description: Segments new light vehicle sales by cars, light trucks less than 8,500 pounds GVWR, and light trucks between 8,500 pounds GVWR and less than 10,000 pounds GVWR.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: TMPGNEW

Description: Starts the fuel economy model, AFV model, and loads data inputs. After completion, the average price of vehicles is computed.

Called by: TRAN

Calls: READNHTSA ; READHIST; AFVADJ; FEMCALC; TREG; TLDV; CAFECALC; CAFETEST

Equations: 1-185

SUBROUTINE: READNHTSA

Description: Reads the NHTSA calibration data file.

Called by: TMPGNEW

Calls: None

Equations: None

SUBROUTINE: READHIST

Description: Reads data for 1990 through the year prior to the MTCS base year from the historical data file. These data are required to support output beginning in 1990. This subroutine assigns historic attribute data to report writer variables, historic technology penetration data to report writer variables, and historic ATV offsets to report writer variables. AFVADJ is called to calibrate current year ATV attributes using current year gasoline data.

Called by: TMPGNEW

Calls: AFVADJ

Equations: None

SUBROUTINE: AFVADJ

Description: Establishes alternate fuel vehicle (AFV) characteristics relative to conventional gasoline. This is an initialization subroutine and calculates the price, weight, fuel economy and horsepower for the AFVs for all historic years through the base year in the MTCS. Most of these are set relative to the gasoline vehicle values. All of the incremental adjustments used for alternative fuels have been exogenously determined and are included in the data input file, trninput.wk1. Sixteen vehicle and fuel types are represented and include conventional gasoline, turbo direct-injection diesel, flex-fuel methanol, flex-fuel ethanol, dedicated ethanol, dedicated CNG, dedicated LPG, CNG bi-fuel, LPG bi-fuel, dedicated electric, diesel/electric hybrid, plug-in gasoline/electric hybrid, gasoline/electric hybrid, methanol fuel cell, hydrogen fuel cell, and gasoline fuel cell.

Called by: TMPGNEW; READHIST

Calls: EVCALC; FCCALC

Equations: 1- 13

SUBROUTINE: FEMCALC

Description: The cost effective market shares of technologies for each vehicle class are determined in this subroutine. The resulting fuel economy, weight, horsepower, and price are calculated. The subroutine then calculates possible market share in the absence of any engineering notes and the basic incremental technology cost by incorporating learning/volume production cost effects. It also determines number of years into production for scientific and design learning and the probabilistic cost change due to scientific learning. The subroutine tracks cumulative penetration as surrogate for cumulative production. It calculates manufacturing cost adjustments and volume production cost adjustments. The mandatory and supersedes engineering notes are then applied to calculate annual horsepower adjustment due to technology introduction alone. Electric hybrid vehicles have an additional price adjustment to account for battery cost. The adjustment is based on the adjusted cost for a midsize gasoline car and is scaled in accordance with the ratio of the weight of the gasoline version of the current vehicle to the weight of a midsize gasoline car. Additional learning curve adjustments are based on the learning curves of Ni-MH, PHEV's, and Li-Ion batteries Consumer performance demand is adjusted downward as HP/Weight ratio increases so that performance gains cannot continue indefinitely. The subroutine calculates the horsepower demand required to maintain a minimum HP/Weight ratio and adjusts fuel economy up or down in accordance with the sum of consumer driven horsepower adjustment and any horsepower giveback.

Called by: TMPGNEW

Calls: NOTE_SUPER; EVCALC; FCCALC; FEMRANGE; CALIBNHTSA;

Equations: 1-185

SUBROUTINE: NOTE_SUPER

Description: This subroutine ensures that related technologies do not exceed a specific cumulative penetration. Although individual technology penetrations are controlled via the basic allowable maximum penetrations, the combined penetrations of two or more technologies are controlled here. Accordingly, this subroutine will never add market penetration, but can subtract excess penetration initially allocated to a superseded technology. The maximum allowable market penetration for a related technology chain is taken as the greater of the maximum penetrations for each component technology and can thus be adjusted externally through the maximum market penetration matrix in the TRNINPUT.WK1 file. Even though the maximum penetration for the chain may exceed that of an individual technology, no problems arise since the penetration of that individual technology is constrained by its specific maximum in the individual technology market penetration algorithms. This subroutine starts the fuel economy model, AFV model, and loads data inputs. After completion, the average price of vehicles is computed.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: EVCALC

Description: Calculates battery costs and related quantities for electric vehicles. Applies learning curves to battery prices and aggregates battery price based on Lead acid, Ni-MH, and Li-Ion market share and adds to vehicle price. The subroutine also calculates vehicle weight as a function of battery weight and market share, and vehicle fuel economy as a function of vehicle weight.

Called by: FEMCALC

Calls: None

Equations: 1- 13

SUBROUTINE: FCCALC

Description: Calculates several parameters that include: base fuel cell cost, and input fuel cell costs in $/kW, base cost of an onboard battery to start the vehicle, and retail price of the fuel cell and battery at 1.75 times cost plus $1,500 amortization cost. The vehicle price is then adjusted to include price of the fuel cell and battery. The routine also estimates fuel cell vehicle fuel economy using estimates of gallons per mile per 1000 pounds of vehicle weight.

Called by: FEMCALC

Calls: None

Equations: 1- 13

SUBROUTINE: CALIBNHTSA

Description: Called to calibrate factors that are based on historical NHTSA data through the last available data year. All ATV calibration factors are set to equal corresponding gasoline vehicle calibration factors to preserve the differential relationships between gasoline vehicles and ATVs.

Called by: FEMCALC

Calls: None

Equations: None

SUBROUTINE: FEMRANGE

Description: Vehicle range estimates are calculated in this subroutine.

Called by: FEMCALC

Calls: None

Equations: 1-185

SUBROUTINE: CGSHARE

Description: This subroutine calculates light duty vehicle size class shares, average horsepower, and weight for cars and light trucks.

Called by: FEMCALC

Calls: None

Equations: 1-185

SUBROUTINE: TREG

Description: This subroutine estimates the regional values for fuel demand, fuel cost, VMT demand, VMT shares, and sales of non-fleet vehicles. It calculates regional shares of fuel, regional income, regional driving demand, regional VMT shares, and regional sales of non-fleet cars and light trucks.

Called by: TMPGNEW

Calls: None

Equations: 1-185

SUBROUTINE: TLDV

Description: This subroutine initiates the vehicle choice routine

Called by: TMPGNEW

Calls: TATTRIB; TALT2; TALT2X; TFLTSTKS; TLEGIS

Equations: 1-185

SUBROUTINE: TATTRIB

Description: This subroutine adjusts the LDV attributes such as MPG, price, range, and horsepower so they can be used throughout the model. The LDV attributes for gasoline are calculated in the subroutine CGSHARE. The subroutine determines vehicle price of ATVs to reflect differing price structures depending on whether they are in low or high volume production. As production moves from low to high volume, prices will decline. It estimates the ATV production volume price point using BASE year price differentials, constrained at both ends by high and low production volume prices (i.e., price can never drop below high production volume price or rise above low volume production price). It then combines domestic & import ATV attributes. The routine assumes the same domestic versus import sales shares as gasoline to provide for an equitable comparison of attributes across vehicle types. It takes into account the EPACT Tax incentives which began in 1994, hybrid vehicle income tax deduction, and the 2005 EPACT Tax Incentives. It bypasses the EPACT routine when PSPR equals zero to ensure that "non-allowable" vehicle classes do not end up with negative prices. All non-zero prices should be larger than the maximum credit, so an abort switch is also included that is activated in any other instances where the vehicle price goes negative.

