Independent Statistics & Analysis
U.S. Energy Information Administration

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

March 2019

U.S. Department of Energy
Washington, DC 20585

Update Information

This twenty-second edition of the Transportation Sector Demand Module of the National Energy Modeling System—Model Documentation 2018 reflects changes made to various sections and submodules of the Transportation Sector Demand Module (TDM) over the past two years for the *Annual Energy Outlook 2018* (AEO2018). These changes include:

Light-Duty Vehicle (LDV) Submodule updates

- Modified the modeling of state level Zero Emission Vehicle (ZEV) credit mandate and added the use of compliance credit bank

Freight Transportation Submodule updates

- Addition of Phase 2 of the heavy-duty vehicle fuel economy and greenhouse emissions standards
- Expansion of modeling heavy-duty vehicles from 3 aggregate size classes to 19 disaggregate size classes and tractor specifications
- Shifted projection modeling of size class 2b from the light-duty vehicle submodules to the heavy-duty vehicle submodules

Expanded the use of the U.S. Department of Transportation's (DOT) Freight Analysis Framework[1] with respect to the National Energy Modeling System (NEMS) application of historical Census division and commodity ton-mile data, going from a maximum of 12 to a maximum of 18 industrial categories.**Air Travel Submodule updates**

- Implemented a model simplification of curvilinear air passenger travel demand trends by applying a natural growth function which resembles a compound interest type of formulation.

International Marine

- Developed fuel selection factors for fuel choice logit to address reduced high sulfur residual fuel oil demands based on January 1, 2020 international maritime sulfur emission regulations.[2]

[1] U.S. Department of Transportation, Federal Highway Administration, "Freight Analysis Framework (FAF3)," http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/.[2] *The 2020 global sulfur limit*, International Maritime Organizations, website: http://www.imo.org/en/MediaCentre/HotTopics/GHG/Documents/FAQ_2020_English.pdf, accessed June 19, 2018.
[2] *The 2020 global sulfur limit*, International Maritime Organizations, website: http://www.imo.org/en/MediaCentre/HotTopics/GHG/Documents/FAQ_2020_English.pdf, accessed June 19, 2018.

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Introduction

The Transportation Sector Demand Module of the National Energy Modeling System (NEMS) is a computer-based energy demand model of the U.S. transportation sector. This report documents the objectives, analytical approach, and development of the NEMS Transportation Sector Demand Module, as well as cataloguing and describing critical assumptions, computational methodology, parameter estimation techniques, and module source code.

The document serves as a reference by providing a basic description of the NEMS Transportation Sector Demand Module 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 Demand Module encompasses a series of semi-independent submodules and components that address different aspects of the transportation sector. The primary purpose of the comprehensive module 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 and liquefied natural gas (CNG/LNG). The current NEMS projection horizon extends to the year 2050 and uses 1995 as the start year. Projections are generated through separate consideration of energy consumption within the various modes of transport: private and fleet light-duty vehicles (LDVs); aircraft; marine, rail, and truck freight. Other transportation demands such as mass transit, military, and recreational boating are also considered. This modular approach is useful in assessing the impacts of policy initiatives, legislative mandates affecting individual modes of travel, and technological developments.

The module also projects selected intermediate values necessary to determine energy consumption. These elements include estimates of passenger travel demand by light-duty vehicles, air, and mass transit; estimates of the energy requirements to meet this demand; projections of vehicle stock 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 Demand Module consists of four submodules representing a variety of travel modes that are different in design and utilization but share the same ultimate purpose: to convey passengers and freight. The four submodules include: Light-Duty Vehicle (LDV), Air Travel, Freight Transport (heavy truck, rail, and marine), and Miscellaneous Energy Demand. Each submodule is comprised of one or more components, consistent with the methodological requirements of the sector and commensurate with the relative impact that sector has on overall transportation demand and energy use. A fifth (inactive) submodule exists in the Transportation Sector Demand Module that is designed to estimate certain air emissions from highway vehicles. The five submodules and their interactions are illustrated in Figure 1 with detailed descriptions of each 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 2018* (AEO2018).

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Model Overview

The Transportation Sector Demand Module is designed to achieve the following objectives:

1. Generate projections of transportation energy demand at the national and the Census Division level.
2. Endogenously incorporate the effects of technological innovation, macroeconomic feedback, infrastructure constraints, and vehicle choice in making the projections.

The transportation module comprises a group of submodules that are sequentially executed in a series of program calls. The flow of information between these submodules is depicted in Figure 1. The transportation module 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 sections.

The transportation module can evaluate a range of policy issues, including fuel taxes and subsidies; fuel economy performance by market class; fuel economy standards for light, medium, and heavy-duty vehicles[3]; vehicle pricing by market class; demand for vehicle performance within market classes; fleet vehicle sales by technology type; alternative-fuel vehicle sales share; the California Low-Emission Vehicle Program; changes in vehicle-miles traveled (VMT); and various other policies and developments related to transportation energy use and greenhouse gas emissions.

The modeling techniques employed in the Transportation Sector Demand Module vary by submodule. The LDV Submodule uses econometric models to forecast passenger travel demand and new vehicle market share and uses engineering and expert judgment for estimating fuel economy. The Air Travel Submodule also uses econometrics to forecast passenger travel demand and aircraft efficiency, as well as using other inputs such as jet fuel prices, world regional population, world regional Gross Domestic Product (GDP), U.S. disposable personal income, and merchandise export. The Freight Transportation Submodule 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 Demand Submodule forecasts passenger travel and energy and oil demand from military, mass transit (including bus and rail), recreational boating, and lubricants.

Light-duty vehicles are classified according to the six EPA size classes for cars and gross vehicle weight rating (GVWR) for light trucks and are divided by fleet and private use. Freight trucks are divided into medium-light, medium-heavy, and heavy-duty market classes and by fleet and non-fleet vehicles. Buses are subdivided into commuter, intercity, and school buses. The air transport submodule 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. Outputs from the submodules are provided to an integrating module which then sends the various transportation demands to the supply modules.

[3] Additional information on fuel economy standards is available at the National Highway Traffic Safety Administration, see www.nhtsa.gov/fuel-economy .

Brief description of submodules

The following is a brief description of each of the submodules shown in Figure 1. Details of each submodule and associated components are provided in subsequent sections and include descriptions, mathematical representations, and graphical illustrations of the structure of each submodule.

Light-Duty Vehicle Submodule

The first submodule executed is the LDV Submodule, which projects attributes and sales distributions of new cars and light trucks. The LDV submodule provides estimates of new LDV fuel economy, the market shares of alternative fuel vehicles (AFVs), and sales of vehicles to fleets. This information is passed to the LDV Fleet Component, a stock-vintaging model that generates estimates of travel demand, fuel efficiency, and energy consumption by business, government, and utility fleets. The LDV Fleet Component subsequently passes estimates of vehicles transferred from fleet to private service to the LDV Stock Component, which also receives estimates of new LDV sales and fuel efficiency from the LDV Submodule. The LDV Stock Component generates travel, fuel economy, and fuel consumption estimates of the entire stock of household LDVs. Information from the LDV Stock Component is subsequently passed to the Miscellaneous Energy Demand Submodule.

Air Travel Submodule

The Air Travel Submodule receives macroeconomic and demographic input from NEMS, including jet fuel prices, world regional population, world regional GDP, U.S. disposable income, and merchandise exports. The Air Travel Submodule uses an econometric estimation method to project travel demand and a stock-vintaging component to estimate the size and other characteristics of the aircraft fleet required to meet that demand. The output of this submodule also includes estimates of the demand for jet fuel and aviation gasoline, which are passed to the Miscellaneous Energy Demand Submodule.

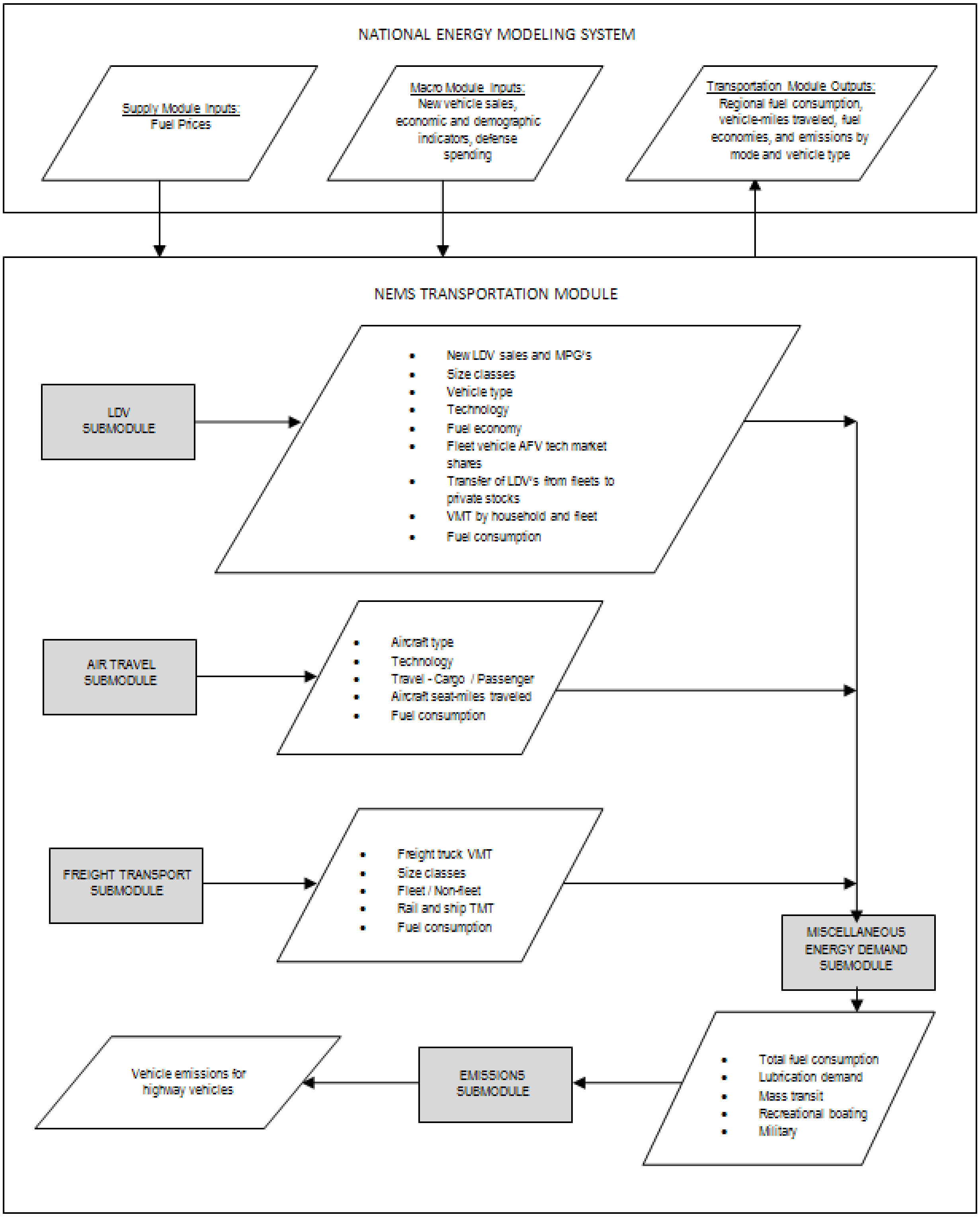
Freight Transportation Submodule

The Freight Transportation Submodule uses NEMS projections of fuel prices, trade indices, and output related to 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 Submodule.

Miscellaneous Energy Demand Submodule

The Miscellaneous Energy Demand Submodule receives estimates of military expenditures from NEMS to generate projections for military fuel demand. Travel demand estimates from the LDV Stock Component and fuel efficiency estimates from the Freight Transportation Submodule are used to calculate regional fuel consumption by buses. Estimates of disposable personal income from NEMS are used to calculate the demand for fuel in recreational boating. Demand for lubricants used in transportation is estimated from aggregate demand for highway travel obtained from the preceding modules. Passenger travel and energy demand are estimated for transit, commuter, and intercity rail.

Figure 1. Structure of the NEMS Transportation Sector Demand Module



Note: Shaded boxes represent the module's main submodules. The Emissions Submodule is currently inactive.

Emissions Submodule

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

Inputs and outputs of the module

The transportation module sends information on regional fuel consumption to NEMS, where it is integrated with the results of the other demand, macroeconomic, and supply modules. In order to generate projections, the transportation module receives a variety of exogenous inputs from other NEMS modules. The primary source of these inputs is the Macroeconomic Activity Module, which provides projections of economic variables, such as new vehicle sales and demographic indicators. Other inputs exogenous to the transportation module, but endogenous to NEMS, include the fuel price projections from the various supply modules.

The transportation module produces projections of travel demand and associated energy demand, disaggregated by Census Division; vehicle and fuel type; conventional and alternative vehicle technology; vehicle stock and efficiency. Within NEMS, the Transportation Module interacts with the Macroeconomic Activity Module and the various supply modules that provide the prices of transportation-related fuels at a given level of demand. For each projection year, NEMS performs several iterations in order to derive a set of fuel prices under which supply and demand converge. The reliance on economic and price inputs to each of the submodules in the transportation module is detailed in the following sections.

Transportation Sector Demand Module Structure

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

The general theoretical approach taken, assumptions, and methodology employed are discussed for each submodule and component. The key computations and equations are presented to provide a comprehensive overview of the transportation sector demand module. The equations follow the logic of the FORTRAN source code to facilitate an understanding of the code and its structure. In several statements, a variable name will appear on both sides of an equal sign. These statements are not to be interpreted as mathematical equations. They are computer assignment statements that allow a previously calculated variable to be updated (for example, multiplied by a factor) and re-stored under the same variable name.

Flowcharts are provided within the text or at the end of each section to facilitate the logic used in the submodules where necessary. These flowcharts are detailed, self-contained representations of the submodule or component. For 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 submodules that comprise the transportation sector demand module. These data sets remain unchanged throughout the projection and constitute a set of assumptions about current and future conditions.

The transportation sector demand module 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 submodule and component. Appendix C provides a mapping of the various subroutines and the order in which they are called.

LDV Submodule

The LDV Submodule tracks the purchase and retirement of cars and light trucks, projects fuel efficiency, and estimates the consumption of transportation fuels based on projections of travel demand. The LDV Submodule shown in Figure 2 requires the largest number of exogenous inputs and primarily consists of seven components:

Manufacturer Technology Choice Component (MTCC)
Regional Sales Component
Consumer Vehicle Choice Component (CVCC)
LDV Fleet Component
Class 2b Vehicle Component
LDV Stock Accounting Component
Vehicle-Miles Traveled Component (VMTC)

Each component 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 nine vehicle manufacturers, including four car and five light truck groups.

Cars 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) size classes and are based on passenger car interior volume. Truck classification is based on vehicle inertia weight class[4] by truck type (pickup, sport utility vehicle, and van). This leads to a total of 12 size classes, which are individually projected to 2050 for nine manufacturer groups.

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

- Technology penetration
- Level of acceleration performance achieved
- Mix of vehicle size classes and vehicle technology types (e.g., hybrid and diesel) sold
- Vehicle fuel economy, safety, and emission standards

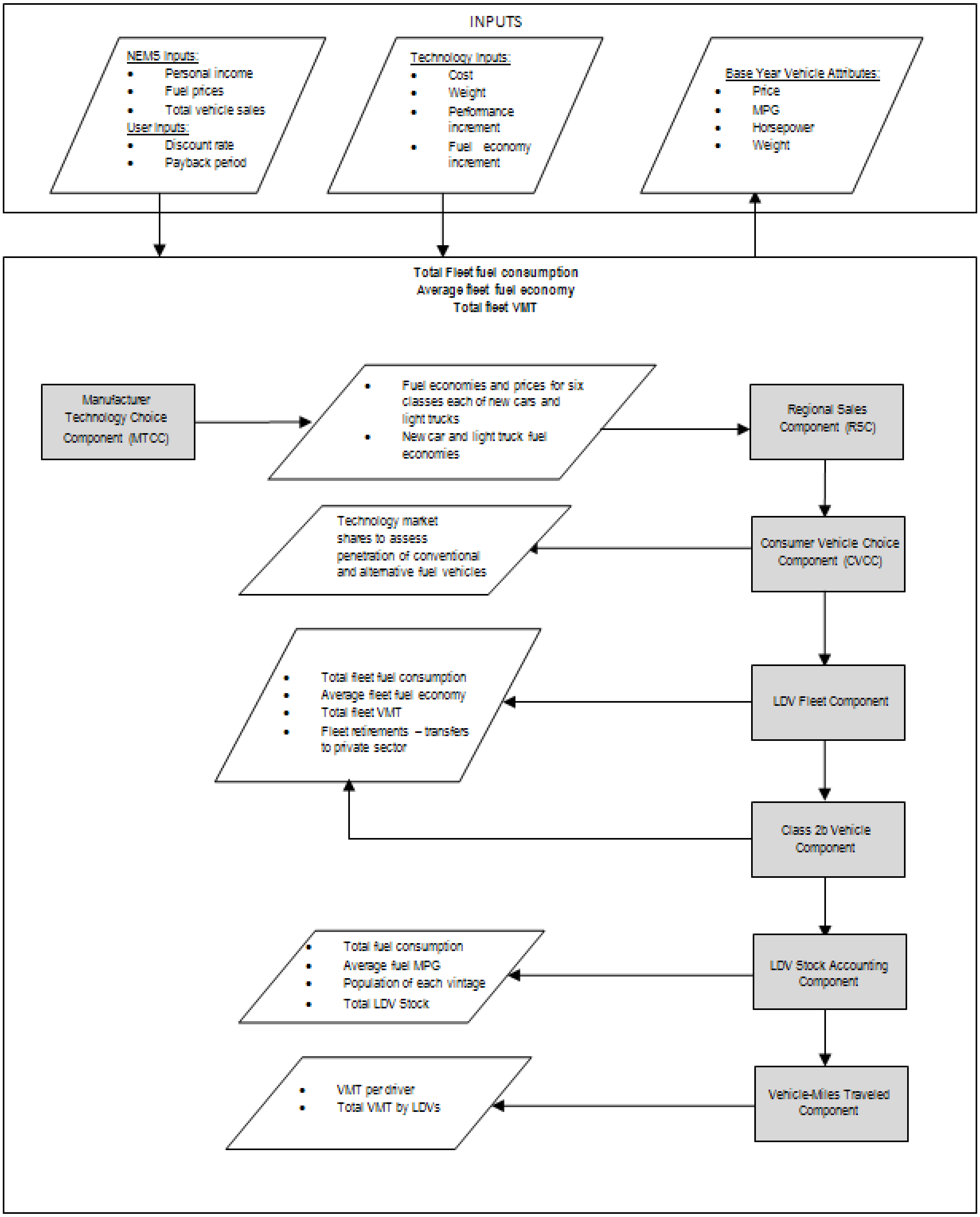
Technological improvements to each of these market classes are then projected based on the availability of new technologies to improve fuel economy as well as their cost-effectiveness under two user-specified alternative scenarios. The central assumptions involved in this technological projection are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

- 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).
- 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.

[4] The term "vehicle inertia weight class" with respect to a motor vehicle is statutorily determined under 40 CFR § 86.129-94. According to 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 the LDV submodule



The fuel economy projection must 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 MTCC utilizes econometric equations for the sales mix choice.[5] 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 Submodule also allows specification of fuel economy standards by year and of different standards for each of nine manufacturer groups, 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. Finally, the submodule also accounts for select state-level regulations, such as California's Zero Emission Vehicle (ZEV) mandate, followed by nine additional Section-177 states: (Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont).

Manufacturers Technology Choice Component (MTCC)

The MTCC[6] component in the LDV Submodule produces estimates of new light-duty vehicle fuel economy. Fuel economy is a significant aspect of the transportation sector demand module because automotive fuel demand is directly affected by the efficiency with which that fuel is used. Due to the disparate characteristics of the various classes of LDVs, this component addresses the commercial viability of up to 86 separate technologies within each of twelve vehicle market classes, nine manufacturer groups, and sixteen vehicle/fuel types. The MTCC component projects fuel economy by vehicle class as shown in the flow chart in Figure 3. The model begins with 2016 data. Baseline vehicle attributes, describing the fuel economy, weight, horsepower, and price for each vehicle class for 2016 are read in and calibrated to NHTSA data. For each projection year, the component identifies technologies that are available.

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 test is used to generate an economic market share for the technology. In certain cases, adjustments must be made to the calculated market shares to reflect the effects of engineering limitations or external forces that require certain types of technologies, including both safety and emissions technologies. All of these adjustments are referred to collectively as

[5] Goldberg, U.S. Department of Commerce, Bureau of Economic Analysis, 1998.
[6] U.S. Department of Energy, U.S. Energy Information Administration, "Documentation of Technologies Included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks," 2002.