Called by: TLDV

Calls: FLEXSHR

Equations: 1-185

SUBROUTINE: FLEXSHR

Description: Subroutine FLEXSHR calculates the VMT shares for flex-fuel and bi-fuel vehicles. After parameters for minimum alternative fuel use in flex-fuel and bi fuel vehicles are set, it calculates an arithmetic average methanol price. It then calculates regional price ratio for minimum alternative fuel use which is used to fill alternative fuel station availability array. The subroutine uses an alternative fuel choice logit model based on fuel price and fuel availability. It can also set an aggressive E-85 penetration with no consideration regarding fuel availability. It then calculates the national average alternative fuel use percentage for flex and bi fuel vehicles. Weighted MPG and VMT shares for PHEV's are then calculated. Since the MPG for the gasoline engine and the electric motor are very different VMT shares are weighted with the MPGs.

Called by: TATTRIB

Calls: None

Equations: 1-185

SUBROUTINE: TALT2

Description: This subroutine calculates regional fuel availability for highway fuels that include gasoline, diesel, ethanol, methanol, CNG, LPG, electricity, and hydrogen. Estimates the vehicle stocks used to calculate the number of refueling stations by weighting flex-fuel and bi-fuel at 25%. Calculates the total number of refueling stations needed based on an historic ratio of vehicle stock per refueling station. Regionalizes the predicted stations by regional vehicle sales and estimates fuel availability.

Called by: TLDV

Calls: None

Equations: 1-185

SUBROUTINE: TALT2X

Description: This subroutine calculates Level 1 and Level 2 light vehicle market penetration estimates in the AFV model. Increases flex fuel make/model availability when E-85 is price competitive. Fuel availability and range are calculated in call statements.

Called by: TLDV

Calls: TALT313; TALT314; TALT315;TALT316

Equations: 1-185

SUBROUTINE: TALT313

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for methanol flex vehicles

Called by: TALT2X

Calls: None

Equations: 1-185

SUBROUTINE: TALT314

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for ethanol flex vehicles.

Called by: TALT2X

Calls: None

Equations: 1-185

SUBROUTINE: TALT315

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for CNG bi-fuel vehicles.

Called by: TALT2X

Calls: None

Equations: 1-185

SUBROUTINE: TALT316

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for LPG bi-fuel vehicles.

Called by: TALT2X

Calls: None

Equations: 1-185

SUBROUTINE: TFLTSTKS

Description: This subroutine calculates sales and stocks of fleet vehicles used in business, government, and utility. It calculates the fleet acquisitions for cars and light trucks. It combines Federal and State EPACT regulations (EPACTREG) into one government mandate for both by averaging based on stocks from each. It calculates fleet stock by fleet type, technology, and vintage and assigns fleet vehicles of retirement vintage to another variable, prior to removal from the fleet. It uses: 1) business = 5 years 2) government = 6 years, and 3) utilities = 7 years. The total surviving vehicles, by vehicle, fleet type, and engine technology are calculated.

Called by: TLDV

Calls: None

Equations: 1-185

SUBROUTINE: TLEGIS

Description: This subroutine adjusts vehicle sales and market shares to reflect legislative mandates on sales of ZEVs and ULEVs. The vehicle group-average technology penetration rate (%) and cost are calculated and summed across domestic and imports to produce market penetration rate (%) and average cost tables, but only for gasoline vehicles. It then calculates regional vehicle sales, by technology, within 6 market classes. The subroutine then calculates mandated sales of ZEVs by participating states including Massachusetts, Maine, Vermont, Connecticut , Rhode Island, New York, New Jersey, California, and Washington. It then calculates ZEVP legislative alternative sales by region. Additional ATV shares based on maximum allowable ZEV hybrid credits are also calculated including hybrid vehicles, fuel cell gasoline, and fuel cell methanol vehicles. After estimating the total adjusted vehicle sales calculations are made for new absolute market shares for each vehicle technology.

Called by: TLDV

Calls: None

Equations: 1-185

SUBROUTINE: CAFECALC

Description: This subroutine combines fuel economies from all vehicles and checks if the combined car and light truck MPG is greater than the CAFE standard.

Called by: TMPGNEW

Calls: None

Equations: 1-185

SUBROUTINE: CAFETEST

Description: This subroutine ensures that CAFE standards are met by increasing the sales of hybrid (gasoline and diesel) and diesel cars and light trucks if the CAFEMEET switch is set.

Called by: TMPGNEW

Calls: None

Equations: 1-185

SUBROUTINE: TFLTVMTS

Description: This subroutine calculates VMT for fleets.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TSMOD

Description: This subroutine calculates light vehicle stocks by technology type. Total new vehicle sales by technology and fraction of a given vintage vehicles that survive are calculated. The routine adds retired fleet vehicles to the appropriate vintage of the non-fleet population and calculates total stocks of cars and light trucks. Vehicle stock by fuel type and LDV shares of each technology are also calculated.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TMPGSTK

Description: This subroutine calculates light vehicle stock MPG by technology and also calculates new car and light truck sales for 6 market classes. It computes the average MPG of the 14 AFVs technologies, average new car and light truck MPG, and stock MPG for cars and light trucks. It also calculates total miles driven by each type of vehicle (cars and light trucks) by vintage, household vehicle stock MPG for cars and light trucks, average MPG of light duty vehicles, average vehicle MPG by technology, and average car and light truck MPG by technology.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TCURB

Description: This subroutine calculates the stock average weight (by vintage) of cars and light trucks.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TFLTMPGS

Description: This subroutine calculates MPG for new cars and light trucks as well as fleet stock. It adjusts the vintage array of fleet stock efficiencies to account for new additions. The routine then calculates overall fleet average MPG by fuel technology.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TFLTCONS

Description: This subroutine calculates fuel consumption of fleet vehicles by regions.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TRANFRT

Description: This subroutine calculates fuel consumption for freight trucks, classes 3-8. The subroutine applies scrappage rates to truck populations, excluding new trucks. It then calculates stock transfers from fleet to non fleet ownership and processes new trucks sales from the macroeconomic model and distributes new truck sales into market classes and ownership classes. It then estimates fuel shares of new truck sales under technology penetration assumptions. Aggregate VMT and per truck VMT are estimated and used to calculate fuel demand by sector and vintage.

Called by: TRAN

Calls: TFRTRPT; INIT; CFFUELS; CFFSHR;WR_FSHFLT; TRUCK_VMT; TRUCK_FUEL

Equations: 219-273

SUBROUTINE: TFRTRPT

Description: Report writing subroutine that supports the freight model.

Called by: TRANFRT

Calls: None

Equations: None

SUBROUTINE: INIT

Description: The subroutine initializes variables in TRANFRT and assigns variables for each run. Copies inputs for prices and macroeconomic output from NEMS global data call for each year. Summarizes Economic Output into 12 Sectors 1) chemicals, rubber and plastic 2) primary metals 3) processed food 4) paper products 5) petroleum products 6) stone, clay, glass, and concrete 7) metal durables 8) other manufacturing 9) agriculture 10) mining 11) utility 12) government.

Called by: TRANFRT

Calls: CFREAD; CFTRIG

Equations: 219-273

SUBROUTINE: CFREAD

Description: Reads input for the freight model from spreadsheet input file afstock.wk1 including variables such as fleet stocks by fuel and vintage, non- fleet VMT per truck by fuel and vintage, new truck sales, Class 4-6 shares of Class 4-8 trucks etc.

Called by: INIT

Calls: None

Equations: 219-273

SUBROUTINE: CFTRIG

Description: Determines the trigger price at which each technology is considered viable. For all emission technologies, the trigger price is set negative so it will penetrate.

Called by: INIT

Calls: None

Equations: 219-273

SUBROUTINE: CFFUELS

Description: Implements fuel-saving technologies that include various technologies that are adopted when commercially available and are cost effective. The subroutine sets a market penetration price sensitivity factor and applies penetration criteria such as: 1) technology availability, 2) technology applicability to the fuel/market class, and 3) economical trigger price or required by regulation. It subtracts the effects of technologies being superseded by more advanced technologies. It calculates combined market share of the chosen technology and more advanced technologies that are competing with it. It then reduces market share of next less advanced technology due to penetration of competing higher technologies. In other words, the market share of a less advanced technology is assumed to apply to that part of the market not yet taken by the more advanced technologies. Determines combined MPG improvement of fuel-saving technologies by weighting each technology's improvement by its market share. In the frozen technology scenario (assumes that regulated efficiency changes due to changes in emission standards) technology adoption is stopped after 2010.

Called by: TRANFRT

Calls: PEN

Equations: 219-273

SUBROUTINE: PEN

Description: Market penetration equation: s-shaped logistical equation to estimate market penetration over time. Outputs market penetration fraction

Called by: CFFUELS

Calls: None

Equations: 219-273

SUBROUTINE: CFFSHR

Description: Determine the share of each fuel for new truck sales. The results of this subroutine can be altered by 1) changing the trigger year, 2) changing the slope, or 3) altering the base year or end year share. Cost of diesel per mile relative to other fuels is considered to derive a logistic penetration curve parameter.

Called by: TRANFRT

Calls: None

Equations: 219-273

SUBROUTINE: CFMKTCRV

Description: Returns SLOPE and Mid-Point on Logistic penetration curve

Called by: CFFSHR

Calls: None

Equations: 219-273

SUBROUTINE: WR_FSHFLT

Description: Calculate fuel shares of the entire truck stock, excluding new trucks, for comparison with the fuel shares assigned in subroutine CFFSHR

Called by: TRANFRT

Calls: None

Equations: 219-273

SUBROUTINE: TRUCK_VMT

Description: Estimates aggregate VMT growth by economic sector by factoring VMT per truck such that the total VMT of the stock, including new trucks, matches the aggregate across sectors. Calculates aggregate VMT growth based on growth in real economic output by sector.

Called by: TRANFRT

Calls: FAC

Equations: 219-273

SUBROUTINE: FAC

Description: Calculates the Freight Adjustment Coefficient which represents the relationship between the value of industrial output and freight demand in terms of VMT.

Called by: TRUCK_VMT

Calls: None

Equations: 219-273

SUBROUTINE: TRUCK_FUEL

Description: Calculate fuel demand from VMT and MPG by market class, fuel and fleet/nonfleet. This subroutine is called by TRANFRT during history years. It determines fuel consumption in gallons gasoline equivalent and passes VMT to TRAN for benchmarking.

Called by: TRANFRT

Calls: None

Equations: 219-273

SUBROUTINE: TVMT

Description: This subroutine calculates total personal light vehicle VMT. Calculates cost of driving per mile, unadjusted VMT per licensed driver, total VMT for light duty vehicles, VMT for personal travel, and VMT by technology

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TMPGAG

Description: This subroutine summarizes personal and fleet light vehicle sales and MPG by technology. It combines fleet and non-fleet cars and fleet and non-fleet light trucks and calculates total sales. Sales shares for each technology within cars and light trucks are calculated and summed. A harmonically averaged new car and light truck MPG is calculated separately. It also calculates fleet average stock car and light truck MPG, fleet average stock vehicle MPG, and fuel economy and sales separately for personal and fleet vehicles.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TCOMML_TRK

Description: Calculates fuel consumption by Class 2b vehicles (8,500 to 10,000 lbs GVWR).Distributes historical stock values across vintages and updates stocks to reflect scrappage and new sales and calculate total Class 2b stocks, vehicle miles traveled, and growth in travel (which is estimated as the weighted average growth of industry sector output for 1) agriculture, 2) mining, 3) construction, 4) manufacturing, 5) utilities, and 6) personal travel). It then calculates aggregate sales weighted new commercial light truck MPG and VMT weighted commercial light truck stock average MPG.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TRAIL

Description: Calculates energy consumption by rail by region and fractional change in fuel efficiency.

Called by: TRAN

Calls: None

Equations: 219-213

SUBROUTINE: TSHIP

Description: This subroutine calculates energy use for shipping. It calculates the international shipping fuel use split by the 2 fuel types: distillate and residual. It calculates ton-miles traveled for domestic shipping and the fractional change in fuel efficiency.

Called by: TRAN

Calls: None

Equations: 219-273

SUBROUTINE: TAIRT

Description: This subroutine calculates total seat miles demanded for domestic and international air travel as well as revenue ton miles for air freight. After initializing aircraft sales, active aircraft, and stock for narrow body, wide body, and regional jets it calculates the yield (ticket price), load factors, revenue passenger miles for domestic and international by aircraft type. It also calculates dedicated revenue ton miles of air freight, available seat-miles demanded-domestic and international, demand for available seat-miles, and revenue ton miles.

Called by: TRAN

Calls: None

Equations: 186-218

SUBROUTINE: TAIREFF

Description: This subroutine calculates aircraft sales, stocks, new technology penetration, efficiency improvement, and energy use for air travel. It calculates total fuel efficiency improvements for aircraft for domestic & international combined. It calculates seat-miles demanded incorporating revenue ton-miles, jet fuel demand in gallons, aviation gas demand, and regionalizes commercial jet fuel and aviation gasoline.

Called by: TRAN

Calls: None

Equations: 186-273

SUBROUTINE: TMISC

Description: This subroutine calculates miscellaneous transportation energy use from the military, mass transit (buses and rail), recreational boating, and lubricant demand. It also calculates bus efficiency in BTU/Passenger Miles, bus energy demand by segment, and regionalizes commuter bus energy demand by regional population. It also calculates demand growth and regional recreational boat demand by population. It calculates regional lubricant demand by summing VMT shares for freight and light duty vehicles.