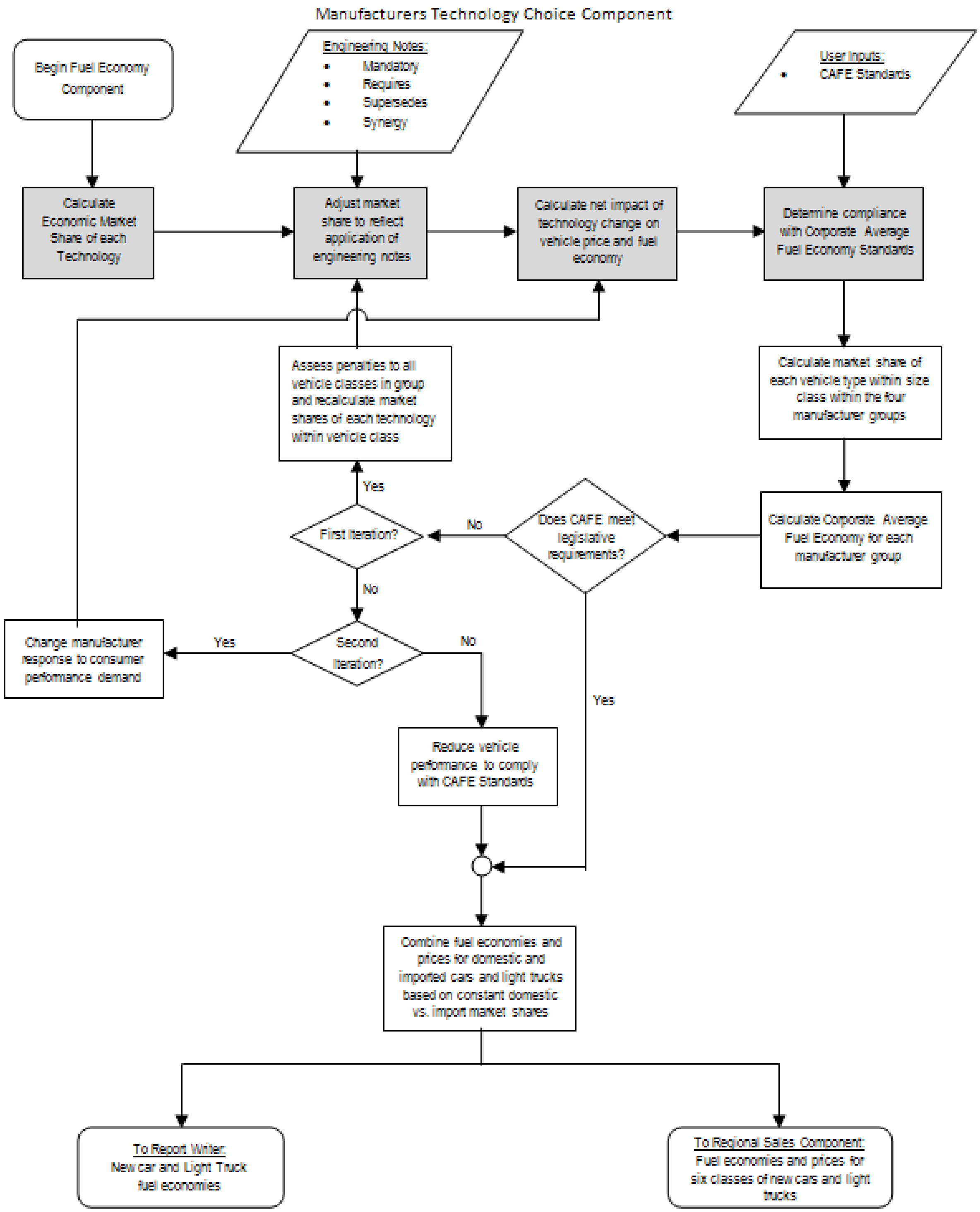
“Engineering Notes." There are four types of engineering notes: Mandatory, Supersedes, Requires, and Synergistic. These engineering notes are described in a subsequent section.

Users of the component are able to specify one of three cases under which these projections are made. The first, identified as the "Standard Technology Scenario," permits the consideration of 86 automotive technologies whose availability and cost-effectiveness are well documented. 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. The third, identified as the "Low Technology Scenario," modifies selected characteristics of the original matrix to render a less-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 made to horsepower. Finally, the fuel economy is adjusted to reflect the new horsepower.

Once these steps have been taken for all vehicle classes, CAFE is calculated for each of the nine manufacturer groups. 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 MTCC 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. This assumes manufacturers will minimize their costs by reducing performance to comply with CAFE standards.

Figure 3. Manufacturers technology choice component



This component follows the following steps in sequence.

1. Establish alternative fuel vehicle (AFV) characteristics relative to conventional gasoline

This AFVADJ subroutine in MTCC establishes alternative fuel vehicle (AFV) characteristics relative to conventional gasoline. This is an initialization subroutine and calculates the price, weight, fuel economy, and horsepower for AFVs for all historic years through the base year in the MTCC. Most of these are initialized 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, trnldv.xml. In the equations that follow, IATV represents the fifteen AFV types: turbo direct-injection diesel, flex-fuel ethanol, plug-in hybrid electric 10-and 40-mile range gasoline vehicles (PHEV10, PHEV40), electric 100-, 200-, and 300-mile range vehicles (EV100, EV200, EV300), diesel/electric hybrid, CNG/LNG and LPG (liquefied petroleum gas) bi-fuel, dedicated CNG/LNG and LPG, methanol fuel cell and hydrogen fuel cell, and gasoline/electric hybrid. For each manufacturer and nameplate, prices are estimated for low production levels (beginning at 2,500 units) and high production levels (beginning at 25,000 units). Because the Transportation Sector Demand Module does not specifically model individual nameplates, low- and high-production price levels are increased to 5,000 and 50,000 units, respectively.

1) Calculate base and historic yearly values for car prices at different production levels by applying an additive adjustment to the price of a gasoline-fueled vehicle.

a) Car and Light Truck at 5,000 units/year:

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

where

PRICE = Low-production vehicle price by market class and group.

AFVADJPR = Incremental price adjustment for a low-production vehicle.

vt = Vehicle type; car and light truck.

IATV = Alternative fuel vehicle type (15 categories).

b) Car and Light Truck prices at 50,000 units/year:

$$PRICEHI_{Year,IATV} = PRICEHI_{Year,Gasoline} + AFVADJPRH_{IATV,vt,Year} \quad \textbf{(2)}$$

where

PRICEHI = High-production vehicle price by market class and group.

AFVADJPRH = Incremental price adjustment for a high-production vehicle.

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

a) Fuel Economy Calculation:

$$FE_{Year,FuelType} = FE_{Year,Gasoline} * \left(1 + AFVADJFE_{FuelType,Year}\right) \quad \textbf{(3)}$$

where

AFVADJFE$_{fueltype,year}$ = Input fuel economy

b) Weight Calculation: adjustment relative to gasoline vehicles.

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

(4)

where

AFVADJWT$_{fueltype,year}$ = Input weight adjustment relative to gasoline vehicles.

c) Horsepower Calculation:

$$HP_{Year,FuelType} = HP_{Year,Gasoline} * \left(1 + AFVADJHP_{FuelType,Year}\right) \quad \textbf{(4)}$$

where

AFVADJHP$_{fueltype,year}$ = Input horsepower adjustment relative to gasoline vehicles.

The characteristics of electric drivetrain vehicles—price, weight, fuel economy, and horsepower—are calculated with a different methodology discussed in Section 5.

2. Calculate technology market shares

The MTCC 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. For 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 standard. During this pass, the cost-effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFE.[7] If a vehicle group fails to meet CAFE after the second pass, no further adjustments to technology

[7] See the variable REGCOST in Equation 12.

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 electric vehicle (HEV), and fuel cell (FC) 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 manufacturer group, class, and vehicle/fuel type. In the interest of legibility, these dimensions are not shown in the subscripts, except to clarify the relationship.

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).

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, three-year lagged fuel costs and the annual rates 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 lagged costs and rate-of-change prices used for this calculation are actually five-year moving average prices and the difference between the three-year lagged five-year moving average price and the four-year lagged five-year moving average price. The expected present value of fuel savings is dependent on the expected price of fuel, payback period (the amount of time the purchaser is willing to wait to recover the initial investment), discount rate (the time value of money), and the distance driven over the period. This estimation involves the following three steps:

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

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

where

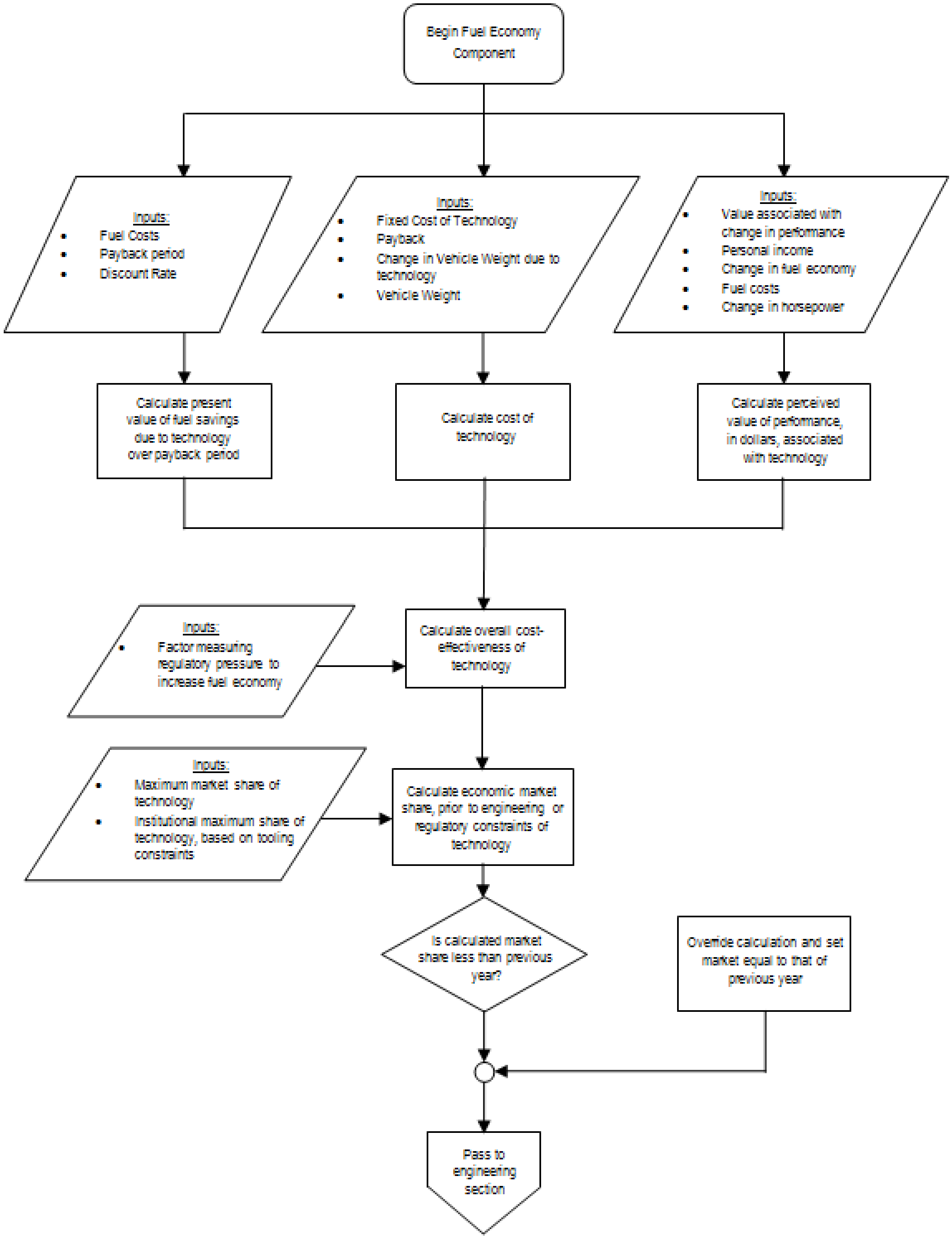
FUELCOST$_i$ = The price of fuel year *i*.

i = Index representing the year considered.

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

$$PRICE\_EX_{Year=i} = PSLOPE * (i+2) + FIVEYR\_FUELCOST_1 \quad \textbf{(6)}$$

Figure 4. Economic market share calculation



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

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{Year-1}} - \left(\frac{1}{1 + DEL\_FE_{itc} * FE_{Year-1}} \right) \right) * PRICE\_EX_i * (1 + DISCOUNT)^{-i} \quad \textbf{(7)}$$

where

VMT_i = Annual vehicle-miles traveled.

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

i = Index: 1, 2, … , PAYBACK; defined locally.

FE_{Year-1} = Fuel economy of previous year.

DEL_FE_{itc} = Fractional change in fuel economy associated with technology *itc*.

PAYBACK = User-specified payback period.

DISCOUNT = User-specified discount rate.

a) Technology cost

Technology costs may have absolute and weight-dependent components. An absolute component is a fixed dollar cost for installing a particular technology on a vehicle. Most technologies have only an absolute component. A weight-dependent component is associated with the material substitution technologies, where a lightweight material replaces heavier material. This component is split between an absolute and relative weight-based cost. In this case, the technology cost is a function of the amount of material, which is in turn a function of the weight of the vehicle. The technology cost equation is a sum of all these components:

$$TECHCOST_{itc,Year,FuelType} = DEL\_COSTABS_{itc} + DEL\_COSTWGT_{itc} * \begin{pmatrix} ABS(DEL\_WGTABS_{itc}) \\ + ABS(DEL\_WGTWGT_{itc}) * WEIGHT_{Year-1,FuelType} \end{pmatrix} \quad \textbf{(8)}$$

where

$TECHCOST_{itc,year,fueltype}$ = Cost per vehicle of technology *itc*.

$DEL\_COSTABS_{itc}$ = Absolute cost of technology *itc*.

$DEL\_COSTWGT_{itc}$ = Weight-based change in cost ($/lb).

DEL_WGTABS_{itc} = Fractional change in absolute weight associated with technology *itc*.

DEL_WGTWGT_{itc} = Fractional change in relative weight associated with technology *itc*.

$WEIGHT_{itc}$ = Original vehicle weight for different fuel type vehicles.

b) Learning cost adjustment

The technology cost is adjusted to include the multiplicative total of two individual cost multiplier adjustments. The two cost multipliers represent two separate portions of the same learning cost curve. The first cost multiplier represents the flattened portion of the learning curve, where most of the effects of learning for that technology have already been gained. The second cost multiplier represents the steeper portion of the learning curve, where the effects of learning are greatest for those technologies. The first cost multiplier applies to most of the technologies, except for those that can gain no more learning. The second cost multiplier applies to technologies that can still gain significant cost reductions due to learning, including micro hybrid and mild hybrid technologies, and level 2 rolling resistance tires.

$$TECHCOST_{itc} = TECHCOST_{itc} * \prod_{l=1}^{2} LEARN\_COST\_MULTIPLIER_{l} \qquad \textbf{(9)}$$

where

LEARN_COST_MULTIPLIER1 = Cost adjustment for flattened portion of learning curve.

LEARN_COST_MULTIPLIER2 = Cost adjustment for steeper portion of learning curve.

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, the model uses vehicle's horsepower-to-weight ratio as 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.

$$\begin{aligned} VAL\_PERF_{itc,Year} = {} & VALUEPERF * PERF\_COEFF * \frac{INCOME_{Year}}{INCOME_{Year-1}} \\ & * \left(1 + DEL\_FE_{itc}\right) * \frac{FUELCOST_{Year-1}}{FUELCOST_{Year}} * DEL\_HP_{itc} \end{aligned} \qquad \textbf{(10)}$$

where

$VAL\_PERF_{itc,year}$ = 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_HP_{itc} = Fractional change in horsepower of technology *itc*.

$FUELCOST_{year}$ = Actual price of fuel for the given year.

$INCOME_{year}$ = Income per capita in 1990 dollars

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:

$$COSTEF\_FUEL_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + \left(REGCOST * FE_{Year-1} * DEL\_FE_{itc}\right)}{TECHCOST_{itc}} \tag{11}$$

$$COSTEF\_PERF_{itc} = \frac{VAL\_PERF_{itc} - TECHCOST_{itc}}{TECHCOST_{itc}} \tag{12}$$

$$MKT\_FUEL_{itc} = \frac{1}{1+e^{MKT\_1COEFF*COSTEF\_FUEL_{itc}}} \tag{13}$$

$$MKT\_PERF_{itc} = \frac{1}{1+e^{MKT\_2COEFF * COSTEF\_PERF_{itc}}} \tag{14}$$

where,

COSTEF_FUEL = A unitless measure of cost effectiveness based on fuel savings of technology.

COSTEF_PERF = A unitless measure of cost effectiveness based on performance of technology.

REGCOST[8] = Factor representing regulatory pressure to increase fuel economy, in dollars per miles per gallon.

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.

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:

[8] 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.

$$ACTUAL\_MKT_{itc,Year} = PMAX_{itc,Year} * MAX\left(MKT\_FUEL_{itc}, MKT\_PERF_{itc}\right) \quad \textbf{(15)}$$

where

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

PMAX = Institutional maximum market share, modeling 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% penetration in half the time and continue at that pace 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:

$$ACTUAL\_MKT_{itc,Year} = MAX\left(ACTUAL\_MKT_{itc,Year-1}, ACTUAL\_MKT_{itc,Year}\right) \quad \textbf{(16)}$$

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

$$ACTUAL\_MKT_{itc,Year} = MIN\left(1, MKT\_MAX_{itc}, ACTUAL\_MKT_{itc,Year}\right) \quad \textbf{(17)}$$

where,

MKT_MAX = Maximum market share for technology *itc*.

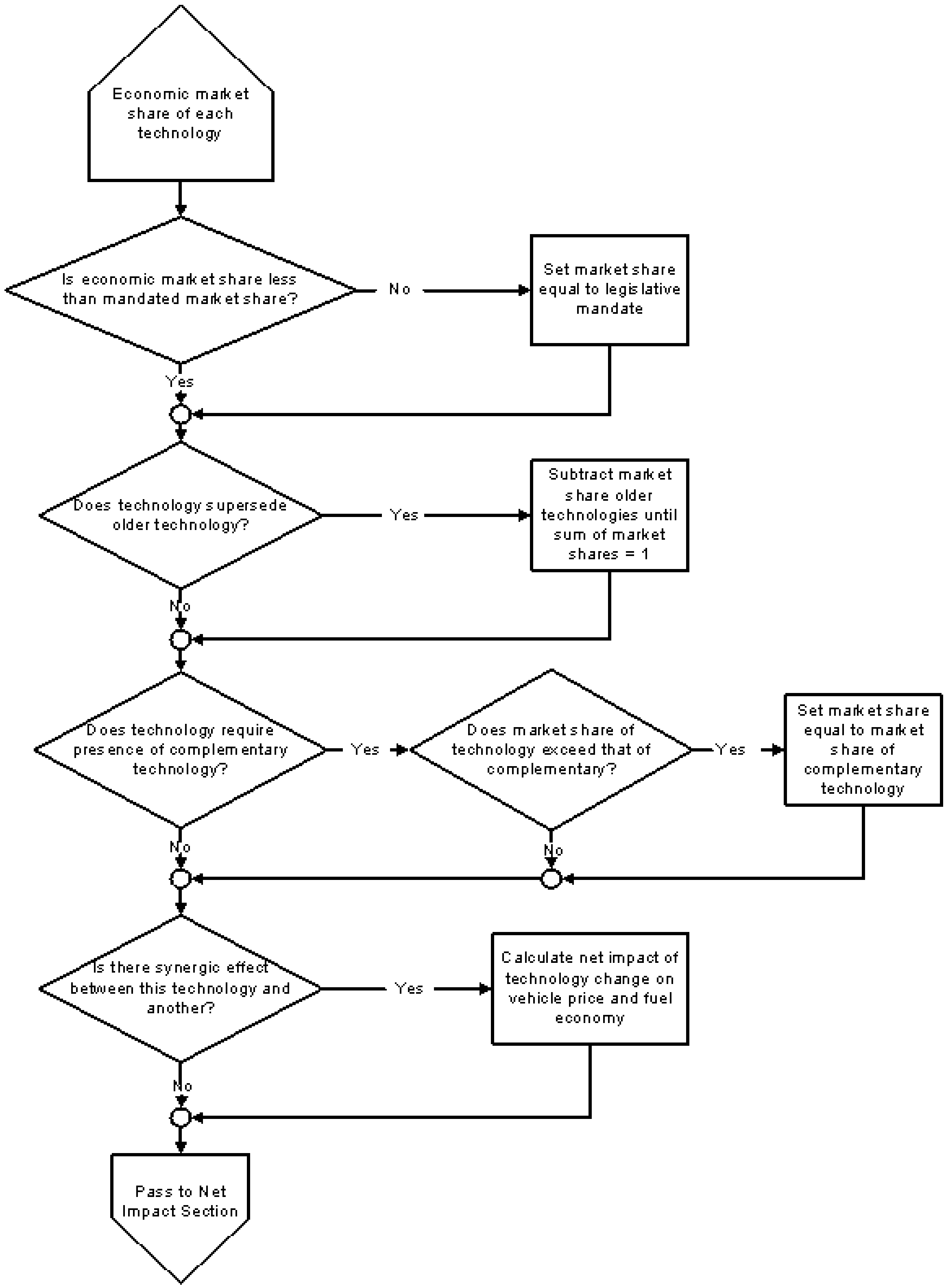
3. Apply the engineering notes

The engineering notes consist of a number of overrides to the economic cost-effectiveness calculations done in the previous step. Three types of notes (mandatory, supersedes, and requires) directly affect the technology market share results obtained above. The synergy note 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
1	2
2	3
3	4
4	5
5	6
6	8
7	11
8	15
9	20
10	26
11	34
12	42
13	51
14	60
15	68
16	76
17	82
18	87
19	91
20	94
21	96
22	97
23	98
24	99
25	100
26	100
27	100
28	100
29	100
30	100

Figure 5. Engineering notes



a) Mandatory notes

These are usually associated with safety or emissions technologies that must be in place by a certain year. 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:

$$ACTUAL\_MKT_{itc,Year} = MAX\left(ACTUAL\_MKT_{itc,Year}, MANDMKSH_{itc,Year}\right) \quad \textbf{(18)}$$

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, the model adds 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:

$$ACTUAL\_MKT_{itc,Year} = X \quad \textbf{(19)}$$

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:

$$ACTUAL\_MKT_{itc,Year} = MIN\left(ACTUAL\_MKT_{itc,Year}, MKT\_MAX_{itc}\right) \quad \textbf{(20)}$$

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, 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. The model first calculates the aggregate market share of all superseding technologies, *ino*, related to technology *itc*:

$$TOT\_MKT_{itc,Year} = \sum_{ino=1}^{num\_sup} ACTUAL\_MKT_{ino,Year} \tag{21}$$

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*.