Called by: TRAN

Calls: None

Equations: 219-273

SUBROUTINE: TCONS

Description: This subroutine combines VMT and efficiencies by technology to estimate fuel consumption for light duty vehicles by fuel type. It calculates gasoline, methanol, ethanol, CNG, and LPG consumption as well as electric, liquid hydrogen and diesel consumption. It sums total consumption of all fuels.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TINTEG

Description: This subroutine calculates total transportation energy consumption by fuel type for all modes.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TBENCHMARK

Description: This subroutine is used for benchmarking transportation specific consumption variables. It benchmarks consumption by fuel type for various transport modes including light duty vehicles, commercial light trucks, freight trucks by fuel type and market class, domestic shipping, international shipping, rail, military, and mass transit. It also is used to benchmark commercial fleet vehicle consumption by fuel type and VMT by technology for commercial fleet, commercial light trucks, and freight truck as well as TMT for rail and ship.

Called by: TRAN

Calls: None

Equations: 1-185

SUBROUTINE: TEMISS

Description: This subroutine calculates vehicle emissions by the three criteria pollutants: hydrocarbons, carbon-monoxide ,and nitrous oxides. The routine sums up total VMT across market classes, reads emission factors in grams per mile and initializes emissions. It aggregates emissions by age (or vintage) for report writer by converting the weight of emissions in grams to million metric tons.

Called by: TRAN

Calls: TRANFRT

Equations: 1-273

SUBROUTINE: TREPORT

Description: This subroutine generates the parameters used in the report writer. It generates tables for total freight truck VMT and energy efficiency index. It calculates energy use by fuel type within light duty vehicles.

Called by: TRAN

Calls: None

Equations: None

FUNCTION: FUNCMAX

Description: This function returns the maximum possible market share given previous period values. It is intended to reflect institutional factors leading to production lags.

Called by: FEMCALC

Calls: None

Equations: 1-185

FUNCTION: HARMONIC_MEAN

Description: This function computes a harmonic mean, used for averaging fuel economy measured in miles per gallon. The calculation essentially takes the reciprocal of MPG, or efficiency and computes the quantity weighted average and then converts the result back to a miles-per-gallons by taking the reciprocal

Called by: TRANFRT; TFRTRPT

Calls: None

Equations: 219-273

Appendix D. Input/Output Variables in Transportation Model

Variable Name	Variable Description
Transportation specific macro variables	
TMC_PGDP	GDP deflator
TMC_CPI	Consumer price index
TMC_EX	Real exports
TMC_IM	Real imports
NEWCARS	New car sales
NEWCLS12A	New light truck sales, class 1-2A
TMC_GFML	Federal government purchases - defense
INC00$NP	Disposable income per capita (2000$)
INC00$NPT	Disposable income per capita (1000's OF 2000$)
INC00$16	Disposable income per capita 16+ (2000$)
Global definitions	
YRS	Actual model year (1989+curiyr)
N	Trans variable for curiyr
LASTID	Parameter for index describing number of technologies
HITECHRUN	Switch to use the alternative LDV technology scenario
MAXGROUP	Number of light duty vehicle size groups (domestic/import, car/truck)
MAXVTYP	Number of light duty vehicle types (car/truck)
MAXCLASS	Number of vehicle classes in each light duty group
MAXTECH	Number of light duty vehicle technologies
MAXFUEL	Number of light duty vehicle fueling configurations
MAXATV	Number of light duty vehicle non-gasoline fueling configurations
MAXNOTE	Number of light duty vehicle engineering notes
MAXAGE	Number of light duty vehicle vintages
MAXLTAGE	Number of commercial light truck vintages
MAXFTYP	Number of light duty fleet types (private/government/utility)
MAXATYP	Number of aircraft types (narrow body/wide body)
MAXACTECH	Maximum number of aircraft technologies
TOPACAGE	Maximum aircraft age (47 years)
MAXNMLM	Number of coefficients for the nested multinomial logit model
MAXFUEL2	Number of distinct fueling station types
FUELYRS	Number of years of fueling station data
GAS	Vehicle fueling configuration index value for gasoline
FCLO	Vehicle fueling configuration minimum fuel

	cell index value
FCHI	Vehicle fueling configuration maximum fuel cell index value
BASE	FEM attribute index value for the base year
PREV	FEM attribute index value for the previous year
CURRENT	FEM attribute index value for the current year
BYR	Base year for TRAN
XYR	Base year for MTCS
LYR	Last forecast year
MIDSIZE	Vehicle class index value for a midsize car
DOMCAR	Vehicle group index value for a domestic car
MAXRAILREGN	Number of rail regions (east/west)
ICL	Vehicle market class
IGP	Vehicle group
IVTYP	Vehicle type
ITECH	Technology type
INOTE,IATV,IYR	Engineering note, ATV type, and year indices
IFUEL,IFUELX	Fuel type indices
IFUEL	Fuel engine technology: 1- Gasoline, 2-TDI Diesel, 3-Ethanol flex, 4-Ethanol, 5-Plug-in gasoline hybrid, 6-Methanol flex, 7-Electric, 8-Diesel hybrid, 9-CNG bifuel, 10-LPG bifuel, 11-CNG, 12-LPG, 13-Fuel cell methanol, 14-Fuel cell hydrogen, 15-Fuel cell gasoline, 16-Gasoline hybrid
IFTYP,IFTYP2	Fleet and aircraft type indices
IREGN,IRAILREGN,IAGE	Region and age indices
I,J,K	Miscellaneous indices
SIGN	Positive or negative indicator
ROUNDOFF_ERROR	Rounding error buffer
NUMTECH	Actual number of input technologies
CARFLG	Alternate Technology Vehicles introduction year for car classes
TRKFLG	Alternate Technology Vehicles introduction year for truck classes
TECHID	Technology identification number
TECHLABEL	Technology label
SYS_AFFECT	Vehicle system affected
TECHFEHT	Incremental change in fuel economy (percent)-high technology case
TECHCOSTAHT	Absolute incremental change in cost ($)-high technology case
TECHCOSTRHT	Relative incremental change in cost ($/lb)-high technology case
TECHMKTSHARELT	Technology base and maximum market shares-low technology case
DEL_FE	Incremental fractional change in fuel economy
DEL_COSTABS	Absolute incremental change in cost ($)
DEL_COSTWGT	Relative incremental change in cost ($/lb)
DEL_WGTABS	Absolute incremental change in weight (lb)
DEL_WGTWGT	Relative incremental change in weight (lb/base

	vehicle lb)
FRSTYEAR	First year of technology introduction
DEL_HP	Incremental fractional change in horsepower
COEFF_SCI	Coefficient for science learning curve
COEFF_MAN	Coefficient for manufacturing learning curve
COEFF_DES	Coefficient for design learning curve
TECH_APPLIC	Fueling type applicability indicator
VMT	Annual VMT by vintage
GROUPLABEL	Vehicle group labels
CLASSLABEL	Vehicle class labels
CLASSBASEYR	Vehicle class first year of sales
CLASSFLAG	Vehicle class applicability flag
FE	Vehicle class base fuel economy
WEIGHT	Vehicle class base curb weight
PRICE	Vehicle class base price (low volume)
PRICEHI	Vehicle class base price (high volume)
HP	Vehicle class base horsepower
VOLUME	Vehicle class base interior volume
VALUEPERF	Vehicle class base performance value
PERFFACT	Vehicle class base performance factor
TANKSIZE	Vehicle class base fuel tank size
PERFCAP	Vehicle class performance cap
USEDCAP	Fraction of vehicle class performance cap used
MKT_PEN	Technology market share
MKT_MAX	Technology market share cap
SUPERSEDES	Supersedes engineering note parameters
REQUIRES	Required engineering note parameters
SYNERGY	Synergy engineering note parameters
SYNR_DEL	Synergy engineering note parameters
MANDYEAR	Mandatory engineering note parameters
MANDMKSH	Mandatory engineering note parameters
MAND_ORIDE	Mandatory engineering note parameters
NUM_REQ	Engineering note counter
NUM_SUP	Engineering note counter
NUM_MAN	Engineering note counter
NUM_SYN	Engineering note counter
PAYBACK	Payback period
DISCOUNT	Discount rate
REG_COST	CAFE non-compliance fine
PRINT_FE,PRINT_TECH,PRINT_DIAG	Print flags
CAFE_STAND	CAFE standards
CAFE_ACT	Actual CAFE achieved
CLASS_SHARE	Vehicle class market shares (within vehicle groups)
OCLASS_SHARE	Vehicle class market shares (across all vehicle groups)
COEF_A	ATV Y-intercept or alpha coefficient
COEF_B	ATV fuel price elasticities
COEF_C	ATV income elasticities
COEF_P	ATV vehicle price elasticities
AFVADJHP	ATV horsepower differential

AFVADJRN	ATV range differential
AFVADJFE	ATV fuel economy differential
AFVADJWT	ATV weight differential
AFVADJPR	ATV price differential (1/2 low volume car/truck,3/4 High volume car/truck)
LEADACID_COST	Lead acid battery cost learning curve
NIMHY_COST	Nickel metal hydride battery cost learning curve
LION_COST	Lithium ion battery cost learning curve
NIMHY_MKTSH	Nickel metal hydride battery market share for Electric Vehicles
LION_MKTSH	Lithium ion battery market share for Electric Vehicles
LION_HEVSH	Lithium ion battery market share for Hybrid Electric Vehicles
LION_PHEVSH	Lithium ion battery market share for Plug-in Hybrid Electric Vehicles
HEV_BCST	Weighted average battery cost learning curve for Hybrid Electric Vehicles
PHEV_BCST	Weighted average battery cost learning curve for Plug-in Hybrid Electric Vehicles
FUELCELL_COST	Fuel cell cost learning curves
TEC_ORNL	Technology cost
MKT_PENF	Technology penetration aggregated over class
AVCOST	Technology cost aggregated over class
MMSWITCH	ATV make/model availability switch
MMAVAIL	ATV make/model availability
MMAVAIL1	INITIAL ATV make/model availability
X210	ATV calibration coefficients
X211	ATV calibration coefficients'
X21	ATV NMLM level 2, vehicle price
X22	ATV NMLM level 2, fuel cost
X23	ATV NMLM level 2, range
X24	ATV NMLM level 2, battery replacement
X25	ATV NMLM level 2, acceleration
X26	ATV NMLM level 2, EV home refueling
X27	ATV NMLM level 2, maintenance cost
X28	ATV NMLM level 2, luggage space
X29	ATV NMLM level 2, make/model availability
BETAFA2	ATV NMLM level 2, fuel availability 1
BETAFA22	ATV NMLM level 2, fuel availability 2
X11	ATV NMLM level 1, technology set general cost
X31	ATV NMLM level 3, multi-fuel generation cost
FAVAIL	Fuel availability by technology, region, year
INITSTA	Initial refueling stations by fuel, year, region
STA_RAT	Refuel stations per vehicle stock
MAINTCAR	Car maintenance cost by technology, market class
MAINTTRK	Truck maintenance cost by technology, market

	class
LUGGCAR	Luggage space by technology, market class
LUGGTRK	Luggage space by technology, market class
PRICE_HY	Regional hydrogen price from EE/RE ,ANL
TTLZEV	Total (%) mandated ZEV sales
ATPZEV	Total (%) mandated gas hybrid and methanol/gas fuel cell vehicles
ZEV	Total (%) mandated electric vehicles
ZFCV	Total (%) mandated hydrogen fuel cell vehicles
ZEVCARCD1	% CD1 cars covered under ZEV mandate
ZEVCARCD2	% CD2 cars covered under ZEV mandate
ZEVCARCD9	% CD9 cars covered under ZEV mandate
ZEVLTKCD1	% CD1 light trucks covered under ZEV mandate
ZEVLTKCD2	% CD2 light trucks covered under ZEV mandate
ZEVLTKCD9	% CD9 light trucks covered under ZEV mandate
FLTCRAT	Fraction of total car sales attributed to fleets
FLTTRAT	Fraction of total truck sales attributed to fleets
FLTCSHR	Fraction of fleet cars purchased by a given fleet type
FLTTSHR	Fraction of fleet trucks purchased by a given fleet type
SURVFLT	Survival rate of given vintage
FLTSSHR	% Of fleet vehicle by fleet type, size, vehicle type
FLTAPSHR1	Fraction of each fleets' purchases which are AFV’s
FLTECHSHR	Alternative technology shares for government and utility fleets
FLTECHSHRH	Historical alternative technology shares fleets
EPACTREG	EPACT regulatory AFV sales percentage mandates
KFLTSIZE	Constants for Q(n) reverse cumulative distribution used for fleet size
FLTSTKC	1990-2003 car fleet stock
FLTSTKT	1990-2003 light truck fleet stock
VINTSHR	Vintage shares
FLTVMTYR	Annual miles of travel per vehicle
FLTTOTMPG	Total fleet mpg
TOTFLTCAR	Total fleet car
FLTMPGTOT2	Total fleet mpg
LDV Stock Accounting Submodule	
SURVP	Survival rates for cars
SURVLT	Survival rates for light trucks
PVMT	Car VMT per vintage
LVMT	Light truck VMT per vintage
CDF	Degradation factor for car
LTDF	Degradation factor for light truck