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

$$MAX\_SHARE = MAX\left(MKT\_MAX_1, \ldots, MKT\_MAX_{num\_sup}\right) \tag{22}$$

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), the model reduces the excess penetration of those technologies that are in the group of related technologies, as follows:

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

$$DEL\_MKT_{itc} = TOT\_MKT_{itc,Year} - MAX\_SHARE \tag{23}$$

where

DEL_MKT = Amount of the superseded technology market share to be removed.

itc = The *i*ndex indicating superseded *t*echnology *c*hoice.

2) The model adjusts the market share of the superseded technology to reflect the decrement:

$$ACTUAL\_MKT_{itc,Year} = ACTUAL\_MKT_{itc,Year} - DEL\_MKT_{itc} \quad \textbf{(24)}$$

3) The model adjusts total market share to reflect this decrement:

$$TOT\_MKT_{itc,Year} = MAX\_SHARE_{itc,Year} \quad \textbf{(25)}$$

c) Requires notes

These notes control the adoption of technologies, which require that other technologies also be present on the vehicle. 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

$$REQ\_MKT_{Year} = MIN\left(\sum_{req} ACTUAL\_MKT_{req,Year-1}, 1.0\right) \quad \textbf{(26)}$$

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*:

$$ACTUAL\_MKT_{itc,Year} = MIN\left(ACTUAL\_MKT_{itc,Year}, REQ\_MKT\right) \quad \textbf{(27)}$$

It is at this point that the adjusted economic market share, ACTUAL_MKT, is assigned to the variable MKT_PEN, by market class and group, for use in the remainder of the calculations:

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

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 MTCC the actual fuel economy is lower than expected. For example, Variable Valve Lift I is synergistic with 8-Speed Automatic Transmissions. If both are present on a vehicle, then the actual fuel economy improvement is 0.7% below what would be expected if the improvements from the two 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:

$$SYNERGY\_LOSS_{itc}$$
$$= \sum_{syn}\left(MKT\_PEN_{itc,Year} * MKT\_PEN_{syn,Year}\right) * SYNR\_DEL_{itc,syn} \quad \textbf{(29)}$$
$$- \sum_{syn}\left(MKT\_PEN_{itc,Year-1} * MKT\_PEN_{syn,Year-1}\right) * SYNR\_DEL_{itc,syn}$$

where

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

syn = Set of technologies synergistic with technology *itc*.

SYNR_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 subsequently calculated. For a given technology *itc*, the change in market share since the last period is calculated as follows:

$$DELTA\_MKT_{itc} = MKT\_PEN_{itc,Year} - MKT\_PEN_{itc,Year-1} \quad \textbf{(30)}$$

where

DELTA_MKT = is the incremental changes in market share since the last time period.

DELTA_MKT 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:

$$FE_{year} = FE_{Year} + FE_{Year-1} * \left[\sum_{itc=1}^{NUMTECH} DELTA\_MKT_{itc} * DEL\_FE_{itc} + SYNERGY\_LOSS_{itc} \right] \quad \textbf{(31)}$$

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.

$$\begin{aligned} WEIGHT_{Year,FuelType} &= WEIGHT_{Year-1,FuelType} + DELTA\_MKT_{itc} \\ &* \left(DEL\_WGTABS_{itc} + WEIGHT_{Year-1,FuelType} * DEL\_WGTWGT_{itc} \right) \end{aligned} \quad \textbf{(32)}$$

where

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

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 5,000 units/year, and high-volume prices, at 50,000 units/year, as described in Equations 1 and 2:

$$PRICE_{Year} = PRICE_{Year-1} + \sum_{itc=1}^{NUMTECH} DELTA\_MKT_{itc} * TECHCOST_{itc} \quad \textbf{(33)}$$

where

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

5. Estimate EV, HEV, PHEV, and FC characteristics

Vehicle attributes, including price, weight, fuel economy, and horsepower are adjusted for the specific characteristics of electric, hybrid electric, plug-in hybrid electric, and fuel cell vehicles.

First, the price of the vehicle is adjusted according to the following assignment statements:

a) Price of Vehicle

$$PRICE_{class,group,Year,FuelType} = PRICE_{class,group,Year,FuelType} + Elec\_Stor\$_{class,group,Year,FuelType}$$
$$PRICEHI_{class,group,Year,FuelType} = PRICEHI_{class,group,Year,FuelType} + Elec\_Stor\$_{class,group,Year,FuelType} \quad \textbf{(34)}$$

where

Elec_Stor$ = Price of storage device for EV, HEV, PHEV10, PHEV40, and FC vehicles.

The price of the storage devices for EV, HEV, PHEV10, PHEV40, and FC vehicles include battery, non-battery systems, and, in the case of FC vehicles, storage tank and fuel cell stack costs. Battery costs are discussed first below. Non-battery systems and FC specific costs are included under each of the subsequent individual vehicle type sections.

1) Battery costs

EV, HEV, PHEV10, PHEV40, and FC vehicles utilize battery technology as energy storage devices. The Transportation Sector Demand Module considers Nickel Metal Hydride and Lithium-ion (Li-ion) batteries for use in HEV and initial EV applications and Li-ion batteries for use in PHEV10, PHEV40, FC, and later EV vehicles. Nickel Metal Hydride (NiMH) battery cost ($/kWh) is read in from TRNLDV.XML and decline is estimated exogenously across the projection period. Li-ion battery cost ($/kWh) is calculated endogenously based on production learning and economies of scale cost reduction across four phases: Revolutionary, Evolutionary, Mature, and High Volume:

$$Li\_ion\_cost_{year} = a * (lion\_prod_{year})^{-b} \quad \textbf{(35)}$$

where

Li_ion_cost = Cost of Li-ion battery ($/kWh).

a = Initial battery cost at start of phase period ($/kWh) / initial production at start of phase period ^ -b, modified by an R&D based Li-ion cost adjustment.

lion_prod = Annual Li-ion battery production (kWh).

b = Learning rate based function.

The Revolutionary, Evolutionary, Mature, and High Volume phase periods are differentiated by different learning rates, with the greater learning taking place during the Revolutionary and Evolutionary periods and the least amount of learning occurring in the Mature and High Volume phases. The Evolutionary, Mature and High Volume phases are reached at an internally specified level of annual battery production.

2) EV – Electric vehicle

$$Elec\_Stor\$_{class,group,Year,EV} = PHEV\_kWhr_{class,group,Year,EV} * EVBat\$\_kWhr_{Year} * EV\_sys\_\$_{class,Year} \quad \textbf{(36)}$$

where

$PHEV\_kWhr_{EV}$ = Required battery size (kWh),

$PHEV\_kWhr_{EV100}$ = $weight_{class,group,year,EV}$ * 0.00823 kilowatthours per vehicle pound / EV_DOD_{year}.

$PHEV\_kWhr_{EV200}$ = $weight_{class,group,year,EV}$ * 0.01618 kilowatthours per vehicle pound / EV_DOD_{year}.

$PHEV\_kWhr_{EV300}$ = $weight_{class,group,year,EV}$ * 0.025 kilowatthours per vehicle pound / EV_DOD_{year}.

EVBat$_kWh = Battery cost ($/kWh),

= $Li\_ion\_cost_{year}$ * $Lion\_MktSh_{year}$ + $NiMH\_cost_{year}$ * (1-$Lion\_MktSh_{year}$).

NiMH_cost = Cost of Nickel Metal Hydride battery ($/kWh).

Lion_MktSh = Market share of Lithium-ion battery.

EV_DOD = Batteries maximum depth of discharge (percent).

EV_sys_$ = EV non-battery system cost.

3) HEV – Hybrid Electric Vehicle

$$Elec\_Stor\$_{class,group,Year,HEV} = HEVBatPack\$_{class,group,HEV} + HEV\_Sys\_\$_{Year} \quad \textbf{(37)}$$

where

HEVBatPack$ = lesser of the Cost of Nickel Metal Hydride battery ($/kWh) or Lithium-ion battery ($/kWh),

HEV_Sys_$ = HEV system cost ($).

4) PHEV10 and PHEV40 – Plug-in Hybrid Electric Vehicle, 10- and 40-mile all-electric range

$$Elec\_Stor\$_{class,group,Year,PHEVXX} = PHEV\_kWh_{class,group,PHEVXX} * PHEVXXBat\$kWh_{Year} + PHEV\_Sys\_\$_{Year} \quad \textbf{(38)}$$

where

for PHEV10, PHEV_kWh = $weight_{class,group,year,gasoline}$ * 0.001115 kilowatthours per vehicle pound / $PHEV\_DOD_{year}$.

for PHEV40, PHEV_kWh = $weight_{class,group,year,gasoline}$ * 0.003617 kilowatthours per vehicle pound / $PHEV\_DOD_{year}$.

PHEV_Sys_$ = PHEV40 system cost adjusted for learning.

PHEV10Bat$kW = $Li\_Ion\_Cost_{year}$, adjusted for production-based learning.

PHEV40Bat$kWh = $Li\_Ion\_Cost_{year}$, adjusted for production-based learning.

PHEV_DOD = Batteries maximum depth of discharge (percent)

5) FC – Fuel cell vehicle

$$Elec\_Stor\$_{class,group,Year,FC} = FUELCELL_{class,group,Year,FC} + BATTERY_{class,group,Year,FC} + TANKCOST_{FC} \tag{39}$$

where

FUELCELL = Fuel cell cost ($),

= $weight_{class,group,year,gasoline}$ * 0.028*$FuelCell\$kW_{year,FC,}$.

FuelCell$kW = Input fuel cell cost ($/kW).

BATTERY = Battery cost ($),

= $weight_{class,group,year,gasoline}$ * 0.0005*$Li\_ion\_Cost_{year}$, kilowatthours per vehicle pound.

TANKCOST = Storage cost of hydrogen, methanol, or ethanol.

Second, consider the vehicle weight.

b) Weight of vehicle

The vehicle weight is modified by the battery weight, depending on the alternative fuel vehicle used:

$$WEIGHT_{class,group,Year,FuelType} = WEIGHT_{class,group,Year,gasoline} + Battery\_Wt_{class,group,Year,FuelType} \tag{40}$$

where

Battery_Wt = Weight of storage device for EV, HEV, PHEV10, and PHEV40.

The weight of the storage device for each alternative fuel vehicle is now determined:

1) EV – Electric vehicle

$$Battery\_Wt_{class,group,Year,EV} = -500 + EV\_Batt\_Wt_{Year} * EV\_kWhr_{class,group,Year,EV} \quad \textbf{(41)}$$

where

EV_Batt_Wt = Average electric vehicle battery weight (lbs/kWh).

= 18.33* $Lion\_MktSh_{year}$ + 53.42 * (1-$Lion\_MktSh_{year}$).

2) HEV – Hybrid electric vehicle

$$Battery\_Wt_{class,group,Year,HEV} = HEV\_Batt\_Wt_{Year} * HEV\_kWh_{class,group,Year,HEV} \quad \textbf{(42)}$$

where

HEV_Batt_Wt = Average hybrid electric vehicle battery weight (lbs/kWh),

= 53.42.

HEV_kWh = $weight_{year,HEV}$ * 0.0005, kilowatthours per vehicle pound.

3) PHEV10 and PHEV40 – Plug-in 10 and 40 Hybrid Electric Vehicle

$$Battery\_Wt_{class,group,Year,PHEVXX} = PHEVXX\_Batt\_Wt_{Year} * PHEVXX\_kWh_{class,group,Year,HEV} \quad \textbf{(43)}$$

where, XX=10 and XX=40,

PHEV10_Batt_Wt = PHEV40_Batt_Wt = 18.33 lbs/kWh.

Third, consider vehicle horsepower.

c) HP - Horsepower of vehicle

The vehicle horsepower for EV, HEV, PHEV10, PHEV40, and FC is calculated by adjusting the gasoline-powered vehicle by the ratio of the weight of the alternative fuel vehicle relative to the weight of the gasoline engine vehicle:

$$HP_{class,group,Year,FuelType} = FAC_{FuelType} * WEIGHT_{class,group,Year,FuelType} * \frac{HP_{class,group,Year,Gasoline}}{WEIGHT_{class,group,Year,Gasoline}} \quad \textbf{(44)}$$

where

FAC = 1.0 for HEV, PHEV10, and PHEV40,

= 0.8 for EV and FC.

Finally, consider the vehicle fuel economy:

d) Fuel economy of the electric vehicle and fuel cell vehicle

1) EV – Electric vehicle:

$$FE_{Year,EV} = \left(\frac{1}{0.125 * (WEIGHT_{class,group,Year,EV} / 2200) / 0.8}\right) * 5253000 * (1/42) * (1/3412) \quad \textbf{(45)}$$

1/3412 = inverse of Btu per kWh

1/42 = share of one gallon per barrel of petroleum

0.125 = Btu per gallon gasoline divided by 100,000

2200 = number of pounds in one metric ton

5253000 = converts Btu to mmbd

0.8 = fuel economy degradation factor

2) FC – Fuel cell:

$$FE_{Year,FC} = \frac{1}{GALPERMILE_{FC} * \dfrac{WEIGHT_{Year,Gasoline}}{1000}} \quad \textbf{(46)}$$

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).

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:

$$HP_{Year,FuelType} = WEIGHT_{Year,FuelType} * \frac{HP_{Year-1,FuelType}}{WEIGHT_{Year-1,FuelType}} \quad \textbf{(47)}$$

where

HP = Vehicle horsepower.

WEIGHT = Vehicle weight.

The horsepower adjustments for dedicated electric vehicles, hybrid electric, and fuel cell vehicles are described above.

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 adjusts for any changes due to 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

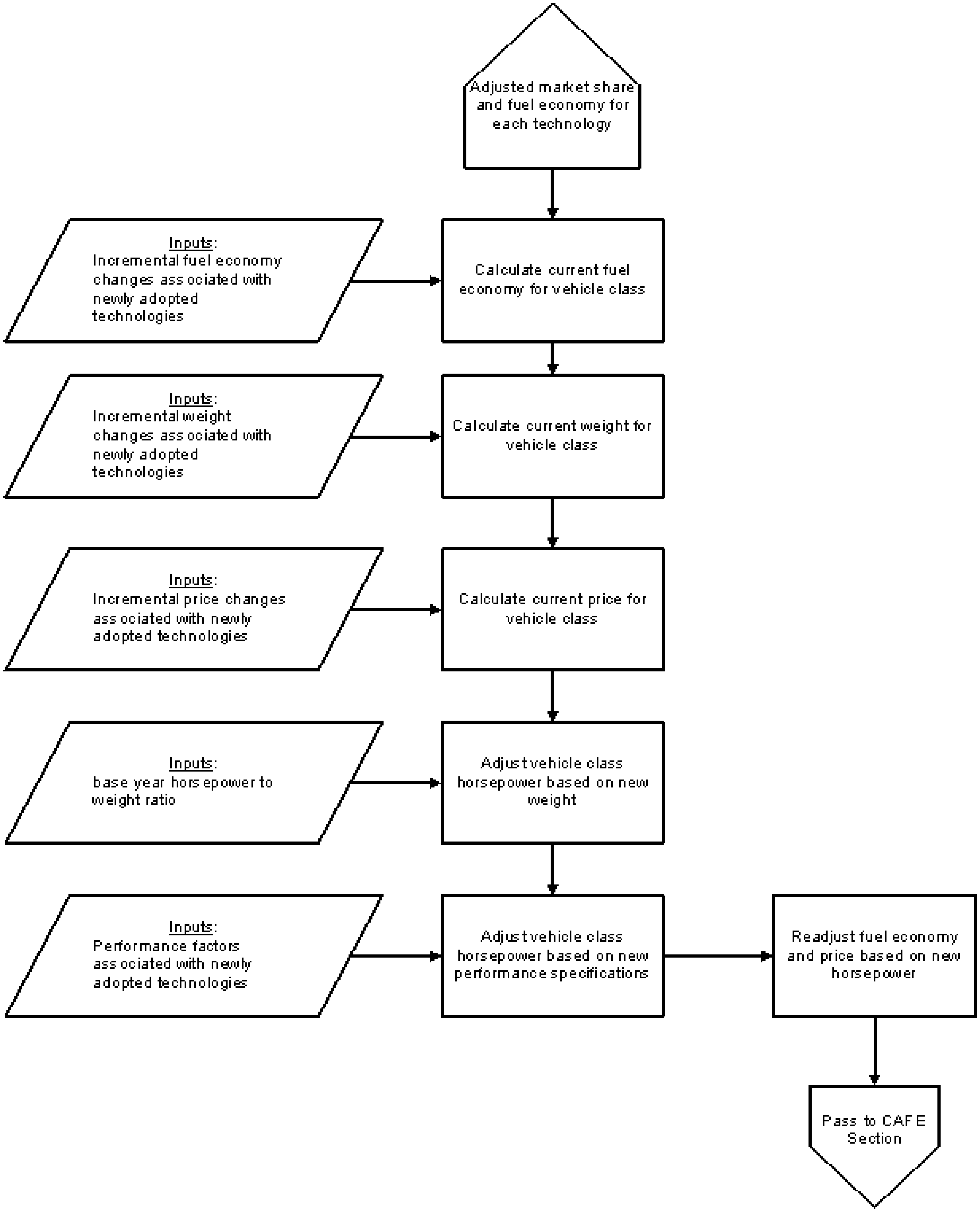
Calculate the annual horsepower adjustment due to technology introductions, which is equal to the sum of incremental changes due to newly adopted technologies:

$$TECH\_ADJHP_{year} = \sum_{itc=1}^{NUMTECH} \left(DELTA\_MKT_{itc} * DEL\_HP_{itc} \right) \tag{48}$$

where

DEL_HP = Fractional change in horsepower by technology type.

Figure 6. Weight and horsepower calculation



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:

$$PERF\_ADJHP_{Year} = \left(\frac{INCOME_{Year}}{INCOME_{Year-1}}\right)^{0.9} * \left(\frac{PRICE_{Year-1}}{PRICE_{Year}}\right)^{0.9} * \left(\frac{FE_{Year}}{FE_{Year-1}}\right)^{0.2} * \left(\frac{FUELCOST_{Year-1}}{FUELCOST_{Year}}\right)^{0.2} - 1 \qquad \textbf{(49)}$$

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.

The model calculates 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 2016, DEMAND_USED, must be accounted for through the use of parameter USEDCAP:

$$DEMAND\_USED = \left(PERFCAP - HP\_WGT_{BaseYear}\right) * \left(\frac{USEDCAP}{1 - USEDCAP}\right) \qquad \textbf{(50)}$$

where

DEMAND_USED = Demand accrued between 1990 and 2016.

PERFCAP = Performance cap.

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

USEDCAP = Input parameter.

and

$$PERF\_COEFF_{Year} = 1 - \left(\frac{HP\_WGT_{Year} - HP\_WGT_{BaseYear} + DEMAND\_USED}{PERFCAP - HP\_WGT_{BaseYear} + DEMAND\_USED}\right) \qquad \textbf{(51)}$$

where

PERF_COEFF = Performance coefficient, between 0 and 1.

and

$$PERF\_ADJHP_{Year} = PERF\_ADJHP_{Year} * PERFFACT * PERF\_COEFF_{Year} \qquad \textbf{(52)}$$

where

PERFFACT = Performance factor, exogenous input from trnldv.xml.

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:

$$TTL\_ADJHP_{Year} = TECH\_ADJHP_{Year} + PERF\_ADJHP_{Year} \quad \textbf{(53)}$$

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%. If an adjustment greater than 10% 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%:

$$\begin{aligned} HP\_GIVEBACK_{Year} &= TTL\_ADJHP_{Year} - 0.1 \\ PERF\_ADJHP_{Year} &= PERF\_ADJHP_{Year} - HP\_GIVEBACK_{Year} \end{aligned} \quad \textbf{(54)}$$

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

$$TECH\_ADJHP_{Year} = TECH\_ADJHP_{Year} + PERF\_ADJHP_{Year} \quad \textbf{(55)}$$

Now, calculate the modified total horsepower adjustment:

$$TTL\_ADJHP_{Year} = TECH\_ADJHP_{Year} + PERF\_ADJHP_{Year} \quad \textbf{(56)}$$

f) Maximum Limit on Horsepower-to-Weight Ratio

This imposes 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 90% of the base year value or 4% for two-seaters and 3.3% 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:

$$\begin{aligned}
&MIN_ADJHP_{Year} = \left(\frac{HP_WGT_MIN_{BaseYear} * WEIGHT_{Year}}{HP_{Year}} - 1\right) \\
&PERF_ADJHP_{Year} = PERF_ADJHP_{Year} + MIN_ADJHP_{Year} - TTL_ADJHP_{Year} \\
&TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year}
\end{aligned} \tag{57}$$

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 constrained to the maximum of either zero or the level of adjustment required to maintain the minimum allowable horsepower-to-weight ratio. In other words, the third pass takes back the technology-driven horsepower demand except that which is 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.

$$\begin{aligned}
&EXCESS_ADJHP_{Year} = MIN(TECH_ADJHP_{Year}, TTL_ADJHP_{Year} - MIN_ADJHP_{Year}) \\
&TECH_ADJHP_{Year} = TECH_ADJHP_{Year} - EXCESS_ADJHP_{Year} \\
&TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year}
\end{aligned} \tag{58}$$

The model first computes the horsepower give back:

$$HP\_GIVEBACK_{Year} = HP\_GIVEBACK_{Year} + EXCESS\_ADJHP_{Year} \tag{59}$$

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

$$HP_{Year,FuelType} = HP_{Year,FuelType} * \left(1 + TTL\_ADJHP_{Year}\right) \quad \textbf{(60)}$$

7. Readjust fuel economy and price

Once the horsepower adjustment has been determined, the final fuel economy, vehicle price, and vehicle range are 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 effects 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 that giveback is “negative demand”:

$$PERF\_ADJHP_{Year} = PERF\_ADJHP_{Year} - HP\_GIVEBACK_{Year} \quad \textbf{(61)}$$

$$ADJFE_{Year} = -0.22 * PERF\_ADJHP_{Year} - 0.56 * SIGN * PERF\_ADJHP_{Year}^{2} \quad \textbf{(62)}$$

where,

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

The final vehicle fuel economy is then determined as follows:

$$FE_{Year} = FE_{Year} * \left(1 + ADJFE_{Year}\right) \quad \textbf{(63)}$$

b) Vehicle price

Vehicle price is finally estimated:

$$PRICE_{Year} = PRICE_{Year} + PERF\_ADJHP_{Year} * VALUEPERF_{Year} \quad \textbf{(64)}$$

Note that as these are final adjustments and 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:

$$RANGE_{Year,FuelType} = TANKSIZE * FE_{Year,Gasoline} * \left(1 + AFVADJRN_{FuelType}\right) \quad \textbf{(65)}$$

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 at a fixed range. For an EV100 vehicle the range is set to 90 miles, for an EV200 the range is set to 200 miles, and for an EV300 the range is set to 300 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. 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:

$$DIFFLN_{Year} = A * \ln\left(\frac{Year}{Year-1}\right) + B * \ln\left(\frac{FUELCOST_{Year}}{FUELCOST_{Year-1}}\right) + C * \ln\left(\frac{INCOME_{Year} - \$13{,}000}{INCOME_{Year-1} - \$13{,}000}\right) + D * \ln\left(\frac{PRICE_{Year,Gasoline}}{PRICE_{Year-1,Gasoline}}\right) \quad (66)$$

where

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

A, B, C, D = Coefficients, elasticities, exogenously introduced from trnldv.xml.

Class market shares

The model solves for the log-share ratio:

$$RATIO\_LN = DIFFLN_{Year} + \ln\left(\frac{CLASS\_SHARE_{class,group,nhtsalyr}}{1 - CLASS\_SHARE_{class,group,nhtsalyr}}\right) \quad (67)$$

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.

nhtsalyr = Last year of National Highway Traffic Safety Administration historical data.

The model solves for the class market share:

$$CLASS\_SHARE_{class,group,Year} = \frac{e^{RATIO\_LN}}{1+e^{RATIO\_LN}} \quad \textbf{(68)}$$

The model normalizes so that shares total 100% within each CAFE group:

$$CLASS\_SHARE_{class,group,Year} = \frac{CLASS\_SHARE_{class,group,Year}}{\sum_{class=1}^{6} CLASS\_SHARE_{class,group,Year}} \quad \textbf{(69)}$$

9. Calculate CAFE

This routine calculates the corporate average fuel economy (CAFE) for each of the nine CAFE groups:

1) Domestic Car
2) Asian Car
3) European Car
4) Luxury / Sport Car
5) Truck – Manufacturer Group 1 - Domestic
6) Truck – Manufacturer Group 2 – Domestic
7) Truck – Manufacturer Group 3 - Domestic
8) Truck – Manufacturer Group 4 - Import
9) Truck – Manufacturer Group 5 - Import

For each vehicle group the CAFE compliance calculation proceeds as follows:

$$CafeMpgWgt_{group,Year} = \frac{\sum_{class=1}^{6} CLASS\_SHARE_{class,group,Year} * apshr55}{\sum_{class=1}^{6} Mpg_{class,group,FuelType,Year}} \quad \textbf{(70)}$$

where

AFVcredit = Alternative fuel vehicle CAFE credits earned by manufacturer.

Flex fuel and dedicated alternative fuel vehicles earn fuel economy credits that last until 2019 for flex fuel vehicles and do not expire for dedicated alternative fuel vehicles. Fuel economy for each manufacturer is then harmonically weighted based upon vehicle sales by size class and fuel type (NewMPG).

This CAFE estimate is then compared with the legislative standard for the nine 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, $FPMpgGrp_{Group,Year}$. $FPMpg_{Class,Group,Year}$ is computed for each class in each group based on the footprint. Passenger cars use the traditional standard before 2011 and the alternative standard for subsequent years.

Light trucks use the traditional standard before 2008. If the year is between 2008 and 2011, the light truck standard is the lesser of the alternative footprint miles per gallon (MPG) standard and the traditional standard. If the alternative standard is chosen, then light trucks must continue to use it in later years.

The alternative CAFE standard is calculated for 2011 as follows:

$$FPMpg_{class,group,Year} = \left(\left(\frac{1}{CFCoefA_{Year}} \right) + \left(\frac{1}{CFCoefB_{Year}} - \frac{1}{CFCoefA_{Year}} \right) * \frac{e^{\frac{FPrint_{class,group,Year} - CFCoefC_{Year}}{CFCoefD_{Year}}}}{1 + e^{\frac{FPrint_{class,group,Year} - CFCoefC_{Year}}{CFCoefD_{Year}}}} \right)^{-1} \tag{71}$$

where

CFCoefA = The maximum fuel economy target for cars or trucks by year.

CFCoefB = The minimum fuel economy target for cars or trucks by year.

CFCoefC = The footprint midway between by year.

CFCoefD = The rate of change parameter by year.

FPrint = Footprint for each class and group of cars or trucks by year.

The alternative CAFE standard for 2012 and subsequent years is calculated as the greenhouse gas emissions equivalent fuel economy value:

$$FPMpg_{class,group,Year} = \frac{1}{\min(\max(((CFCoefC2 * FPrint) + CFCoefD2), \frac{1}{CFCoefA2}), \frac{1}{CFCoefB2})} \tag{72}$$

where

CFCoefA2 = The function's upper fuel economy limit for cars or trucks by year.

CFCoefB2 = The function's lower fuel economy limit for cars or trucks by year.

CFCoefC2 = The slope of the function

CFCoefD2 = The intercept of the sloped portion of the function.

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

The banking of MPG credits occurs in the first pass of the fuel economy calculation. On the first pass, if the manufacturing group passes CAFE, then it banks its excess MPG credits. Otherwise it pulls the credit values out of the bank, with the older credits being withdrawn first. There is no credit trading in the model.

10. CAFE standard compliance

This algorithm adjusts sales of electric drive train and diesel light-duty vehicles so that CAFE standards are met, followed by a corresponding decrease in the sale of gasoline vehicles.

The CAFETEST routine is called after the third pass of MTCC. New vehicle sales are re-computed for the alternative fuel types, CAFETYP, in the most cost-effective order determined by incremental vehicle cost and fuel savings over a specified period of time. For passenger cars, the EPA size classes are used and for light-duty trucks, classes are defined for SUVs, pickups and vans by gross vehicle weight rating. For each vehicle group the CAFE calculation proceeds as follows.

For any of the nine vehicle manufacturing groups described above that fail to meet the CAFE standard a new set of sales values is computed through the following steps: First, the model calculates the share of total sales.

$$DELTA_{class,group} = 0.0125 * CLASS\_SHARE_{class,group} * SALESHR_{group} \quad \textbf{(73)}$$

where

SALESHR = Car and light truck sales share by group.

For each alternative fuel type, CAFETYP, new sales are computed up to a total of twenty times at increments of 1.25%. A new set of CAFE calculations is 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:

$$AVSALES_{vt,class,11,FuelType} = AVSALES_{vt,class,11,FuelType} + DELTA_{vt,class,FuelType} \quad \textbf{(74)}$$

$$AVSALES_{vt,class,11,GAS} = AVSALES_{vt,class,11,GAS} - DELTA_{vt,class,GAS} \quad \textbf{(75)}$$

where

FuelType = Gasoline hybrids, diesel, and diesel hybrids.

The new shares, APSHR55, are then re-calculated. Total sales, AVSALEST, remain unchanged.

If at any time sales of conventional gasoline or FFV vehicles become negative, sales of these vehicles are increased until sales reach a non-negative number, with a corresponding decrease in vehicle sales of electric drive train or diesel vehicles. There are constraints on new vehicle sales. For each CAFETYP, sales adjustments are limited to twenty cycles to meet the standard.

11. Combine results of domestic and imported vehicles

In subsequent submodules of the transportation sector demand module, vehicle sales by manufacturer groups 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 computed as weighted sums of vehicle class totals, where each vehicle class, *class*, is weighted by its relative share of the market (PERGRP). These numbers are assumed to be constant across classes and time and have been obtained from NHTSA data for the domestic, *dom*, and imported, *imp*, market shares:

$$MPG_{vt,class} = \frac{1}{\dfrac{PERGRP_{dom,class}}{FE_{dom,class}} + \dfrac{PERGRP_{imp,class}}{FE_{imp,class}}} \quad \textbf{(76)}$$

$$HPW_{vt,class} = HP_{dom,class} * PERGRP_{dom,class} + HP_{imp,class} * PERGRP_{imp,class} \quad \textbf{(77)}$$

$$PRI_{vt,class} = PRICE_{dom,class} * PERGRP_{dom,class} + PRICE_{imp,class} * PERGRP_{imp,class} \quad \textbf{(78)}$$

$$VRNG_{vt,class} = RNG_{vt,class} = RANGE_{dom,class} * PERGRP_{dom,class} + RANGE_{imp,class} * PERGRP_{imp,class} \quad \textbf{(79)}$$

$$WGT_{vt,class} = WEIGHT_{dom,class} * PERGRP_{dom,class} + WEIGHT_{imp,class} * PERGRP_{imp,class} \quad \textbf{(80)}$$

where

MPG = Vehicle fuel economy.

HPW = Vehicle horsepower.

PRI = Vehicle price.

VRNG = RNG = Vehicle range.

WGT = Vehicle weight (lbs)

PERGRP = Proportion of vehicles imported 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 Consumer Vehicle Choice Component (CVCC) and the overall fleet stock component to produce estimates of fleet efficiencies.

Regional Sales Component

The Regional Sales Component is a simple accounting mechanism using exogenous estimates of new car and light truck sales and the results of the MTCC to produce estimates of regional sales and the characteristics of light-duty vehicles that are subsequently passed to the Light-Duty Vehicle Stock Component.

Nationwide estimates of total new vehicle sales come from the NEMS Macroeconomic Activity Module. In order to comply with the NEMS requirement for regional fuel consumption estimates, the Regional Sales Component allocates new car and light truck sales among the nine Census divisions and permits regional variations in vehicle attributes. This also gives the transportation sector demand module the capability to analyze regional differences in alternative vehicle legislation. For example, California's Zero Emission Vehicles Program requires a minimum percentage of vehicles sold to be zero emission vehicles, transitional zero emission vehicles, and partial zero emission vehicles. This is earned in part through credits obtained from their sale. The program has been adopted by Connecticut, Maine, Maryland, Massachusetts, New jersey, New York, Oregon, Rhode Island, and Vermont, and is included in the Transportation Sector Demand Module.

This is not a separate component in itself, but rather a series of intermediate calculations used to generate several regional variables which are used in subsequent steps in the transportation sector demand module. 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 MTCC sale shares among six market classes

The first stage in this component 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 MTCC. 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 the nine manufacturing groups have already been combined, the separate market shares are recorded and the calculations are performed separately for each manufacturing group.

It is first necessary to estimate car and light truck sales after getting total sales from the Macroeconomic Activity Module. 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 Submodule; trucks from 8,500 to 10,000 pounds, modeled separately in the Class 2b Vehicle Component; and trucks over 10,000 pounds, included in the Highway Freight Submodule. Additionally, the LDV Submodule 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, CARSHRT:

$$CARSHRT_{Year} = e^{\left\{\begin{array}{l}\beta_0(1-\rho)+\left[\rho LOG\left(CARSHARE_{Year-1}\right)\right]+\\ \beta_1\left[LOG\left(INC00\$16_{Year}\right)-\rho LOG\left(INC00\$16_{Year-1}\right)\right]+\\ \beta_2\left[LOG\left(PMGTR00\$C_{Year}\right)-\rho LOG\left(PMGTR00\$C_{Year-1}\right)\right]+\\ \beta_3\left[LOG\left(AHPCAR_{Year-1}\right)-\rho LOG\left(AHPCAR_{Year-2}\right)\right]+\\ \beta_4\left[LOG\left(AWTCAR_{Year-1}\right)-\rho LOG\left(AWTCAR_{Year-2}\right)\right]+\\ \beta_5\left[LOG\left(TRUEMPG_{Year-1}\right)-\rho LOG\left(TRUEMPG_{Year-2}\right)\right]+\\ \beta_6\left[LOG\left(DUMM_{Year}\right)-\rho LOG\left(DUMM_{Year-1}\right)\right]\end{array}\right.} \quad \textbf{(81)}$$

where,

CARSHARE = historic car share

INC00$16 = Disposable income per capita for population age 16+, expressed in 2000 dollars..

PMGTR00$16 = Fuel price in 2000$ per gallon.

AHPCAR = average car horsepower

AWTCAR = average car weight

TRUEMPG = vehicle fuel economy

DUMM = Dummy variable

ρ = autocorrelation coefficient for the difference equation.

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

$$\begin{gathered} NEWCARS_{Year} = \left(MC\_SUVA_{Year} + TEMPCLS12A_{Year}\right) * CARSHARE_{Year} \\ and \\ NEWCLS12A_{Year} = \left(MC\_SUVA_{Year} + TEMPCLAS12A_{Year}\right) * \left(1 - CARSHARE_{Year}\right) \end{gathered} \quad \textbf{(82)}$$

where

NEWCARS = Total new car sales.

NEWCLS12A = Total new light truck sales.

MC_SUVA = Total car sales, from the Macroeconomic Activity Module.

TEMPCLAS12A = Sales of class 1 and 2 light trucks.

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

Calculate non-fleet, non-commercial sales of cars (*group=1-4*) and light trucks (*group=5-9*) across the 6 market classes:

$$\begin{aligned} NVS7SC_{group=1-4,class,Year} &= CLASS\_SHARE_{group=1-4,class,Year} * NEWCARS_{Year} * \\ &\quad (1 - FLTCRAT_{Year}) * SALESHR_{group=1-4,Year} \\ &\quad and \\ NVS7SC_{group=5-9,class,Year} &= CLASS\_SHARE_{class,group=5-9,Year} * NEWCLS12A_{Year} * \\ &\quad (1 - FLTTRAT_{Year}) * SALESHR_{group=5-9,Year} \end{aligned} \tag{83}$$

where

NVS7SC = Non-fleet, non-commercial sales.

FLTCRAT = Fraction of new cars purchased by fleets by year.

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

Sales are then combined for the nine manufacturing groups, as follows:

$$\begin{aligned} NCSTSC_{class,Year} &= \sum_{group=1}^{4} NVS7SC_{group,class,Year} \\ &\quad and \\ NLTSTSC_{class,Year} &= \sum_{group=5}^{9} NVS7SC_{group,class,Year} \end{aligned} \tag{84}$$

where

NCSTSC = Sales of cars by the EPA vehicle size classes.

NLTSTSC = Sales of light trucks by vehicle size class.

The estimation of non-fleet market shares for cars and light trucks by market class starts with the most recent historical data and assumes growth at the same rate as the non-fleet, non-commercial share of sales of cars and light trucks:

$$PASSHRR_{class,Year} = PASSHRR_{class,Year-1} * \frac{\left(\frac{NCSTSC_{class,Year}}{\sum_{class=1}^{6} NCSTSC_{class,Year}} \right)}{\left(\frac{NCSTSC_{class,Year-1}}{\sum_{class=1}^{6} NCSTSC_{class,Year-1}} \right)}$$

and

$$LTSHRR_{class,Year} = LTSHRR_{class,Year-1} * \frac{\left(\frac{NLTCSTSC_{class,Year}}{\sum_{class=1}^{6} NLTSTSC_{class,Year}} \right)}{\left(\frac{NLTSTSC_{class,Year-1}}{\sum_{class=1}^{6} NLTSTSC_{class,Year-1}} \right)} \quad \textbf{(85)}$$

where

PASSHRR = The non-fleet market share for cars; for the last historical data year, this is the fraction of car sales as reported by the National Highway Traffic Safety Administration.

LTSHRR = The non-fleet market share for light trucks; for the last historical data year, this 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 non-fleet market shares, is then calculated:

$$AHPCAR_{Year} = \sum_{class=1}^{6} (PASSHRR_{class,Year} * HPW_{class,Year})$$

$$and \quad \textbf{(86)}$$

$$AHPTRUCK_{Year} = \sum_{class=1}^{6} (LTSHRR_{trkclass,Year} * HPW_{trkclass,Year})$$

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 in the State Energy Data System (SEDS), are initialized, ensuring that no region has a zero share in the preceding time period. Shares are then adjusted for change over time, assuming growth at the rate of personal income growth in each region, and renormalized so the shares add to 1.0:

$$SEDSHR_{FUEL,REG,Year} = \frac{SEDSHR_{FUEL,REG,Year-1} * \left(\frac{MC\_YPDR_{REG,Year}}{MC\_YPDR_{REG,Year-1}} \right)}{\sum_{REG=1}^{9} \left(SEDSHR_{FUEL,REG,Year-1} * \left(\frac{MC\_YPDR_{REG,Year}}{MC\_YPDR_{REG,Year-1}} \right) \right)} \quad \textbf{(87)}$$

where

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

MC_YPDR = Estimated disposable personal income by region REG.

REG = Index referring to Census region.

These shares are passed to other submodules in the transportation sector demand module and used for the first year computation of VMTLDR and VMTEER, in this case 1995.

The national total of new car and light truck sales is then allocated among regions. The allocation 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:

$$PMGTR00\$_{REG,Year} = 0.1251 * \left(\frac{PMGTR_{REG,Year}}{MPGFLT_{Year}} \right) \quad \textbf{(88)}$$

where

PMGTR00$ = The cost of driving per mile in region *REG*, in $/mile.

PMGTR = The regional price of motor gasoline, in $/million Btu (MMBtu).

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

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

Calculate regional per capita income:

$$INC90\$NP_{REG,Year} = \left(\frac{MC\_YPDR_{REG,Year}}{MC\_N_{REG,Year}} \right) \quad \textbf{(89)}$$

where

INC90$NP = Regional per capita disposable income.

MC_YPDR = Total disposable income in region REG.

MC_N = Total population in region REG.

Estimate regional driving demand[9]:

$$VMTLDR_{REG,Year} = e^{X+Y} \quad \textbf{(90)}$$

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

where,

$$X = \begin{Bmatrix} \rho LOG\left(VMTLDR_{REG,\,Year\,-\,1}\right) + \beta_0\left(1-\rho\right) \\ + \beta_1\left[LOG\left(VMTLDR_{REG,\,Year\,-\,1}\right) - \rho LOG\left(VMTLDR_{REG,\,Year\,-\,2}\right)\right] \end{Bmatrix}$$

$$Y = \begin{Bmatrix} \beta_2\left[LOG\left(INC00\$16_{REG,Year}\right) - \rho LOG\left(INC00\$16_{REG,Year-1}\right)\right] \\ + \beta_3\left[LOG\left(PMGTR00\$_{REG,Year}\right) - \rho LOG\left(PMGTR00\$_{REG,Year-1}\right)\right] \end{Bmatrix}$$

and

$$VMTEER_{REG,Year} = VMTLDR_{REG,Year} * LICDRIVER_{REG,Year} \quad \textbf{(91)}$$

where

VMTEER = Total VMT in region *REG*.

VMTLDR = Regional vehicle-miles traveled per licensed driver.

LICDRIVER = Total regional licensed drivers

PMGTR00$ = Fuel price in 2000 dollars per gallon

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,Year} = \frac{VMTEER_{REG,Year}}{\sum_{REG=1}^{9} VMTEER_{REG,Year}} \quad \textbf{(92)}$$

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

$$NCS_{REG,class,Year} = NCSTSC_{class,Year} * RSHR_{REG,Year} \quad \textbf{(93)}$$

and,

$$NLTS_{REG,class,Year} = NLTSTSC_{class,Year} * RSHR_{REG,Year} \quad \textbf{(94)}$$

where

NCS = New car sales, by market class and region.

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

RSHR = Regional share of VMT and (assumed) sales.

Consumer Vehicle Choice Component (CVCC)

The CVCC is a projection tool designed to support the LDV Submodule in the Transportation Sector Demand Module. The objective of the CVCC is to estimate the market penetration of conventional and alternative-fuel vehicles during the period 1995-2050. To project technology market shares, the component uses estimates of the following variables and vehicle attributes: new car fuel economy (obtained from the MTCC), vehicle price, vehicle range, fuel availability, battery replacement cost, performance (measured by the horsepower-to-weight ratio), home refueling capability, maintenance costs, luggage space, make and model diversity or availability, and fuel price estimates generated by NEMS.

The component is useful for assessing the market penetration of conventional and alternative-fuel vehicles and for analyzing policies that might impact their penetration.

The CVCC uses 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 uses projections of the changes in vehicle and fuel attributes for the considered technologies to estimate the market share penetration for the various technologies.

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

$$\log\left(\frac{P_k}{1-P_k}\right) = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_k X_k + \varepsilon_k \qquad \textbf{(95)}$$

where

P_k = Probability of consumer choosing vehicle (k).

β_1 = Constant term.

$\beta_{1\ldots}, \beta_k$ = Coefficients of vehicle and fuel attributes.

$X_i, \ldots X_k$ = 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* year of projection. 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:

$$S_{it} = P_{it} = \sum_{n=1}^{N} \frac{P_{itn}}{N} \quad , \qquad P_{itn} = \frac{e^{V_{itn}}}{\sum_{i=1}^{I} e^{V_{itn}}} \tag{96}$$

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 a population of size N.