PASSTK90GAS	Vehicle stock gas 1990-2000
PASSTK90DES	Vehicle stock diesel 1990-2000
CMPGSTKGAS95	On road mpg 1990 gasoline
STKAVGWGT	Stock average weight by vintage
HIST_SHARE	Vehicle class market shares (within vehicle groups)
LDV VMT Stock Submodule	
BETACOST	Beta coefficient price effect
BETAINC	Beta coefficient income effect
BETAVMT	Beta coefficient VMT effect
ALPHA	Beta constant for LDV VMT equation
RHO	Rho constant
VMTLD	VMT per licensed driver
LICDRIVER	Licensed drivers
LICRATE	Licensing rate of population 16+
VMTLDV	Total LDV (<8,500 lbs. GVWR) VMT
VMTEE	Total household LDV VMT
COSTMI	Fuel cost of driving 1 mile (2004 cents per gallon)
VMTECH	Total VMT by vehicle type (16)
Commercial light truck Submodule	
CLTVMTDIST	Distribution of VMT by Industry
CLTMPGV	Class 2b fuel economy by vintage
CLTVMTV	Class 2b vehicle travel by vintage
CLTSTKIN	Initial CLT stock by year, 1990:2000
CLTSURV	Survival fraction from prior year by vintage
CLTVINTSHR	Base year (2000) stocks by vintage as shares
CLTSTK	CLT stocks by vintage, cur/lag year
CLTSIC	SIC output averaged across 6 categories
CLTVMT	VMT by vintage, cur/lag year
CLTBTUT	Total CLT consumption by Btu
CLTGAL	CLT consumption in gals
CLTMPG	CLT stock mpg by vintage, cur/lag year
BCLTBTU	Regional CLT fuel consumption Btu
CLTVMTT	Total CLT VMT
CLTVMTVA	VMT by vintage, cur/lag year
NEWCLS2B	New Class 2b vehicles
AIR DEMAND MODULE	
Air Energy Use	
QJETR	Total jet fuel demand (quads)
JFBTU	Jet fuel demand (Btu)
AGDBTU	General aviation gasoline demand
Aircraft Efficiency	
SMPGD	2002 domestic aircraft efficiency. By type and vintage
SMPGI	2002 international aircraft efficiency. By type and vintage

NEW_SMPG	New aircraft efficiency by type
SMPG	Average efficiency by aircraft type and vintage
SMPG_AVG	Average efficiency by aircraft type
ASMPGT	Aircraft efficiency after technology ad (1 = new, 2 = Stock)
ASMAC	ASM per aircraft by type
Aircraft Technology Penetration	
TRIGYEAR	Year of technology introduction by aircraft type
TRIGPRICE	Jet fuel price in $/gal necessary for cost effectiveness
EFFIMP	Fractional improvement associated w/ a given technology
TIMECONST	Time constant
BASECONST	Base constant
Revenue Passenger Miles (RPM)	
RPMD	Domestic revenue passenger miles by aircraft type
RPMI	International revenue passenger miles by aircraft type
RPMTD	Total domestic revenue passenger miles
RPMTI	Total international revenue passenger miles
RPMTOT	Total revenue passenger miles (domestic + international)
SRPMD	Domestic share-RPM
SRPMI	International share-RPM
DUMMYD	DUMMY array - independent variable for domestic RPM
DUMMYI	DUMMY array - independent variable for int RPM
RPM_MAXCAP	Infrastructure constraint
MC_COMMFLSP_REF	Common floor space, miscellaneous includes airports
Load Factors	
LFDOM	Load factor for domestic travel by aircraft type
LFINTER	Load factor for international travel by ac type
LFDOMAVG	Average load factor for domestic travel
LFINTAVG	Average load factor for international travel
Available Seat Miles (ASM)	
ASMD_DOM	Domestic ASM by aircraft type
ASMD_INT	International ASM by aircraft type
ASMDEMD	Total ASM by aircraft type
ASM_DOM	Total domestic available seat miles
ASM_INT	Total international available seat miles
SMDEMD	Total available seat miles
SMD_TOT	Total available seat miles + revenue ton miles

Aircraft Sales	
PCTAC_SALES	Aircraft sales growth factor (0.8)
SHR_NEW_STK	Share of new aircraft sales by type
Aircraft Stocks	
STKAC2002	2002 passenger aircraft stock by type and vintage
STKCAC2002	2002 cargo aircraft stock by type and vintage
STKAC_PARKED02	2002 parked aircraft stock by type and vintage
STKCAC_PARKED02	2002 parked cargo aircraft stock by type and vintage
STK_PASS	Passenger aircraft stock by aircraft type and vintage
STK_PASS_TOT	Passenger aircraft stock total by aircraft type
STKPASS_ACTIVE_TOT	Passenger aircraft total active stock by aircraft type
STKPASS_PARKED_TOT	Passenger aircraft total parked stock by aircraft type
STK_CARGO_TOT	Total aircraft cargo stock by aircraft type
STK_SUP	Aircraft stock (passenger +cargo) by aircraft type and vintage
STK_SUP_TOT	Aircraft stock (passenger +cargo) total by aircraft type
SURVAC	Aircraft survival curves by aircraft type
PCT_PARKED	Percent of aircraft parked by type vintage
Air Freight	
RTM	Total revenue ton miles
RTMD	Demand for revenue ton miles
SRTMD	Demand share - rtm
RTMAC	RTM per aircraft by type
RTM_FAC	Revenue ton miles growth factor
EQSM	Factor to convert rtm to equivalent seat miles
Yield	
YIELD	Revenue per passenger mile
LCPMD	Domestic yield lower bound
LCPMI	International yield lower bound
Coefficients for air model	
Domestic yield	
ALPHAYD	Beta constant
RHOYD	Rho coefficient
BETAFUELD	Beta fuel price
BETATIMED	Beta time
International yield	
ALPHAYI	Beta constant
RHOYI	Rho coefficient
BETAFUELI	Beta fuel price
BETATIMEI	Beta time

Domestic RPM demand	
ALPHARD	Beta constant
RHORD	Rho coefficient
BETARPMD	Beta RPM
BETAINCD	Beta income
BETAYLDD	Beta yield
BETADMYD	Beta dummy
International RPM demand	
ALPHARI	Beta constant
RHORI	Rho coefficient
BETARPMI	Beta RPM
BETAINCI	Beta income
BETAYLDI	Beta yield
BETADMYI	Beta dummy
New aircraft sales	
ALPHASAL	Beta constant
BETARPMS	Beta RPM
BETAGDPS	Beta GDP
BETATIMS	Beta time
Revenue ton miles (rtm) demanded	
ALPHARTM	Beta constant
RHORTM	Rho coefficient
BETAPJFR	Beta fuel price
BETAXIMR	Beta export/import
FREIGHT TRANSPORT MODULE	
Rail Freight Model	
FACR	Rail freight adjustment factors
RTMT88	Billion ton-miles traveled 1988
TSICGR	Industrial output growth
FERAIL	Freight rail efficiency (1000 Btu/ton-mile)
RTMTT	Travel (billion ton-miles)
TQRAILT	Total energy demand
TQRAIL	Energy demand by fuel type (1-diesel, 2-residual, 3-electric)
TQRAILR	Regional energy demand by fuel type
BTQRAILR	Benchmarked energy demand
BRTMTT	Benchmarked travel demand
XRAILEFF	Percent change in freight rail efficiency
Waterborne Freight Submodule	
Domestic Waterborne	
FACS	Waterborne freight adjustment factors
STMT89	Billion ton-miles traveled 1989
FESHIP	Vessel efficiency
STMTT	Travel (billion ton-miles)
SFD	Energy demand by fuel type (1-diesel, 2-