P_{itn} = Probability of individual n choosing type *i* in year t.

V_{itn} = 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.

This formulation assumes 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 estimates. 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 CVCC 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. A *V* value is produced for each of the vehicle technologies, each of the target regions, sizes, and scenarios.

The CVCC operates in three stages by 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 MTCC), the CVCC goes through two iterations. First, the CVCC estimates sales volume using the previous year's volume-dependent prices and then re-estimating prices and consequent sales.

The component projects market shares for 14 alternative-fuel technologies as well as for conventional gasoline and diesel technologies. As stated above, there are three stages or levels to the “tree” structure of the CVCC-logit model. In the first stage, the shares of vehicle sales are determined for five aggregate vehicle groups: conventional, hybrid, dedicated alternative fuel, fuel cell, and electric. The second stage of the logit model subdivides each of the five groups to estimate sales shares for the specific vehicle types within the each group. The conventional vehicles consist of gasoline, diesel, flex-fuel ethanol, CNG/LNG, and LPG bi-fuels. Hybrid electric vehicles comprise gasoline and diesel hybrids and gasoline plug-in hybrid electric. Dedicated CNG/LNG and LPG make up the dedicated AFV group. Fuel cell vehicles include gasoline, methanol reformers, and hydrogen-based fuel cells. The fifth group is represented by 100-, 200-, and 300-mile-range electric vehicles. The third level of the CVCC estimates the proportion of the travel in which flex or bi-fuel vehicles are using the alternative 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, performance (measured by the horsepower-to-weight ratio), 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, battery cost, and fuel availability are discussed in detail below.

The model first calculates the vehicle purchase price in nominal dollars:

$$PSPR_{vt,FuelType,class} = PRI_{vt,FuelType,class} * MC\_JPGDP \quad \textbf{(97)}$$

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 MTCC, and constrained not to drop below gasoline vehicle price plus the high volume differential between gasoline and ATV.

MC_JPGDP = GDP price deflator from the Macroeconomic Activity Module.

Next the model estimates fuel costs per mile traveled:

$$FLCOST_{vt,FuelType,class,REG} = \frac{FPRICE_{FuelType,REG}}{MPG_{vt,FuelType,class}} \quad \textbf{(98)}$$

where

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

FPRICE = Vehicle fuel price, in nominal $ per gallon.

REG = Index referring to nine census regions.

MPG = Aggregate vehicle fuel economy.

The model estimates the time, in seconds, the vehicle requires to accelerate from 0-60 mph:

$$ACCL_{vt,FuelType,class} = e^{-0.00275} * \left(\frac{HPW_{vt,FuelType,class}}{WGT_{vt,FuelType,class}} \right)^{-0.776} \quad \textbf{(99)}$$

where

ACCL = Acceleration time, in seconds, to accelerate from 0 to 60 miles per hour.

HPW = Horsepower.

The model then calculates vehicle maintenance and battery costs in nominal dollars:

$$\begin{gathered} MAINT_{1,FuelType,class,REG} = MAINTCAR_{FuelType,REG} * TMC\_PGDP \\ and \\ MAINT_{2,FuelType,class,REG} = MAINTTRK_{FuelType,REG} * TMC\_PGDP \end{gathered} \quad \textbf{(100)}$$

where

MAINTCAR = Car maintenance and battery costs.

MAINTTRK = Light truck maintenance and battery costs.

TMC_PGDP = GDP deflator.

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 logit-based CVCC 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 CVCC to allocate 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.

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 and diesel hybrid, gasoling plug-in hybrid electric	Gasoline/diesel/electricity
Flex-fuel ethanol	Ethanol/gasoline
Fuel cell methanol	Methanol/gasoline
Bi-fuel and dedicated CNG/LNG	CNG/LNG/gasoline
Bi-fuel and dedicated LPG	LPG/gasoline
Dedicated electricity 100-, 200-, and 300-mile range	Electricity
Hydrogen fuel cell	Hydrogen

The model then calculates the vehicle stocks by the highway fuel type to determine the number of refueling stations that might be using the fuel. It estimates the vehicle stock used to calculate needed refueling stations:

$$PREDSTK_{hwy\_fuel,Year} = LDVSTK_{FuelType,Year-1} + W * LDVSTK_{FuelType=flex:bi-fuel,Year-1} \tag{101}$$

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, 25% for flex and bi-fuel.

hwy_fuel = Highway fuel type, 1...8

Next the model estimates the number of new refueling stations needed to meet the requirements of the vehicle stock:

$$ALTSTAT_{hwy\_fuel,Year} = ALTSTAT_{hwy\_fuel,Year-1} + \frac{PREDSTK_{hwy\_fuel,Year} - PREDSTK_{hwy\_fuel,Year-1}}{STA\_RAT_{hwy\_fuel}} \tag{102}$$

where

ALTSTAT = Total national level alternative-fuel refueling stations.

STA_RAT = Ratio of refueling stations to vehicle stock based on history.

The total number of refueling stations is then allocated to the regions based on proportions of vehicle sales:

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

$$AFVSHREG_{REG,hwy\_fuel,Year} = \frac{FUELVSAL_{REG,hwy\_fuel,Year}}{\sum FUELVSAL_{REG,hwy\_fuel,Year}} \tag{103}$$

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

where

NCSTECH = Regional car sales by fuel type.

NLTECH = Regional light truck sales by fuel type.

FUELVSAL = Regional vehicle sales within a fuel type.

AFVSHREG = Regional vehicle sales share within fuel type.

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

Fuel availability is estimated as an index relative to the number of gasoline refueling stations on a regional basis:

$$FAVAIL_{hwy\_fuel,Year,REG} = \frac{ALTSTA_{REG,hwy\_fuel,Year}}{ALTSTA_{REG,Gasoline,Year}} \quad \textbf{(104)}$$

where

FAVAIL = Regional fuel availability index of alternative fuel.

The model then sets regional fuel availability equal to the corresponding index by engine technology fuel type:

$$FAVL_{FuelType,REG,Year} = FAVAIL_{hwy\_fuel,Year,REG} \quad \textbf{(105)}$$

Operation of the component begins at the third level and progresses to the first level, because the values from the third and second levels are used as a part of the evaluation in the second and first levels of the logit model. The component starts at level three because it is the value function for all vehicle technologies. At level two the component then calculates the share of technologies within each group, using the results of level three. Next at level one, the component computes the value function and the share of each group using the previous two level results. Finally, the market share of each vehicle technology is calculated using the shares computed in level one and level two.

a) Level three

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

$$X31XX_{vt,class} = X31_{vt,class} * \frac{X23_{vt,class}}{X22_{vt,class}}$$

$$\textbf{(106)}$$

$$BETAFA_{vt,class} = X31_{vt,class} * \frac{BETAFA2_{vt,class}}{X22_{vt,class}}$$

where X31XX = Coefficient for vehicle range,

XX = (42 = Flex ethanol, 52 = CNG/LNG Bi-fuel, and 62 = 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 element

BETAFA2 = Coefficient for fuel availability non-linear element

2) Utility values (value of monetized and non-monetized attributes to consumers) are estimated for the general cost function:

$$UISUM_{vt,FuelType,class,REG} = X31_{vt,class} * FLCOST_{vt,FuelType,class,REG} + X31XX * \frac{1}{VRNG_{vt,FuelType,class}} + BETAFA * e^{BETAFA2_{vt,class} * FAVL_{FuelType,REG}} \quad \textbf{(107)}$$

where

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

VRNG = Vehicle range in miles

FAVL = Fuel availability indexed relative to gasoline

FuelType = Fuel technologies, gasoline, flex-fuel ethanol, and bi-fuels CNG/LNG and LPG

3) Utility values are exponentiated and summed:

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

$$ETOT = \sum_{FuelType} ESUM_{FuelType} \quad \textbf{(108)}$$

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:

$$GENCOST_{vt,class} = \frac{1}{X31_{vt,class}} * \log(ETOT) \tag{109}$$

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 CVCC 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 ethanol, and bi-fuels CNG/LNG and LPG), 2) hybrid electric vehicles (gasoline and diesel hybrid electric and gasoline plug-in hybrid electric), 3) dedicated AFVs (CNG/LNG and LPG fueled), 4) fuel cell vehicles (gasoline, methanol, and hydrogen fueled), and 5) 100-, 200-, and 300-mile range electric vehicles. 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:

$$\begin{aligned} UISUM_{jt} = {} & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * GENCOST \\ & + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\ & + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\ & + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log\left(MMAVAIL_{vt,FuelType,class,Year}\right) \\ & + X210_{vt,FuelType} \end{aligned} \tag{110}$$

where

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

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

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 = Represents the utility the consumer assigns to the vehicle not captured in the vehicle attributes of the model.

PSPR = Vehicle price at the second level in dollars.

BRCOST25 = Battery replacement cost at the second level.

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 trnldv.xml.

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 (*jg*) 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.

$$\begin{aligned}
UISUM_{jt} = {} & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * FLCOST \\
& + X23_{vt,class} * \left(\frac{1}{VRNG_{vt,FuelType,class,Year}} \right) \\
& + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\
& + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\
& + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log\left(MMAVAIL_{vt,FuelType,class,Year} \right) \\
& + X210_{vt,FuelType} + BETAFA2 * e^{BETAFA22_{vt,class} * FAVL_{FuelType,REG,Year}}
\end{aligned} \quad \textbf{(111)}$$

3) Exponentiate the utility value for each vehicle technology (*jt*) and sum across all vehicle technologies within a given group (*jg*):

$$\begin{aligned}
ESUM_{jt} &= e^{UISUM_{jt}} \\
ETOT_{jg} &= \sum_{jt \subset jg} ESUM_{jt} \\
XSHARE_{jg,jt} &= \frac{ESUM_{jt}}{ETOT_{jg}}
\end{aligned} \quad \textbf{(112)}$$

where

XSHARE = Market share of alternative vehicles by the five vehicle groups and by technology.

c) Level one

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

$$GCOST_{jg} = \frac{1}{X21_{vt,class}} * \log(ETOT_{jg}) \quad \textbf{(113)}$$

where

GCOST = Generalized cost function of the group (*jg*).

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

$$UISUM_{jg} = X11_{vt,class} * GCOST_{jg} \quad \textbf{(114)}$$

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

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

$$YSHARE_{jg} = \frac{ESUM_{jg}}{\sum_{jg=1}^{5} ESUM_{jg}} \quad \textbf{(115)}$$

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

where

YSHARE = market share of alternative vehicles by the five vehicle groups.

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

APSHR44 = Percent of total light-duty vehicles sales by technology type.

Legislative mandates affecting alternative vehicle sales in subroutine TLEGIS

Subroutine TLEGIS adjusts light-duty vehicle sales to relect state-level mandates on the sales of Zero Emission Vehicles (ZEV), including allowance for Transitional Zero Emission Vehicles (TZEV) and Adanced Technology Partial Zero Emission Vehicle (ATPZEV) towards credit compliance. States that currently have these legislative requirements include California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.

1) Determine regional ZEV credit mandate compliance requirements:

$$ZEV\_COVERED\_SALES_{iregn} = (\sum_{ivtyp=1}^{2} vsales_{iregn,year} + \sum_{iclass=1}^{6} vsales_{iregn,year} + \sum_{ildv=1}^{16} vsales_{iregn,year}) * zev\_state\_alloc_{iregn,year}$$

$$ZEV\_CREDIT\_REG_{iregn,izev} = ZEV\_COVERED\_SALES_{iregn} * ZEV\_Requirement_{izev,year}$$

(116)

where

$ZEV\_COVERED\_SALES_{iregn}$ = total vehicle sales by region covered under ZEV mandate

ivtyp = vehicle type (n = 1 to 2)

ildv = vehicle fuel type (n = 1 to 16)

iregn is in the set {Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)}

iclass = vehicle size class (n = 1 to 6)

$zev\_state\_alloc_{iregn,year}$ = share of Census Division vehicle sales belonging to a ZEV participating state

$ZEV\_CREDIT\_REG_{iregn,izev}$ = credit requirement by region and ZEV classification type

izev = ZEV mandate classification (1=ATPZEV, 2=TZEV, 3=ZEV)

2) Calculate ZEV mandate credits earned through vehicle sales by region

$$ZEV\_CREDIT\_LDV_{iregn,ildv,year} = VSALES\_T_{iregn,ildv,year} * zev\_state\_alloc_{iregn,year} * zev\_mulitplier_{ildv,year}$$

(117)

where

ZEV_CREDIT_LDV = total ZEV credits earned by region and vehicle fuel type by year

ildv = vehicle fuel type (n = 1 to 16)

iregn is in the set {Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New Jersey and

New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)}

zev_state_alloc = share of Census Division vehicle sales belonging to a ZEV participating state

zev_multiplier = credits earned by vehicle fuel type per 1 unit new vehicle sale

3) Add ZEV credits earned from traveling provisions

$$ZEV\_CREDIT\_EARN_{iregn,izev,year} = ZEV\_CREDIT\_LDV_{iregn,ildv,year} + traveling\_CA\_credits_{iregn,izev,year}$$

(118)

where

ZEV_CREDIT_EARN = total ZEV credits earned by sales and S177 states and California credit transfer provisions

ildv = vehicle fuel type (n = 1 to 16)

iregn is in the set {Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New Jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)}

izev = ZEV mandate classification (1=ATPZEV, 2=TZEV, 3=ZEV)

4) Adjust vehicle sales to reflect ZEV mandate adjustment, including use of credit bank

After calculating ZEV credit compliance requirements and ZEV credits earned, including traveling credit provisions, banked credits may be used for compliance. The credit bank includes ZEV and TZEV credits. TZEV credits include the transition of existing ATPZEV and PZEV credits into TZEV credits at a discount in 2017. The bank also includes maintaining a minimum threshold in the bank that is time dependent as a risk mitigation stragetgy.

$$sales\_adjustment = (ZEV\_CREDIT\_REG_{iregn,izev,year} * (1 + bank\_buffer_{year})) / (ZEV\_CREDIT\_EARN_{iregn,izev,year} + bank\_draw_{iregn,izev,year})$$

(119)

where

sales_adjustment = amount of sales adjustment required to meet ZEV mandate and bank buffer compared to ZEV credits earned and bank draw

ZEV_CREDIT_REG = credit requirement by region and ZEV classification type

Bank_buffer = amount of credits maintained in bank as a risk mitigation strategy

ZEV_CREDIT_EARN = total ZEV credits earned by sales and S177 states and California credit transfer provisions

Bank_draw = amount of credit bank used towards meeting compliance

iregn is in the set {Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New Jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)}

izev = ZEV mandate classification (1=ATPZEV, 2=TZEV, 3=ZEV)

LDV Fleet Component

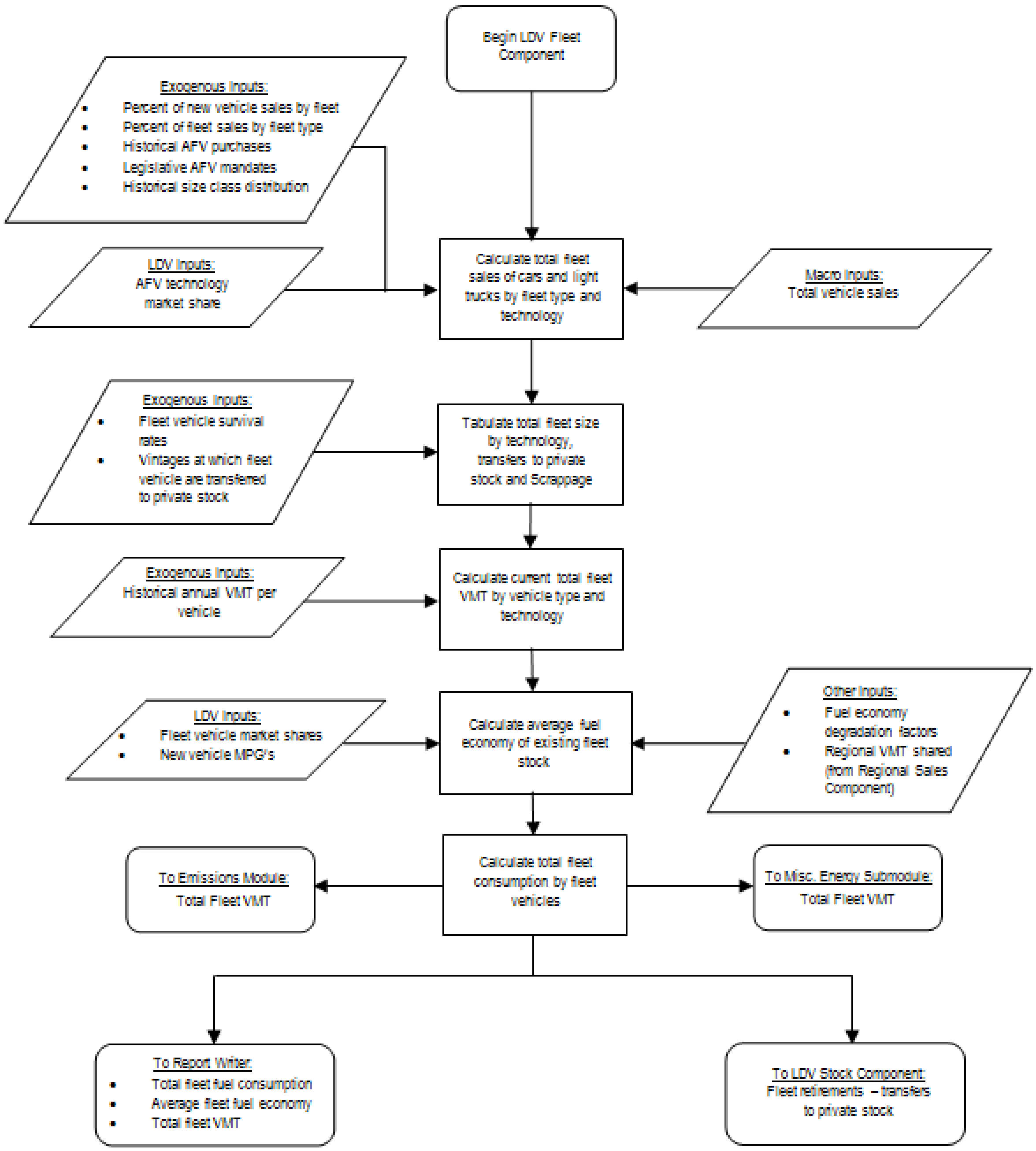
The Light-Duty Vehicle Fleet Component generates estimates of the stock of cars and trucks used in business, government, utility, and autonomous ride-hail vehicle fleets and subsequently estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined vintages.

Fleet vehicles are treated separately in the transportation sector demand module because of the special characteristics of these vehicles. The LDV Fleet Component generates estimates of the stock of cars and light trucks, VMT, fuel efficiency, and energy consumption that are distinct from those generated for personal light-duty vehicles in the LDV Submodule and LDV Stock Component. The primary purpose is not only to simulate as accurately as possible the very different sets of characteristics expected in fleets but also to allow for the greater opportunity for regulation and policy-making incorporation in fleet purchasing decisions. Legislative mandates for AFV purchase, such as fleet fuel economy, can be incorporated through the subroutine TFLTSTKS, which has been set up specifically for this purpose.

The component uses the same variable names used 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, utility, and autonomous vehicle ride-hail fleets are assumed to have different operating characteristics and retirement rates. This component includes three stages: 1) determine total vehicle purchases, surviving fleet stock, and travel demand; 2) calculate the fuel economy of fleet vehicles; and 3) estimate fuel consumption.

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

Figure 7. LDV fleet component



Note: The Emissions Module is currently inactive.

1. Calculate fleet sales and stocks

The model calculates fleet acquisitions of cars and light trucks (Figure 8):

$$FLTSAL_{vt=1,flt,Year} = FLTCRAT_{Year} * NEWCARS_{Year} * FLTCSHR_{flt,Year}$$
$$and \tag{120}$$
$$FLTSAL_{vt=2,flt,Year} = FLTTRAT_{Year} * NEWCLS12A_{Year} * FLTTSHR_{flt,Year}$$

where

FLTSAL = Sales to fleets by vehicle and fleet type

FLTCRAT = Fraction of total car sales attributed to fleets

FLTTRAT = Fraction of total light 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, 4 = ride-hail autonomous vehicles.