	residual, 3-electric)
TQDSHIPR	Regional energy demand by fuel type
BSTMTT	Benchmarked travel demand
BTQDSHIPR	Benchmarked energy demand
XSHIPEFF	Percent change in efficiency
International Waterborne	
GROSST	Gross tons shipped
ISFD	Energy demand by fuel type (1-diesel, 2-residual)
TQISHIPR	Regional energy demand by fuel type
BTQISHIPR	Benchmarked energy demand
MISCELLANEOUS TRANSPORTATION ENERGY DEMAND MODULE	
PMGTR04$	Regional gasoline price 2004$
PDSTR04$	Regional diesel price 2004$
MILTRSHR90	Military regional consumption shares by fuel region
Transit Rail Submodule	
TRCON	Travel demand constant term
TRINC	Travel demand log of income
TRFC	Travel demand fuel cost 2004$
TRDUM	Travel demand dummy
TRRPM	Transit rail passenger miles traveled
TRRPMHIST	Historic transit rail passenger miles traveled
TREFF	Transit rail efficiency (Btu/passenger mile)
TREFFHIST	Historic transit rail efficiency
TRED	Transit rail energy demand by CD
TREDHIST	Historic transit rail energy use
Commuter Rail Submodule	
CRCON	Travel demand constant term
CRINC	Travel demand log of income
CRFC	Travel demand fuel cost 2004$
CRDUM	Travel demand dummy
CRRPM	Commuter rail passenger miles traveled
CRRPMHIST	Historic commuter rail passenger miles traveled
CREFF	Commuter rail efficiency (Btu/passenger mile)
CREFFHIST	Historic commuter rail efficiency
CRED	Commuter rail energy demand by CD
CREDD	Commuter rail diesel demand by CD
CREDE	Commuter rail electricity demand by CD
CREDDHIST	Historic commuter rail diesel demand
CREDEHIST	Historic commuter rail electricity demand
CREDDSHR	Share of commuter rail energy demand that is diesel

Intercity Rail Submodule	
IRCON	Travel demand constant term
IRINC	Travel demand log of income
IRPMCL	Lag of travel demand per capita
IRFC	Travel demand fuel cost 2004$
IRPMPC	Passenger miles per capita (16+)
IRPMPCHIST	Historic passenger miles per capita (16+)
IRRPM	Intercity rail passenger miles traveled
IRRPMHIST	Historic intercity rail passenger miles traveled
IREFF	Intercity rail efficiency (Btu/passenger mile)
IREFFHIST	Historic intercity rail efficiency
IRED	Intercity rail energy demand
IREDD	Intercity rail diesel demand
IREDE	Intercity rail electricity demand
IREDDSHR	Diesel share of total demand
IRREGSHR	Fuel shares by region
IREDDR	Intercity rail diesel demand by CD
IREDER	Intercity rail electricity demand by CD
IREDDHIST	Historic intercity rail diesel demand
IREDEHIST	Historic intercity rail electricity demand
Bus Mass Transit	
TMODINIT	Historic bus passenger miles
TMOD	Bus passenger miles
TMEFFINIT	Historic bus efficiency (Btu/passenger mile)
TMEFF	Bus efficiency (Btu/passenger mile)
QMODFSHR	Bus fuel shares
QMODFSHRH	Historic bus fuel shares
TMFD	National bus energy demand
Recreational Boating Submodule	
RECFD	Energy demand by fuel type (gasoline, diesel)
RBCON	Energy demand constant term
RBINC	Energy demand log of income
RBFC	Energy demand fuel cost 2004$
RBEDPC	Energy demand per capita by fuel type
Miscellaneous Transportation Energy Variables	
QMILTR	Military energy demand by fuel by region
QMTRR	Passenger rail energy demand by fuel by region
QMTBR	Bus energy demand by fuel by region
QRECR	Recreational boat energy demand by region
QLUBR	Lubricant energy demand by region
Car light truck sales shares	
CARLTSHR	Historical car share of LDV sales
CARSHARE	Projected car share of LDV sales
DUMM	Car share dummy

STEO BENCHMARKING	
STMGTR	STEO History + forecast for motor gasoline, shared to regions
STJFTR	STEO History + forecast for jet fuel, shared to regions
STDSTR	STEO History + forecast for distillate, shared to regions
STRSTR	STEO History + forecast for residual, shared to regions
PRAT	AFV price ratios to gasoline
MRAT	AFV mpg ratios to gasoline
RRAT	AFV range ratios to gasoline
FUELTAX	Incremental petroleum fuel tax - nominal $/million Btu
FUELTAX87	Incremental petroleum fuel tax - in 1987$
FTYPELABEL	Fueling type labels based on index scheme one
NHTSASAL	NHTSA sales
NHTSAHP	NHTSA horsepower
NHTSAFE	NHTSA fuel economy
NHTSAWGT	NHTSA weight
NHTSALYR	Last year of NHTSA data
FEMMPG	FEM fuel economy data for report writer
FEMHP	FEM horsepower data for report writer
FEMPRI	FEM low volume price data for report writer
FEMPRIH	FEM high volume price data for report writer
FEMWGT	FEM weight data for report writer
FEMRNG	FEM range data for report writer
FEMTSZ	FEM fuel tank size data for report writer
FEMVOL	FEM volume data for report writer
FEMPEN	FEM technology penetration data for report writer
SALESHR	Car and light truck sales shares by group
PASSHRR	Car market shares by class
LTSHRR	Light truck market shares by class
NCSTSC	Car sales by class
NLTSTSC	Light truck sales by class
AHPCAR	Average car horsepower
AHPTRUCK	Average light truck horsepower
AWTCAR	Average car weight
AWTTRUCK	Average light truck weight
TLDVMPG	On-road stock fuel economy for all cars, light trucks, total
PCTAF	Percent alt. Fuel for flex and bi vehicles
SCMPG	On-road stock mpg household cars
STMPG	On-road stock mpg household light trucks
PassNo	Controls two passes for high and low volume sales.

PARAMETERS IN TRANFRT MODULE	
AGE	Number of vintages for truck stocks
HRATE	Btu/Gallon ratio to Gasoline
SEC	Number of Industrial sectors:1 - Chemicals, Rubber, and Plastic, 2 - Primary Metals, 3 - Processed Food, 4 - Paper Products, 5 - Petroleum Products, 6 - Stone, Clay, Glass, Concrete, 7 - Metal Durables, 8 - Other Manufacturing, 9 - Agriculture,10 - Mining, 11 - Utility, 12 - Government
SC	Number of Truck Market classes:1 - Medium Light, Class 3, 2 - Medium Heavy, Classes 4-6, 3 - Heavy, Classes 7-8
MDL	Market class of vehicle: medium light , Class 3
MDH	Market class of vehicle: medium heavy , Classes 4-6
HV	Market class of vehicle: heavy Classes 7-8
FUEL	Number of fuel types: 1 - Diesel, 2 - Gasoline, 3 - LPG, 4 - CNG
FNEW	NEW VEHICLE for reporting variables
FSTK	FREIGHT STOCK for reporting variables
EMISTECH	Emission Technologies are for technologies - 24(to 40)
TK	Truck
NFT	Truck: Non fleet
FLT	Truck: fleet
TECH	New technologies available: 1 - Aero Dynamics I, 2 - Aero Dynamics II, 3 - Aero Dynamics III, 4 - Aero Dynamics IV: pneumatic blowing, 5 - Tires I: radials, 6 - Tires II, 7 - Tires III, 8 - Tires IV, 9 - Transmission: lock-up, 10 - Diesel Engine I, 11 - Diesel Engine II, 12 - Diesel Engine III, 13 - Diesel Engine IV, 14 - Diesel Engine V, 15 -