A new variable is then established, FLTECHSAL, disaggregating AFV sales by engine technology fuel type, *ildv,* namely E85, battery electric, plug-in hybrid electric, CNG/LNG, LPG, hydrogen, diesel, and gasoline:

$$FLTECHSAL_{vt,flt,icl,ildv} = FLTSAL_{vt,flt,year} * FLTLDVSHR_{ildv,flt,year} * FLTSSHR_{flt,icl,vt} \tag{121}$$

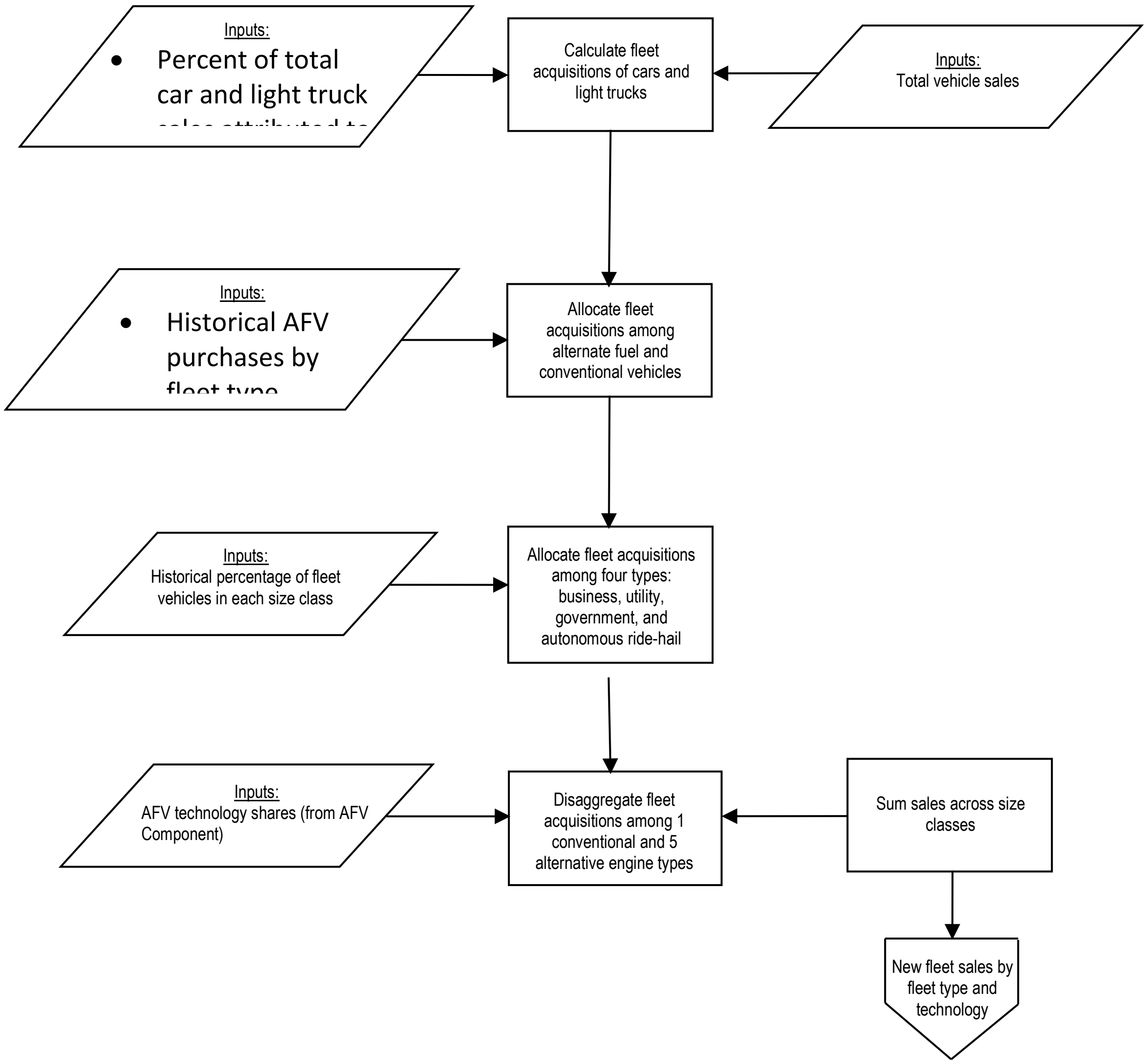
where

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

FLTLDVSHR = Alternative technology shares by fleet type

FLTSSHR = Percent of fleet vehicles by fleet type, size class, and vehicle type.

Figure 8. LDV new fleet acquisitions component



Sales are then summed across market classes:

$$FLTECH_{vt,flt,ildv} = \sum_{icl=1}^{6} FLTECHSAL_{vt,flt,icl,ildv}$$

(122)

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 new acquisitions (Figure 9), done by applying the appropriate survival factors to the current vintages and inserting FLTECH into the most recent vintage:

$$FLTSTKVN_{vt,flt,ildv,iage,year} = FLTSTKVN_{vt,flt,ildv,iage-1,year-1} * SURVFLTT_{vt,iage-1}$$

and

$$FLTSTKVN_{vt,flt,ildv,iage=1,year} = FLTECH_{vt,flt,ildv}$$

(123)

where

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

SURVFLTT = Survival rate of a given vintage

iage = Index referring to vintage of fleet vehicles.

The stocks of fleet vehicles of a given vintage (Table 3) are then identified, assigned to another variable, and removed from the fleet:

$$OLDFSTK_{vt,flt,ildv,iage,year} = FLTSTKVN_{vt,flt,idlv,iage,year}$$

(124)

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 Component 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 (Table 3).

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{vt,flt,ildv} = \sum_{iage=1}^{25} FLTSTKVN_{vt,iflt,ildv,iage,year}$$

(125)

where

TFLTECHSTK = Total stock by technology and fleet type.

Figure 9. Determine characteristics of existing LDV fleets

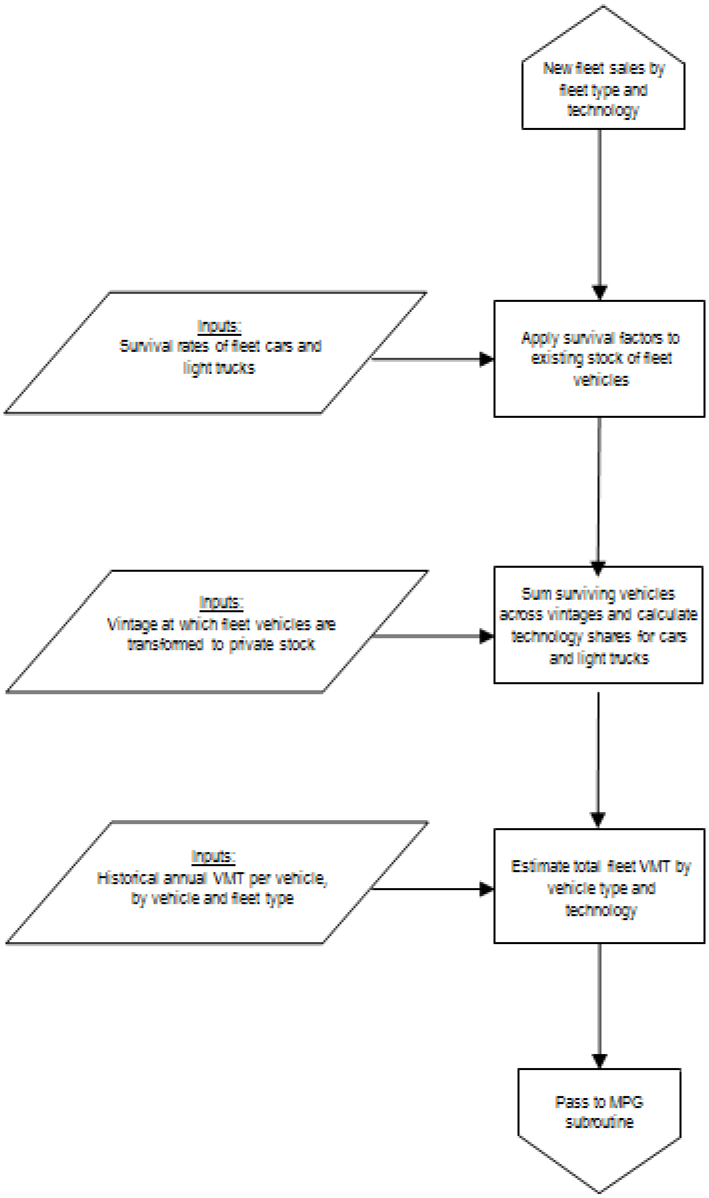


Table 3. Transfer vintage of fleet vehicles

Vehicle Type (vt)	Fleet Type (flt)	Transfer Vintage (vint) (years)
Car (vt = 1)	Business (flt = 1)	3
Car	Government (flt = 2)	6
Car	Utility (flt = 3)	5
Car	Autonomous ride-hail (flt = 4)	Does not transfer
Light Truck (vt = 2)	Business	3
Light Truck	Government	6
Light Truck	Utility	5
Light truck	Autonomous ride-hail	Does not transfer

Vehicle sales and market shares are then adjusted on a regional basis to reflect sales of vehicles from state-level Zero Emission Vehicle (ZEV) credit mandates. States that currently have these legislative requirements include California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.

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

$$VSALES_{vt=1,icl,iregn,ildv,year} = APSHR44_{vt=1,icl,iregn,ildv,year} * NCS_{iregn,icl,year}$$

$$VSALES_{vt=2,icl,iregn,ildv,year} = APSHR44_{vt=2,icl,iregn,ildv,year} * NLTS_{iregn,icl,year}$$

(126)

where

APSHR44 = Percent of total light-duty vehicles sales by technology type

NCS = Regional non-fleet car sales by market class

NLTS = Regional non-fleet light truck sales by market class

iregn is in the set {Census Division 1 (participating states Connecticut, Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New Jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)}.

2) Mandated sales of ZEVs by participating states are then calculated:

a) Determine regional ZEV credit mandate compliance requirements:

$$ZEV\_FLTCREDIT\_REG_{iregn,ifleet,izev,year} = COVERED\_FLTSALES_{iregn,ifleet} * ZEV\_Requirement_{izev,year} * zev\_state\_alloc_{iregn,year}$$

(127)

where

$ZEV\_FLTCREDIT\_REG_{iregn,ifleet,izev,year}$ = credit requirement by region and ZEV classification type

$COVERED\_FLTSALES_{iregn,ifleet}$ = total vehicle sales by region and fleet type covered under ZEV mandate

$zev\_state\_alloc_{iregn,year}$ = share of Census Division vehicle sales belonging to a ZEV participating state

ifleet = fleet type (1=business, 2=government, 3=utilities, 4=autonomous ride-hail

iregn = Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New Jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)

izev = ZEV mandate classification (1=ATPZEV, 2=TZEV, 3=ZEV)

b) Calculate ZEV mandate credits earned through vehicle sales and traveling provisions by region

$$ZEV\_FLTCREDIT\_EARN_{iregn,ifleet,izev,year} = ZEV\_FLTCREDIT\_LDV_{iregn,ifleet,ildv,year} + California\_fltcredit_{iregn,ifleet,ildv}$$

(128)

where

ZEV_FLTCREDIT_EARN = total ZEV credits earned by sales and S177 states and California credit transfer provisions

ZEV_FLTCREDIT_LDV = ZEV compliance credits earned by ildv type requirement by region and fleet type

California_fltcredit = ZEV compliance credits transfer between California and other Section-177 states

ifleet = fleet type (1=business, 2=government, 3=utilities, 4=autonomous ride-hail

ildv = vehicle fuel type (n = 1 to 16)

iregn is in the set {Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)}

izev = ZEV mandate classification (1=ATPZEV, 2=TZEV, 3=ZEV)

c) If ZEV credit requirements are more than ZEV credits earned, including traveling credit provisions, then

$$afltsales_{iregn,izev,year} = COVERED\_FLTSALES_{iregn,ifleet} * FLTSHR_{ifleet,icl,ivtyp} * zev\_state\_alloc_{iregn,year} * ZEV\_Requirement_{izev,year} / zev\_multiplier_{ildv,year}$$

(129)

where

$afltsales_{iregn,izev,year}$ = amount of sales adjustment required to meet ZEV mandate

$COVERED\_FLTSALES_{iregn,ifleet}$ = total vehicle sales by region and fleet type covered under ZEV mandate

$FLTSHR_{ifleet,icl,ivtyp}$ = share of vehicles by fleet type, size class, and vehicle type

$zev\_state\_alloc_{iregn,year}$ = share of Census Division vehicle sales belonging to a ZEV participating state

$ZEV\_Requirement_{izev,year}$ = credit requirement by region and ZEV classification type

$zev\_multiplier_{ildv,year}$ = credits earned by vehicle fuel type per 1 unit new vehicle sale

iregn = Census Division 1 (participating states Maine, Massachussetts, Rhode Island, and Vermont), Census Division 2 (participating states New Jersey and New York), Census Division 5 (participating state Maryland), and Census Division 9 (participating states California and Oregon)

izev = ZEV mandate classification (1=ATPZEV, 2=TZEV, 3=ZEV)

ifleet = fleet type (1=business, 2=government, 3=utilities, 4=autonomous ride-hail

ivtyp = vehicle type (n = 1 to 2)

ildv = vehicle fuel type (n = 1 to 16)

iclass = vehicle size class (n = 1 to 6)

3. Calculate Fleet VMT

$$FLTVMTECH_{vt,flt,ildv,year} = TFLTECHSTK_{vt,flt,ildv} * FLTVMTYR_{flt,idlv,year}$$

(130)

where

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

FLTVMTYR = Annual miles of travel per vehicle by vehicle type and fleet.

3. Calculate Fleet Stock MPG

The average efficiencies are calculated as follows (Figure 10):

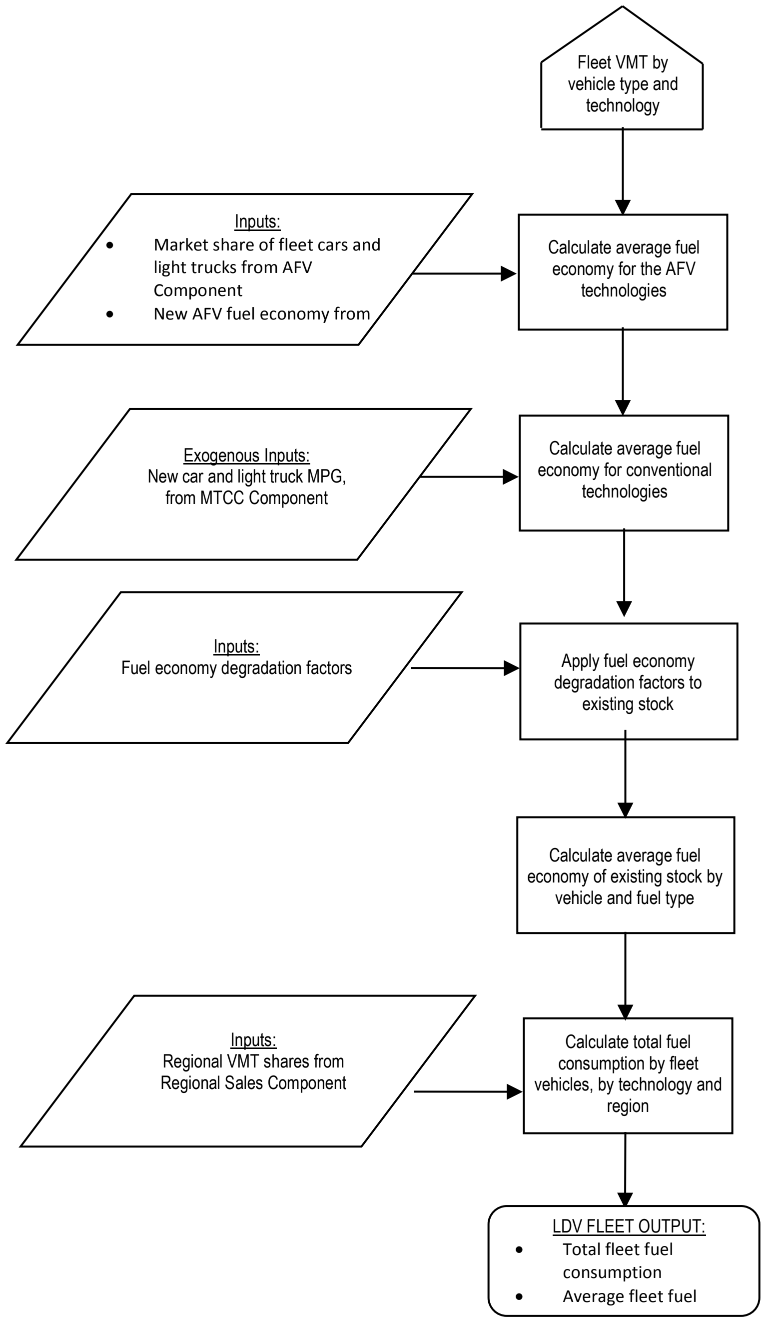
$$FLTMPG_{vt,flt,ildv,year} = \frac{\sum_{icl=1}^{6} FLTECHSAL_{vt,flt,icl,ildv}}{\sum_{icl=1}^{6}\left(\frac{FLTECHSAL_{vt,flt,icl,ildv}}{MPG_{vt,ildv,icl,year}}\right)}$$

(131)

where

FLTMPG = New fleet vehicle fuel efficiency, by fleet type and vehicle technology type.

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.

$$CMPFGSTK_{flt,ildv,iage=1,year} = FLTMPG_{vt=1,flt,ildv,year}$$

$$TMPGFSTK_{flt,ildv,iage=1,year} = FLTMPG_{vt=2,flt,ildv,year}$$

(132)

where

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

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

For *iage*=2 to maxage:

$$CMPGFSTK_{flt,ildv,iage,year} = CMPGFSTK_{flt,ildv,iage-1,year-1}$$

$$TMPGFSTK_{flt,ildv,iage,year} = TMPGFSTK_{flt,ildv,iage-1,year-1}$$

(133)

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

$$MPGFLTSTK_{vt=1,flt,ildv} = \frac{\sum_{iage=1}^{maxage} FLTSTKVN_{vt=1,flt,ildv,iage,year}}{\sum_{iage=1}^{maxage} \frac{FLTSTKVN_{vt=1,flt,ildv,iage,year}}{CMPGFSTK_{flt,idlv,iage,year} * CDFRFG_{year}}}$$

$$MPGFLTSTK_{vt=2,flt,ildv} = \frac{\sum_{iage=1}^{maxage} FLTSTKVN_{vt=2,flt,ildv,iage,year}}{\sum_{iage=1}^{maxage} \frac{FLTSTKVN_{vt=2,flt,ildv,iage,year}}{TMPGFSTK_{flt,idlv,iage,year} * LTDFRFG_{year}}}$$

(134)

where

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

maxage = Maximum vintage of vehicle in given fleet type

CDFREG = Car fuel efficiency degradation factor

LTDFRFG = Degradation factor for light trucks.

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

$$FLTTOTMPG_{vt} = \frac{\sum_{flt=1}^{4} \sum_{ildv=1}^{16} TFLTECHSTK_{vt,flt,ildv}}{\sum_{flt=1}^{4} \sum_{ildv=1}^{16} \frac{TFLTECHSTK_{vt,flt,ildv}}{MPGFLTSTK_{vt,flt,ildv}}}$$

(135)

where

FLTMPGTOT = Overall fuel efficiency of new fleet 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:

$$FLTLDVC_{vt,flt,ildv} = \frac{FLTVMTTECH_{vt,flt,ildv}}{MPGFLTSTK_{vt,flt,ildv}} * 1000000$$

(136)

where

FLTLDVC = Fuel consumption by technology, vehicle and fleet type.

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

$$FLTFCLDVBTU_{vt,ildv,year} = \sum_{flt=1}^{4} FLTLDVC_{vt,flt,ildv} * 0.125$$

(137)

where

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

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

$$FLTFCLDVBTUR_{iregn,ildv} = \sum_{vt=1}^{2} FLTFCLDVBTU_{vt,ildv,year} * RSHR_{iregn,year}$$

(138)

where

RSHR = Regional VMT shares, from the Regional Sales Submodule.

LDV Stock Component

The LDV Stock Component takes sales and efficiency estimates for new cars and light trucks from the LDV Submodule 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 Component flowchart is presented in Figure 11.

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

The LDV Stock Component is perhaps the most important transportation sector component, 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 Component takes the results of the LDV Submodule (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 Component, which determines the average number of miles driven by each vehicle in each projection year. The vehicle characteristics and VMT are then used to project regional fuel consumption.

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

$$TECHNCS_{ildv,year} = \sum_{icl=1}^{6} \sum_{iregn=1}^{9} NCSTECH_{iregn,icl,ildv,year}$$

$$TECHNLT_{ildv,year} = \sum_{icl=1}^{6} \sum_{iregn=1}^{9} NLTTECH_{iregn,icl,ildv,year}$$

(139)

where

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

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

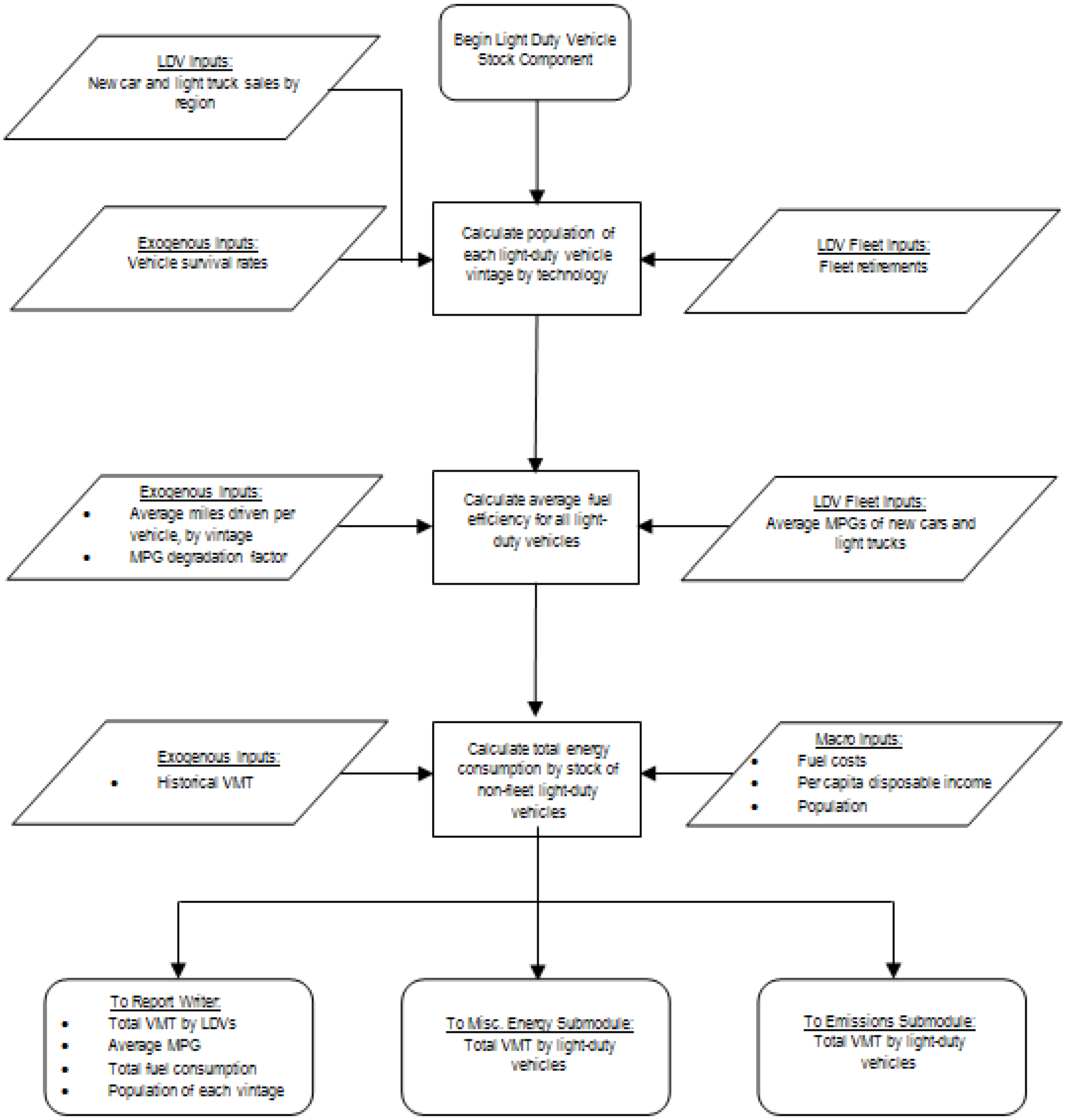
icl = Index for six size classes

iregn = Census division

ildv = Index for LDV powertrain.