	Diesel Engine VI, 16 - Diesel Engine VII, 17 - Diesel Engine VIII, 18 - Gasoline Engine I, 19 - Gasoline Engine II, 20 - Gasoline Engine III, 21 - Gasoline Engine IV, 22 - Weight Reduction I, 23 - Blank, 24 - Diesel Emission- NO_x I, 25 - Diesel Emission- NO_x II, 26 - Diesel Emission- NO_x III, 27 - Diesel Emission- NO_x IV, 28 - Diesel Emission-PM I, 29 - Diesel Emission-PM II, 30 - Diesel Emission-HC/CO I, 31 - Diesel Emission-HC/CO II, 32 - Blank, 33 - Gasoline Emission-PM I, 34 - Gasoline Emission- NO_x I, 35 - Gasoline Emission- NO_x II: oxygen sensors, 36 - Gasoline Emission- NO_x III: , 37 - Gasoline Emission-HC/CO I: oxygen sensors, 38 - Gasoline Emission-HC/CO II, 39 - Gasoline Emission-HC/CO III, 40 - Blank
RGN	Regions
BSYR_VMT	NEMS year index of base year for VMT data, 10 is 1999
BSYR_STK	NEMS year index of base year for Truck Stock data, 11 is 2000 (Stock data as of 2000)
CUR	Current and Lag year subscripts
Subscripts	
IAGE	Index for vintage
IFUEL	Index for fuel type
IFLT	Index for fleet
ISC	Index for market class or ship region
IMODE	Index for Transportation Mode TK,RL,SP
ISEC	Index for industrial sector
IYR	Index for year
ITECH	Index for Technology
ITR	NEMS iteration
IR	Census division
Variables	

CAVLXG	1st year technologies commercially available
CYAFVXG	Logistic Market penetration curve parameter # of years, AFV
FLAPLXG	10's Mapping technologies to trucks by fuel type
PAYBKXG	Payback period
TRGSHXG	Logistics parameter: 1/2 way to maximum Market penetration
ANNVMT	Average annual VMT per vehicle
BAVSHXG	Market penetration curve parameter: Market share of technology in 1992
BFSHXG	Base year(92) Market share of each fuel
BSMPGXG	Fuel economy for medium/heavy trucks w/ no fuel saving technology's
CAPCXG	Exogenous capital cost of a technology
CFAVPC	Average price of fuel over 3 years
CFMPG	Fuel economy in mpg miles/cubic CNG
CFPRCXG	Price of fuel, in $ per MBtu
COEFTXG	Market penetration curve for existing technologies
CSTCXG	Market penetration curve for existing technologies
CSTDXG	Market penetration curve parameter for diesel
CSTDVXG	Market penetration curve parameter for diesel
CYLXG	Exogenous parameter: num of years to maximum penetration
DISCRTXG	Discount rate
EAVSHXG	Market penetration curve parameter: Final Market share of technology
preff	Market Penetration Price sensitivity multiplier
prefflag	Market Penetration Price sensitivity multiplier,

	lagged
EFSHXG	Final market share of each fuel
ENDSHXG	Market penetration parameter: final market share technology
FAC_K	Constant associated w/ F.A.C. function
FAC_T0	Initial factors
FAC_T5	FOR FACTORS IN YEAR 5: Variables can be use
FAC_T9	FOR FACTORS IN YEAR 9: to shape FAC curve
FOUT	Function Output Variable
FSHFLT	Fuel shares for New trucks by market class, fleet/non fleet
FSHFLT_STK	Fuel shares for the entire stock of trucks
FUELBTU	Total truck fuel consumption in trillion Btu
FUELDMD	Freight truck fuel consumption: gallons of gasoline equivalent?
HTRTXG	Heat rate: Btu per gallon (conversion factor)
OUTPUT	Economic output of each sector
MBTUTKXG	Average truck fuel usage
USFUEL	Temporary summing variable for fuel
MPGEFF	Total effect of all fuel-saving technology on new truck fuel efficiency
MPGIPXG	% Improvement fuel economy by technology
PRAFDFXG	Parameter: variation AFV Market share due to different fuel prices
PRVRXG	Fuel price sensitivity parameter for each technology
SCRAP	Truck scrappage rate
SPRSDEFF	Market shares of superseding technology

SPRSDMTXG	The 2nd technology supercedes the 1st \technology
TGPRCXG	Exogenous fuel price where a technology becomes economical
TRF	Trucks trans fleet to non-fleet w/ no restrictions
TRKSTK	Truck population (current/lag year, market class, vintage, fuel, fleet/non-fleet)
TFFXGRT	Exogenous % of trucks/vintage transferred from fleet to non-fleet
VMTFLT	VMT at its most detailed
STKCLS3FL	Truck stock 2000 from ORNL-processed Polk data, class 3, fleet
STKCLS3NFL	Truck stock 2000 from ORNL-processed Polk data, class 3, nonfleet
STKCLS46FL	Truck stock 2000 from ORNL-processed Polk data, class 4-6, fleet
STKCLS46NFL	Truck stock 2000 from ORNL-processed Polk data, class 4-6, non-fleet
STKCLS78FL	Truck stock 2000 from ORNL-processed Polk data, class 7-8, fleet
STKCLS78NFL	Truck stock 2000 from ORNL-processed Polk data, class 7-8, non-fleet
VMTCLS3V	VMT per truck by fuel and vintage, class 3
VMTCLS46V	VMT per truck by fuel and vintage, class 4-6
VMTCLS78V	VMT per truck by fuel and vintage, class 7-8
NEWCLS46	Share of truck sales in class 4-8 that are class 4-6, by year
VMTDMD	Aggregate VMT by sector
FUELDMD_FAS_T	Summation of fuel demand by (F)leet (A)GE (S)ECTORS
FTMPG	MPG by size, and fuel
FTMPG_S	MPG by market class

FHWA_VMT	Annual VMT through BSYR_VMT from FHWA
FHWA_VMT_SC	Annual VMT through BSYR_VMT from FHWA, allocated to market class
VMT_BY_SEC	Shares of VMT by Sector
NEWTRUCKS	Sales of new trucks by market class and fleet/non-fleet + total
NEWTRUCKS_TOT	Temporary for new truck sales from macro
NEW_CLASS_3	Temporary new Class 3 sales
HARMONIC_MEAN	Function to calculate average mpg weighted by VMT

Appendix E. Bibliography

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