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 component



Note: The Emissions Submodule is currently inactive.

For *iage* = 2-24:

$$PASSTKREGN_{iregn,year,ildv,iage} = PASSTKREGN_{iregn,year-1,ildv,iage-1} * SSURV25_{vt=,iage-1}$$

$$LTSTKREGN_{iregn,year,ildv,iage} = LTSTKREGN_{iregn,year-1,ildv,iage-1} * SSURV25_{vt=2,iage-1}$$

(140)

where

PASSTKREGN = Light-duty vehicle car stock by fuel type, vintage and region

LTSTKREGN = Light-duty vehicle light truck stock by fuel type, vintage and region

SSURV25 = Survival rate of cars (vt = 1) and light trucks (vt = 2) by vintage

iage = 25 vintages.

For *iage* = 25:

$$\begin{aligned} PASSTKREGN_{iregn,year,ildv,maxage} &= PASSTKREGN_{iregn,year-1,ildv,maxage-1} * SSURV25_{1,maxage-1} \\ &+ PASSTKREGN_{iregn,year-1,ildv,maxage} * SSURV25_{1,maxage} \end{aligned}$$

$$\begin{aligned} LTSTKREGN_{iregn,year,ildv,maxage} &= LTSTKREGN_{iregn,year-1,ildv,maxage-1} * SSURV25_{2,maxage-1} \\ &+ LTSTKREGN_{iregn,year-1,ildv,maxage} * SSURV25_{2,maxage} \end{aligned}$$

(141)

where

maxage = Vintage 25 for light-duty vehicles.

The component encompasses 25 vintages, with the 25th being an aggregate of all vehicles 25 years or older. SSURV25 contains 25 values measuring the percentage of vehicles of each vintage that survive into the next year. 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.

$$\begin{aligned} PASSTKREGN_{iregn,year,ildv,iage} &= PASSTKREGN_{iregn,year,ildv,iage} \\ &+ \left(OLDFSTKT_{vt=1.ildv,iage} * CDCARSHR_{iregn,year-iage}\right) \end{aligned}$$

$$\begin{aligned} LTSTKREGN_{iregn,year,ildv,iage} &= LTSTKREGN_{iregn,year,ildv,iage} \\ &+ \left(OLDFSTKT_{vt=2.ildv,iage} * CDLTSHR_{iregn,year-iage}\right) \end{aligned}$$

(142)where

OLDFSTKT = Total transfered vehicles from fleets to households

CDCARSHR = Share of total cars by region

CDLTSHR = Share of total light trucks by region.

National car stocks are determined by summing over the census division.

$$PASSTK_{ildv,iage,year} = \sum_{iregn=1}^{9} PASSTKREGN_{iregn,year,ildv,iage}$$

$$LTSTK_{ildv,iage,year} = \sum_{iregn=1}^{9} LTSTKREGN_{iregn,year,ildv,iage}$$

(143)

where

PASSTK = Light-duty vehicle car stock by fuel type and vintage

LTSTK = Light-duty vehicle light trucl stock by fuel type and vintage.

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

$$STKCAR_{year} = \sum_{ildv=1}^{16} \sum_{iage=1}^{25} PASSTK_{iregn,year,ildv,iage}$$

$$STKTR_{year} = \sum_{ildv=1}^{16} \sum_{iage=1}^{25} LTSTK_{iregn,year,ildv,iage}$$

(144)

where

STKCAR = Total stock of non-fleet cars

STKTR = Total stock of non-fleet light trucks.

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:

$$NVSALES_{vt=1,icl,ildv,year} = \sum_{iregn=1}^{9} NCSTECH_{iregn,icl,ildv,year}$$

$$NVSALES_{vt=2,icl,ildv,year} = \sum_{iregn=1}^{9} NLTECH_{iregn,icl,ildv,year}$$

(145)

where

NVSALES = Total new LDV sales by size class.

The harmonic average efficiencies of the light-duty vehicles are calculated as follows:

$$MPGC_{ildv,year} = \frac{\sum_{icl=1}^{6} NVSALES_{vt=1,icl,ildv,year}}{\sum_{icl=1}^{6} \frac{NVSALES_{vt=1,icl,ildv,year}}{MPG_{vt=1,ildv,icl,year}}}$$

$$MPGT_{ildv,year} = \frac{\sum_{icl=1}^{6} NVSALES_{vt=2,icl,ildv,year}}{\sum_{icl=1}^{6} \frac{NVSALES_{vt=2,icl,ildv,year}}{MPG_{vt=2,ildv,icl,year}}}$$

(146)

Where

MPG = New car fuel efficiency, by size class

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 25 vintages addressed in the component.[10] 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:[11]

$$TOTMICT = \sum_{ildv=1}^{16} \sum_{iage=1}^{maxage} PASSTK_{ildv,iage,year} * PVMT_{iage,year}$$

[10] Initial values for on-road car and light truck fleet MPG are obtained from the Federal Highway Administration, *Highway Statistics, 2015,* U.S. Department of Transportation (2017).
[11] 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.

$$TOTMITT = \sum_{ildv=1}^{16} \sum_{iage=1}^{maxage} LTSTK_{ildv,iage,year} * LVMT_{iage,year}$$

(147)

where

TOTMICT = Total miles driven by cars

TOTMITT = Total miles driven by light trucks

PVMT = Average miles driven by each vintage of car

LVMT = Average miles driven by each vintage of light truck.

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:

$$CMPGT_{year} = \frac{\sum_{ildv=1}^{16} \sum_{iage=1}^{maxage} PASSTK_{ildv,iage,year} * PVMT_{iage,year}}{\sum_{ildv=1}^{16} \sum_{iage=1}^{maxage} CMPGSTK_{ildv,iage,year} * CDFRFG_{year}}$$

$$TMPGT_{year} = \frac{\sum_{ildv=1}^{16} \sum_{iage=1}^{maxage} LTSTK_{ildv,iage,year} * LVMT_{iage,year}}{\sum_{ildv=1}^{16} \sum_{iage=1}^{maxage} TTMPGSTK_{ildv,iage,year} * LTDFRFG_{year}}$$

(148)

where

CMPGT = Car stock MPG

TMPGT = Light truck stock MPG

CMPGSTK = Car fuel economy

TTMPGSTK = Truck fuel economy.

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

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

$$and$$

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

(149)

SCMPG = Stock car fuel efficiency

STMPG = Stock light truck fuel efficiency.

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

$$MPGFLT_{Year} = \frac{TOTMICT_{Year} + TOTMITT_{Year}}{CMPGT_{Year} + TMPGT_{Year}}$$

(150)

MPGFLT = Average fuel efficiency for all light-duty vehicles.

Calculate the average fuel efficiency for cars and light trucks by technology:

$$CMPG\_IT_{ildv,year} = \frac{\sum_{iage=1}^{maxage} PASSTK_{ildv,iage,year} * PVMT_{iage,year}}{\sum_{iage=1}^{maxage} \frac{PASSTK_{ildv,iage,year} * PVMT_{iage,year}}{CMPGSTK_{ildv,iage,n} * CDFRFG_{year}}}$$

$$TMPG\_IT_{ildv,year} = \frac{\sum_{iage=1}^{maxage} LTSTK_{ildv,iage,year} * LVMT_{iage,year}}{\sum_{iage=1}^{maxage} \frac{LTSTK_{ildv,iage,year} * LVMT_{iage,year}}{TTMPGSTK_{ildv,iage,n} * LTDFRFG_{year}}}$$

(151)

CMPGT_IT = Average fuel efficiency of cars by powertrain

TMPGT_IT = Average fuel efficiency of light trucks by powertrain.

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

VMT Component

The Vehicle Miles Traveled Component of the NEMS Transportation Module is a subcomponent of the LDV Stock Component 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 licensed 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 in the model are the fuel cost of driving, disposable personal income, employment, vehicles per licensed driver and past VMT trends. Historical licensed driver rates are provided by FHWA by age cohort, gender, and region.

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 VMT equation in the NEMS VMT Component:

$$LOG\left(VMTLD_{Year}\right) - \rho LOG\left(VMTLD_{Year-1}\right) = \alpha + \beta_1\left[LOG\left(INC00\$16_{Year}\right)\right] + \beta_2\left[LOG\left(COSTMI_{Year}\right)\right] + \beta_3\left[LOG\left(VPLD_{Year}\right)\right] + \beta_4\left[LOG\left(EMP_{Year}\right)\right] \quad (152)$$

where

VMTLD = VMT per licensed driver for the driving age population

COSTMI = Fuel cost of driving

VPLD = Light-duty vehicles per licensed driver

EMP = Employment rate of population 16+ from the Macroeconomic Activity Module

α, β = Coefficient estimates for the VMT per driver estimation.

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 scope of the LDV Submodule. 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 with the heavy-duty vehicles, based on aggregate measures of industrial output from the Macroeconomic Activity Module.

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

$$VMTLD_{year} = \exp\left(\alpha + \beta_1 * \ln\left(VMTLD_{year-1,}\right) + \beta_2 * \ln\left(INC00\$16_{year}\right) + \beta_3 * \ln\left(COSTMI_{year}\right) + \beta_4 * \ln\left(VPLD_{year}\right) + \beta_5 * \ln\left(EMP\_RATE\_VMT_{year}\right)\right) \quad (153)$$

Air Travel Submodule

The Air Travel Submodule of the NEMS transportation sector demand module comprises two separate components: the Air Travel Demand Component and the Aircraft Fleet Efficiency Component. These components 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 Submodule 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 Component

The Air Travel Demand Component produces projections of domestic and international per-capita passenger travel demand by thirteen world regions (Table 4) on a per-capita basis, measured in revenue passenger-miles per-capita (RPMT_PC), and world regional air freight demand, measured in revenue ton-miles (RTM). Domestic travel means both takeoff and landing occur in the same region, while international travel means that either takeoff or landing is in the region but not both. Domestic and international travel are combined into a single regional demand for seat-miles and passed to the Aircraft Fleet Efficiency Component, 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.

Table 4. NEMS world regions

Region Number	Region	Major Countries in Region
1	United States	United States
2	Canada	Canada
3	Central America	Bahamas,Cayman Islands,Colombia,Costa Rica,Cuba, Dominican Republic,El Salvador, Guadeloupe, Guatemala, Honduras,Jamaica, Mexico,Netherlands Antilles,Panama, Peru, Trinidad,Tobago
4	South America	Argentina,Bolivia,Brazil,Chile,Colombia,Ecuador, Paraguay, Peru,Suriname,Uruguay,Venezuela
5	Europe	Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, Malta, Montenegro, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovenia, Slovakia, Spain, Sweden, Switzerland, Turkey, United Kingdom
6	Africa	Angola,Burundi,Benin,Botswana,Congo,Cote D'Ivoire, Cameroon,Cape Verde,Djibouti,Algeria,Western Sahara, Eritrea,Ethiopia,Gabon,Ghana,Gambia,Guinea,Kenya,Liberia, Lesotho,Libya,Morocco,Madagascar,Mali,Mauritania, Mauritius,Malawi,Mozambique,Namibia,Niger,Nigeria,Reunion, Rwanda,Seychelles,Sudan, Sierra Leone,Senegal,Somalia, Swaziland,Chad,Togo,Tunisia,Tanzania,Uganda, Rodrigues, Mauritius,Mayotte,South Africa,Zambia,Zimbabwe
7	Mideast	Bahrain,Egypt,Israel,Iraq,Iran,Jordan,Kuwait,Lebanon,Oman, Qatar,Saudi Arabia,Syrian,United Arab Emirates, Yemen
8	CIS	Armenia, Azerbaijan,Belarus,Georgia,Kyrgyzstan,Kazakhstan, Moldova, Republic of Mongolia, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
9	China	China, Hong Kong, Macao
10	Northeast Asia	Japan, North Korea, South Korea
11	Southeast Asia	Bhutan, Brunei, Cambodia, Guam, Indonesia, Malaysia, Burma, Philippines, Singapore, Taiwan, Thailand, Vietnam
12	Southwest Asia	Afghanistan,Bangladesh, India, Nepal, Pakistan, Sri Lanka
13	Oceania	Australia,Fiji,New Zealand,French Polynesia, Nauru, New Caledonia

The Air Travel Demand Component 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. It is further assumed that travel demand is influenced by economic conditions.

The Air Travel Demand Component, as implemented in NEMS, is a series of fitted non-linear functions estimated over the period 1995 to 2015 for the United States and 2000 to 2015 for the non-U.S. regions–which appear curvilinear–as well as informed by domestic and international travel propensities and projected travel demands from outlooks published by aircraft manufacturers. While more complex demand models using external factors are possible, projected travel demands were reduced to a minimum of three explanatory variables to project travel demands. As noted above, it is assumed that domestic and international U.S. travel are motivated by economic measures, namely, per-capita disposable income, and for the non-U.S. regions described in Table 4, the main drivers for travel demand are population and GDP. Population growth was introduced in the equation by expressing the socio-economic variables in per capita form.

Key model relationships are presented below. Where numbers appear in place of variable names, parameters have been estimated statistically from trends. Figure 12 is a flowchart representing the Air Travel Submodule. The steps involved in calculating Air Travel Demand are listed below:

1) Calculate per-capita revenue passenger-miles for domestic and international travel in the 13 world regions:

United States:

$$RPMT\_PC_{wreg=1,di,Year} = CONSTANT\_RPM_{wreg=1,di} + \left[\frac{INC00\$NP_{Year}}{INC00\$NP_{BASE\_YEAR}} * \left(1 + SHAPE_{wreg=1,di}\right)^{(Year-BASE\_YEAR)}\right]$$

(154)

Twelve non-U.S. regions:

$$RPMT\_PC_{wreg,di,Year} = CONSTANT\_RPM_{wreg,di} + \left[\frac{PER\_CAPITA\_GDP_{Year}}{PER\_CAPITA\_GDP_{BASE\_YEAR}} * \left(1 + SHAPE_{wreg,di}\right)^{(Year-BASE\_YEAR)}\right]$$

(155)

where

RPMT_PC = Per capita revenue passenger-miles for domestic (di=1) and international (di=2) travel in the 13 regions.

INC00$NP = U.S. per capita personal disposable income in chain-weighted 2005 dollars.

PER_CAPITA_GDP = $GDP_{wreg,Year}$ / $Population_{wreg,Year}$, wreg = 2 through 13.

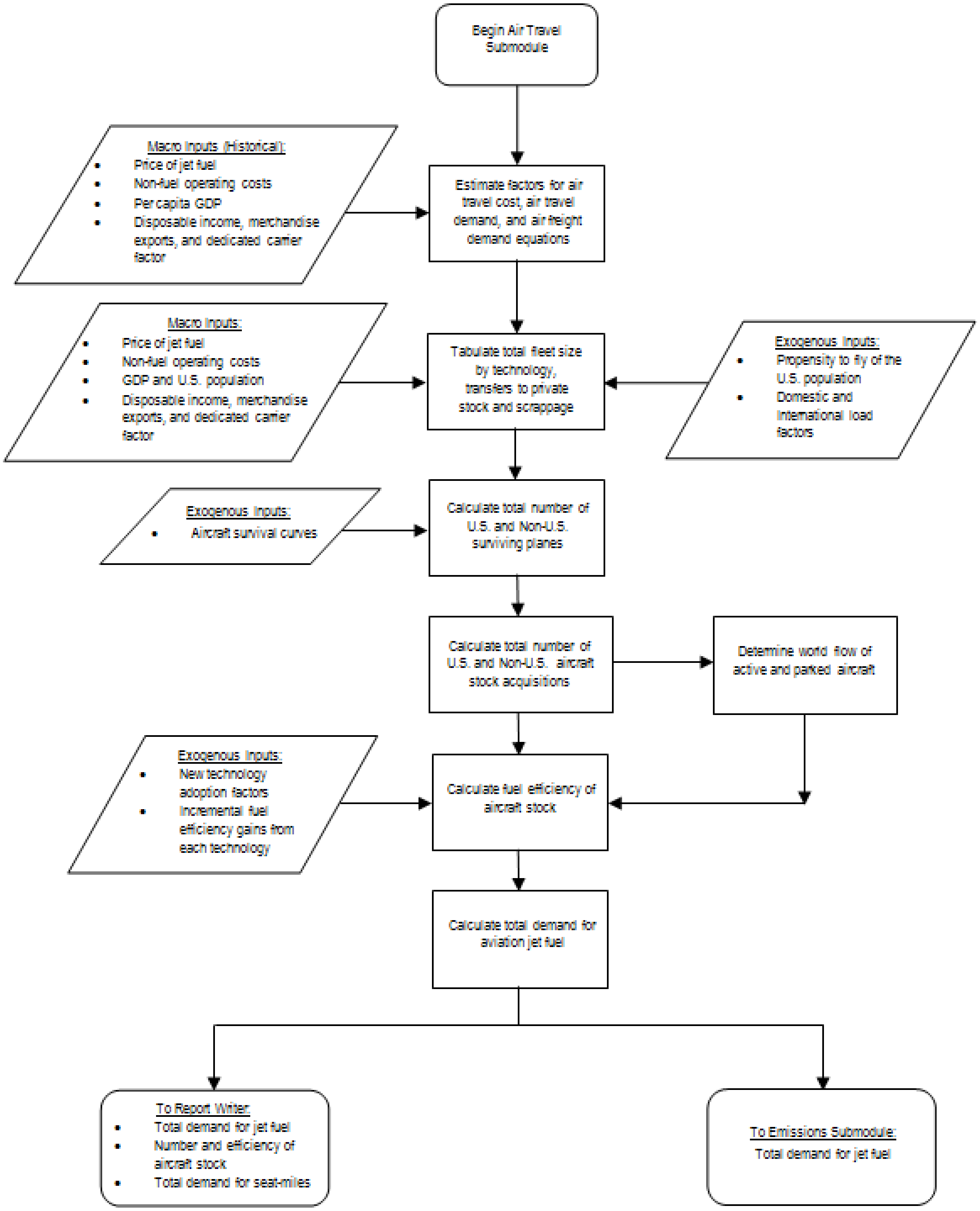
CONSTANT_RPM = Intercept per capita revenue passenger mile for domestic (di=1) and international (di=2) travel in the 13 regions.

SHAPE = Time trend to represent a natural growth function which resembles a compound interest type of formulation for domestic (di=1) and international (di=2) travel in the 13 regions.

wreg = World regions = 1 through 13.

BASE_YEAR = Base year for GDP and population values for domestic (di=1) and international (di=2) travel in the 13 regions

Figure 12. Air travel submodule



Note: The Emissions Submodule is currently inactive.

2) Calculate domestic and international total revenue passenger-miles by region:

$$RPMT_{wreg,di,Year} = RPMT\_PC_{wreg,di,Year} * WLD\_POP_{wreg,Year} \quad \textbf{(156)}$$

where

RPMT = Total revenue passenger-miles for domestic and international travel in the thirteen regions.

wld_pop = World regional population for the thirteen NEMS regions.

3) Calculate domestic and international revenue passenger-miles by region, by aircraft type:

For each aircraft body type (*atyp*), defined as narrow body, wide body, and regional jet aircraft,[12]

$$RPM_{wreg,di,atyp,Year} = RPMT_{wreg,di,Year} * SHR\_RPM_{wreg,di,atyp} \quad \textbf{(157)}$$

where

RPM = Revenue passenger-miles for domestic and international travel by region, by aircraft type.

SHR_RPM = Static share of domestic and international travel performed by region, by aircraft type in the most recent historical data year.

4) Calculate the dedicated U.S. and non-U.S. regional RTM of air freight:

$$\begin{aligned} RTM_{us,Year} &= \alpha + (\beta_1 * PJFTR_{Year} * MC\_JPGDP_{Year-1}) \\ &\quad + (\beta_2 * MC\_XGR_{Year}) \\ &\text{and} \\ RTM_{wreg,Year} &= RTM_{wreg,Year-1} * \frac{WLD\_GDP_{wreg,Year}}{WLD\_GDP_{wreg,Year-1}} \end{aligned} \quad \textbf{(158)}$$

where

[12] 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 planned Boeing 777X, carry from 350-400+ passengers. Regional jets, such as the Canadair RJ-100, have seating for approximately 50-110 passengers.

MC_XGR = Value of merchandise exports, in 1996 dollars, from the NEMS Macroeconomic Activity Module.

WLD_GDP = World regional GDP by the thirteen world NEMS regions.

RTM = revenue ton-miles.

PJFTR = Jet Fuel costs in 1987 dollars.

MC_JPGDP = conversion to 2009 dollars.

5) Calculate the available seat-miles demanded, incorporating the estimated load factors for domestic and international travel:

$$ASM_{wreg,di,atyp,Year} = \frac{RPM_{wreg,di,atyp,Year}}{Load\_Factor_{wreg,di,atyp,Year}}$$
$$and \tag{159}$$
$$SMDEMD_{wreg,Year} = \sum_{di=1}^{2} \sum_{atyp=1}^{3} ASM_{wreg,di,atyp,Year}$$

where

ASM = Domestic and international demand for available seat-miles, by region, by aircraft type.

SMDEMD = Demand for available seat-miles, by region.

Load_Factor = Exogenously determined load factor for domestic and international travel, by region, by aircraft type from the Boeing Current Market Outlook 2009.

Aircraft Fleet Efficiency Component

The Aircraft Fleet Efficiency Component is a structured accounting mechanism that provides estimates of the number of narrow-body, 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 harmonically weighted average of the characteristics of active aircraft and those acquired to meet demand.

- The intent of this component is to provide a quantitative approach for estimating aircraft fleet energy efficiency. Fuel efficiency of new acquisitions of aircraft are calculated based on estimates of technology penetration and efficiency improvements of a slate of nine aircraft technologies.
- A structured accounting method used to provide estimates of the movement of aircraft, active and parked, both within and between regions. The structured accounting defines a priority scheme to determine which regions receive the aircraft.
- The fleet average efficiency for each body type is then calculated as a weighted harmonic mean of efficiencies for the active aircraft stock.

The resulting fleet average efficiencies along with the demand for travel provide the projection of commercial passenger and freight carriers' jet fuel consumption to the year 2050.

The air travel submodule estimates only commercial aircraft efficiencies. Efficiencies and fuel use of general aviation aircraft and military planes are not addressed. U.S. military jet fuel use is estimated in another model using projections of military budgets. Non-U.S. military jet fuel demand is not modeled.

Total fleet efficiency is based on separate estimates of the stock and efficiency of the three types of aircraft considered by the component: narrow-body, wide-body, and regional jets. The development of the hub and spoke system has led airlines to invest in smaller aircraft. In 1991, narrow-body aircraft accounted for approximately 54% of total available seat-miles and wide-body aircraft accounted for 41%, with regional jets accounting for the remaining 5%. By 2009, narrow-body aircraft accounted for 62% of total available seat-miles, and wide-body aircraft accounted for 28%, with regional jets accounting for the remaining 10%.

The component 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 U.S. and Non-U.S. 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 economic and travel demand growth. Travel demand, expressed as a demand for revenue passenger-miles, is obtained from the Air Travel Demand Component. Sales of new aircraft are based on the previous years' sales and on economic activity.

$$STKPASS\_SALES_{wreg=US,Year} = \alpha + \beta_1 * \left(MC\_GDPR_{Year-1}\right)$$
$$and \tag{160}$$
$$STKPASS\_SALES_{wreg,Year} = STKPASS\_SALES_{wreg,Year-1} * \frac{WLD\_GDP_{wreg,Year}}{WLD\_GDP_{wreg,Year-1}}, wreg = 2,...,13$$

where

$STKPASS\_SALES_{US,Year}$ = Total U.S. sales of new passenger aircraft.

$STKPASS\_SALES_{wreg,Year}$ = Total sales of new passenger aircraft by region.

US = Index representing U.S. region = 1.

wreg = Index representing world NEMS regions = 1 through 13.

MC_GPDR = GDP in 2005 chain-weighted dollars, from the Macroeconomic Activity Module.

Sales of new passenger aircraft are then allocated between the three aircraft types considered by the component. The fraction of sales attributable to each aircraft type is based on historic data:

$$STK\_PASS_{wreg,atyp,age=1,Year} = STKPASS\_SALES_{wreg,Year} * SHR\_NEW\_STK_{wreg,atyp,Year} \tag{161}$$

where

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

SHR_NEW_STK = Fraction of total sales attributable to each aircraft type.

atyp = Wide Body, Narrow Body and Regional Jet Aircraft.

The rate of new aircraft acquisition significantly affects the average energy intensity of the fleet and, subsequently, the projection of energy demand. This component differs from other stock models in that retirements are not assumed to take place abruptly once the aircraft have reached a specified age. Instead, the survival function is based on an analysis of historical data obtained from Jet Information Services, Inc.

2. Stock estimation

The aircraft stock component provides an accounting for aircraft stocks and sales. The component 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 world fleet, including the U.S. commercial fleet, which in 2009, the latest data year available, numbered 21,500 for the world fleet and 7,500 for U.S. aircraft.[13] This distribution helps determine 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. The stock of surviving passenger aircraft is subsequently estimated with the following equation:

$$STK\_PASS_{wreg,atyp,age,Year} = STK\_PASS_{wreg,atyp,age-1,Year-1} * SURVAC_{atyp,age} \tag{162}$$

where

[13] Jet Inventory Services, *World Jet Inventory: Year-End 2009*, (March 2010).

STK_PASS = Stock of surviving passenger aircraft by aircraft type, world region, and given age.

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

The stock component also accounts for the stock of cargo aircraft and cargo plane retirement. The surviving cargo aircraft are projected from historical data using the following equation:

$$STK\_CARGO_{wreg,atyp,age,Year} = STK\_CARGO_{wreg,atyp,age-1,Year-1} * SURVAC_{wreg,atyp,age} \quad \textbf{(163)}$$

where

STK_CARGO = Thirteen world region stock of surviving cargo aircraft by aircraft type, by age.

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

$$\begin{aligned} STK\_CARGO_{wreg,atyp,age,Year} = {} & STK\_CARGO_{wreg,atyp,age-1,Year-1} \\ & + STK\_PASS_{wreg,atyp,age,Year} * CARGO\_PCT_{age} \end{aligned} \quad \textbf{(164)}$$

where

CARGO_PCT = Percent of passenger planes, aged 25 years or older, shifted to cargo service, based on historical data.

The stock of passenger aircraft is then adjusted for the older planes that moved into cargo service:

$$STK\_PASS_{wreg,atyp,age,Year} = STK\_PASS_{wreg,atyp,age,Year} * \left(1 - CARGO\_PCT_{age}\right) \quad \textbf{(165)}$$

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

$$STK\_SUP\_TOT_{wreg,atyp,Year} = \sum_{age} STK\_PASS_{wreg,atyp,age,Year} \quad \textbf{(166)}$$

where

STK_SUP_TOT = Total regional stock of passenger aircraft by aircraft type.

3. Demand for commercial aircraft

The demand for commercial aircraft is then calculated, 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 Component, and the passenger demand for aircraft is calculated as

$$STKPASS\_DMD_{wreg,atyp,Year} = \frac{ASMDEMD_{wreg,atyp,Year}}{ASMAC_{wreg,atyp,Year}} \quad \textbf{(167)}$$

where

STKPASS_DMD = Passenger stock of aircraft demanded for each of the thirteen world regions, by aircraft type.

ASMDEMD = Seat-miles demanded by region, by aircraft type

ASMAC = Available seat-miles flown per aircraft, by region, by aircraft type.

Available seat-miles per aircraft for the U.S. are computed historically by aircraft type, and are assumed to vary over time, but are constant for all regions.

The initial supply of active passenger aircraft, STKPASS_ACTIVE, consists of the total stock of aircraft less aircraft that are parked, and is defined as

$$STKPASS\_ACTIVE_{wreg,atyp,age,Year} = STK\_PASS_{wreg,atyp,age,Year} - STKPASS\_PARKED_{wreg,atyp,age,Year} \quad \textbf{(168)}$$

where

STKPASS_ACTIVE = Active stock of passenger aircraft, for each of the thirteen world regions, by aircraft type and age.

The total supply of active passenger aircraft, STKPASS_ACTIVE_TOT, is then calculated for each region, aircraft type, and year:

$$STKPASS\_ACTIVE\_TOT_{wreg,atyp,Year} = \sum_{age} STKPASS\_ACTIVE_{wreg,atyp,age,Year} \quad \textbf{(169)}$$

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 demand and supply for active aircraft, DEL_STKPASS, is estimated:

$$DEL\_STKPASS_{wreg,atyp,Year} = STKPASS\_DMD_{wreg,atyp,Year} - STKPASS\_ACTIVE\_TOT_{wreg,atyp,Year} \quad \textbf{(170)}$$

Test the Difference:

- First, for each region, 1 through 13, if the demand for aircraft is greater than the supply of aircraft, then more aircraft are needed. Keep unparking all aircraft in that region until either 10% of the stock is left or until all aircraft demanded is supplied. Repeat this for all regions, skipping those whose supply of aircraft is greater than demanded.

- Second, loop through all regions, wreg =1 through 13. For each region, wreg, if the demand for aircraft is greater than the supply of active aircraft, then loop through the remaining regions, nreg, not equal to wreg, and if the supply of aircraft is greater than the demand for aircraft in that region, nreg, export active aircraft from nreg to wreg until either no more aircraft are needed in wreg or no more active aircraft are available from nreg. Then, move to the next region, wreg, and repeat this process.

- Third, repeat the second step for the exporting and unparking of parked aircraft from nreg to wreg.

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. The model accounts for nine technologies, *ifx = 1,2,…,9*. The first five technologies are generic, each being slightly more efficient, approximately 3%, and each entering the market at five-year intervals. The remaining four technologies are specific, and in order to model a smooth transition from old to new technologies, the efficiencies 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 new generation of technology replaces the previous one every 5 to 6 years 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 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:

$$TIMEFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year-1} + \left(TIMECONST_{atyp} * TPN_{ifx,atyp} * TYRN_{ifx,atyp}\right) \quad \textbf{(171)}$$

where

TIMEFX = Factor reflecting the length of time that aircraft technology *ifx* has been commercially viable, by year and 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 technologies (6-9).

The cost effect is now calculated:

$$COSTFX_{ifx,atyp,Year} = \left[\frac{TPJFGAL_{Year} - TRIGPRICE_{ifx,atyp}}{TPJFGAL_{Year}} \right] * TPN_{ifx,atyp} * TYRN_{ifx,atyp} * TPZ_{ifx,atyp} \tag{172}$$

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.

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

$$TOTALFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year} + COSTFX_{ifx,atyp,Year} - BASECONST \tag{173}$$

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

$$TECHPEN_{ifx,atyp,Year} = \left[1 + e^{-TOTALFX_{ifx,atyp,Year}} \right]^{-1} \tag{174}$$

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

$$FRACIMP_{atyp,Year} = 1.0 + \sum_{ifx=1}^{9} EFFIMP_{ifx} * TECHPEN_{ifx,atyp,Year} \tag{175}$$

where

FRACIMP = Fractional efficiency improvement for each aircraft type *atyp*.

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

atyp = Wide Body, Narrow Body and Regional Jet 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:

$$\begin{gathered} ASMPGD_{atyp,age=1,Year} = ASMPGD_{atyp,age=1,Year=2008} * FRACIMP_{atyp,Year} \\ and \\ ASMPGI_{atyp,age=1,Year} = ASMPGI_{atyp,age=1,Year=2008} * FRACIMP_{atyp,Year} \end{gathered} \quad \textbf{(176)}$$

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

$$\begin{gathered} ASMPGD_{atyp,age,Year} = ASMPGD_{atyp,age-1,Year-1} \\ and \\ ASMPGI_{atyp,age,Year} = ASMPGI_{atyp,age-1,Year-1} \end{gathered} \quad \textbf{(177)}$$

Total available seat-mpg, ASMPGT, is computed as the harmonic average of domestic fuel efficiency and international fuel efficiency, weighted by the supply of regional aircraft and by domestic and international available seat-miles.

$$ASMPGT_{atyp,age,Year} = \left[\frac{ASM\_DOM_{Year} + ASM\_INT_{Year}}{(ASM\_DOM_{Year} / ASMPGDT_{atyp,age,Year}) + (ASM\_INT_{Year} / ASMPGIT_{atyp,age,Year})} \right] \quad \textbf{(178)}$$

where

ASM_DOM = Available domestic deat miles.

ASM_INT = Available international seat miles.

ASMPGDT = Domestic aircraft efficiency.

ASMPGIT = International aircraft efficiency.

6. Estimating fuel consumption

The total seat-miles demanded are estimated by combining the demand for passenger seat-miles and the revenue ton-miles which are converted to seat-miles as follows:

$$SMD\_TOT_{wreg,Year} = SMDEMD_{wreg,Year} + (RTM_{wreg,Year} * EQSM) \qquad \textbf{(179)}$$

where

SMD_TOT = Total seat-miles demanded.

EQSM = Factor converting Revenue Ton-Miles to Seat-miles.

The demand for jet fuel is then calculated as

$$JFGAL_{wreg,Year} = \frac{SMDTOT_{wreg,Year}}{ASMPGT_{Year}} \qquad \textbf{(180)}$$

The demand for aviation gasoline is calculated as

$$AGD_{Year} = BASEAGD + GAMMA * e^{-KAPPA*(Year-1979)} \qquad \textbf{(181)}$$

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:

$$\begin{gathered} JFBTU_{Year} = JFGAL_{Year} * \frac{5.670 MMBtu/bbl}{42 gal/bbl} \\ and \\ AGDBTU_{Year} = AGD_{Year} * \frac{5.048 MMBtu/bbl}{42 gal/bbl} \end{gathered} \qquad \textbf{(182)}$$

Jet fuel and aviation gasoline demand is allocated to the U.S. regions as follows:

$$\begin{gathered} QJETR_{REG,Year} = JFBTU_{Year} * SEDSHR_{JetFuel,REG,Year} \\ and \\ QAGTR_{REG,Year} = AGDBTU_{Year} * SEDSHR_{AvGas,REG,Year} \end{gathered} \qquad \textbf{(183)}$$

where

SEDSHR = Regional shares of fuel (jet fuel or aviation gasoline) demand, from the State Energy Data System.

Freight Transportation Submodule

The Freight Transportation Submodule addresses the three primary modes of freight transport: truck, rail, and marine. This submodule uses NEMS projections of real fuel prices, trade indices, coal production, and selected industries' output from the Macroeconomic Activity Module 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 by 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 submodule provides estimates of modal efficiency growth, driven by assumptions about systemic improvements and the adoption of new technology.

Projections are made for each of the freight modes with travel projections based on the industrial output of specific industries and a ton-mile per industrial dollar output measure determined using the U.S. Department of Transportation's Freight Analysis Framework (FAF), based on the U.S. Census Bureau's 2012 Commodity Flow Survey (CFS).[14] For rail, the model also 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, taking into consideration the cost effectiveness of alternate fuels when considering fuel prices, travel behavior and incremental engine and fuel storage costs. Rail and marine are considered in the aggregate with no distinction drawn between classes of carriers.

The truck sector of the Freight Transportation Submodule incorporates additional levels of detail. The trucking sector is divided according to market class with stock adjustments for each market class and fuel type.

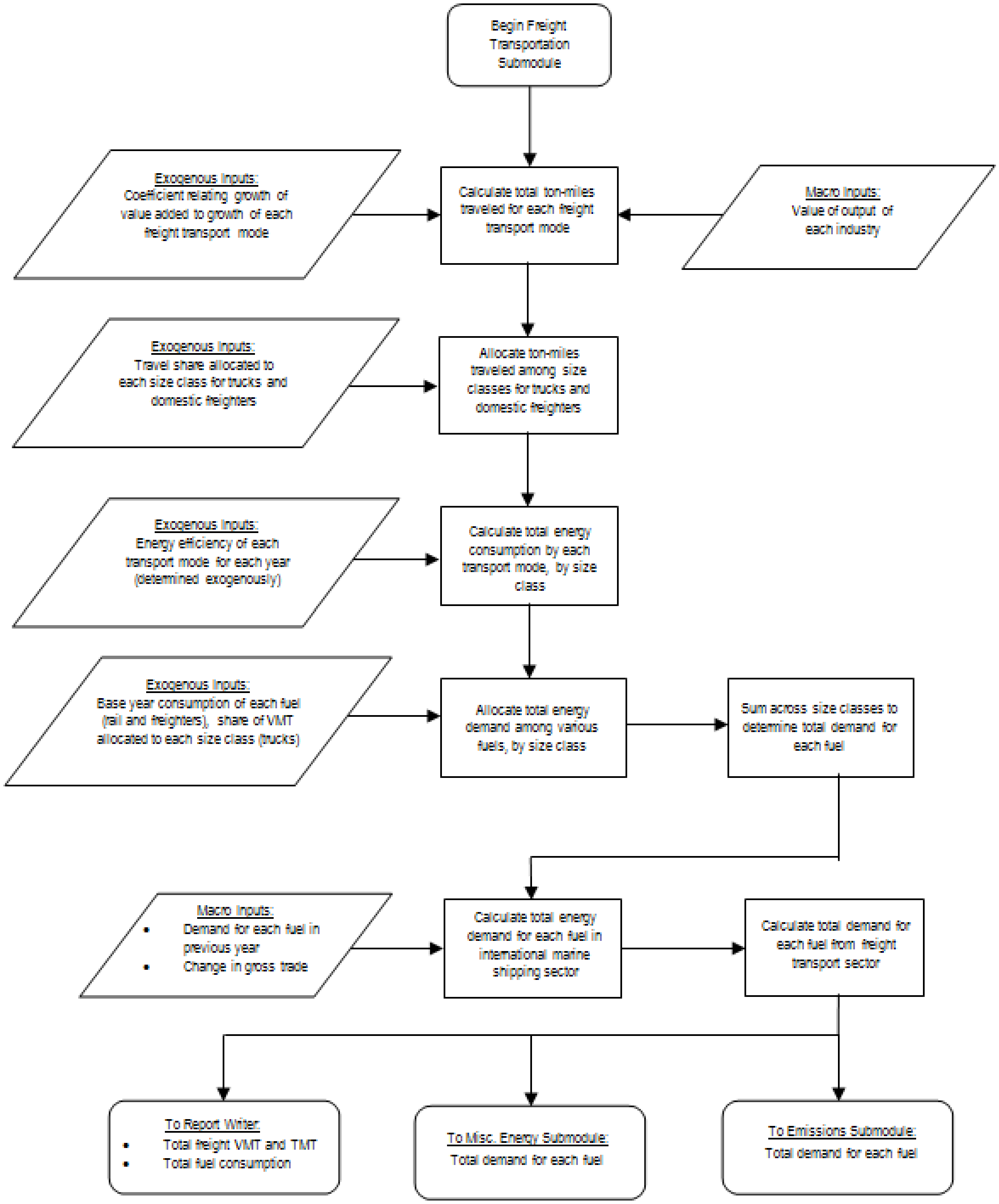
The Freight Transportation Submodule aggregates the value of output from various industries into a reduced classification scheme, relating the demand for transport to the growth in the value of output of each industrial category. The relationships used for truck, rail, and waterborne freight are presented in sequence below. The flowchart for the Freight Transportation Submodule is presented in Figure 13, which is further described in a report prepared for EIA by IHS, Inc.[15]

Freight Truck Stock Adjustment Component (FTSAC)

The FTSAC 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 to meet market demand and fuel efficiency standards. The FTSAC uses projections of real fuel prices and selected industries' output from the Macroeconomic Activity Module 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 Sector Demand Module.

[14] CFS, which is undertaken through a partnership between the Census Bureau and the Bureau of Transportation Statistics (BTS), is conducted every five years (years ending in "2" and "7") as part of the Economic Census.
[15] IHS Global, Inc., "NEMS Freight Transportation Module Improvement Study" (June 20, 2014).

Figure 13. Freight transportation submodule



Note: The Emissions Submodule is currently inactive.

The FTSAC projects the consumption of diesel, motor gasoline, LPG, CNG/LNG, flexfuel, electricity, and hydrogen accounted for by freight trucks in each of twelve industrial sectors. Thirty-four truck vintages, nineteen truck market classes, fourteen fuel-efficiency standard market subclasses and two fleet types are tracked throughout the submodule, each having its own average fuel economy and number of miles driven per year (Table 5). The results, reported in four truck market classes, are defined as follows: Class 2b includes trucks 8,501 to 10,000 GVWR; Class 3 includes trucks 10,001 to 14,000 pounds GVWR; Classes 4 through 6 include trucks 14,001 to 26,000 pounds; and Classes 7 and 8 include trucks over 26,000 pounds.[16] The fourteen fuel-efficiency market subclasses include one breakout for Classes 2b-3 pickups and vans, three breakouts for vocational vehicles – Classes 2b-5, Classes 6-7, and Class 8, nine breakouts for tractors, and one heavy-haul breakout. The ten subclasses for heavy trucks include parceling the class by Class 7 or Class 8, day cab or sleeper cab, and low-, mid- or high-roof. This section presents and describes the methodology used by the component to project characteristics of each class. Figure 14 shows a flow chart of the Highway Freight Component.

There are four main steps executed for each projection year of the model run to produce estimates of fuel consumption. First, fuel economies of the incoming class of new trucks are estimated, allowing for market penetration of existing and new fuel-saving technologies to comply to minimum fuel-efficiency requirements or consumer-driven demand. Relative fuel economies are used in this routine to determine the market share of each fuel technology in the current year's truck purchases. The second 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 Activity Module are used to determine new truck purchases in the fourth routine. In the third 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 component is prepared for the next projection year.

[16] Class 2b, 3, 4 to 6, and 7 to 8 trucks are also referred to as commercial light- medium light-, medium heavy-, and heavy trucks, respectively.

Table 5. Freight truck vehicle fuel-efficiency market subclass category

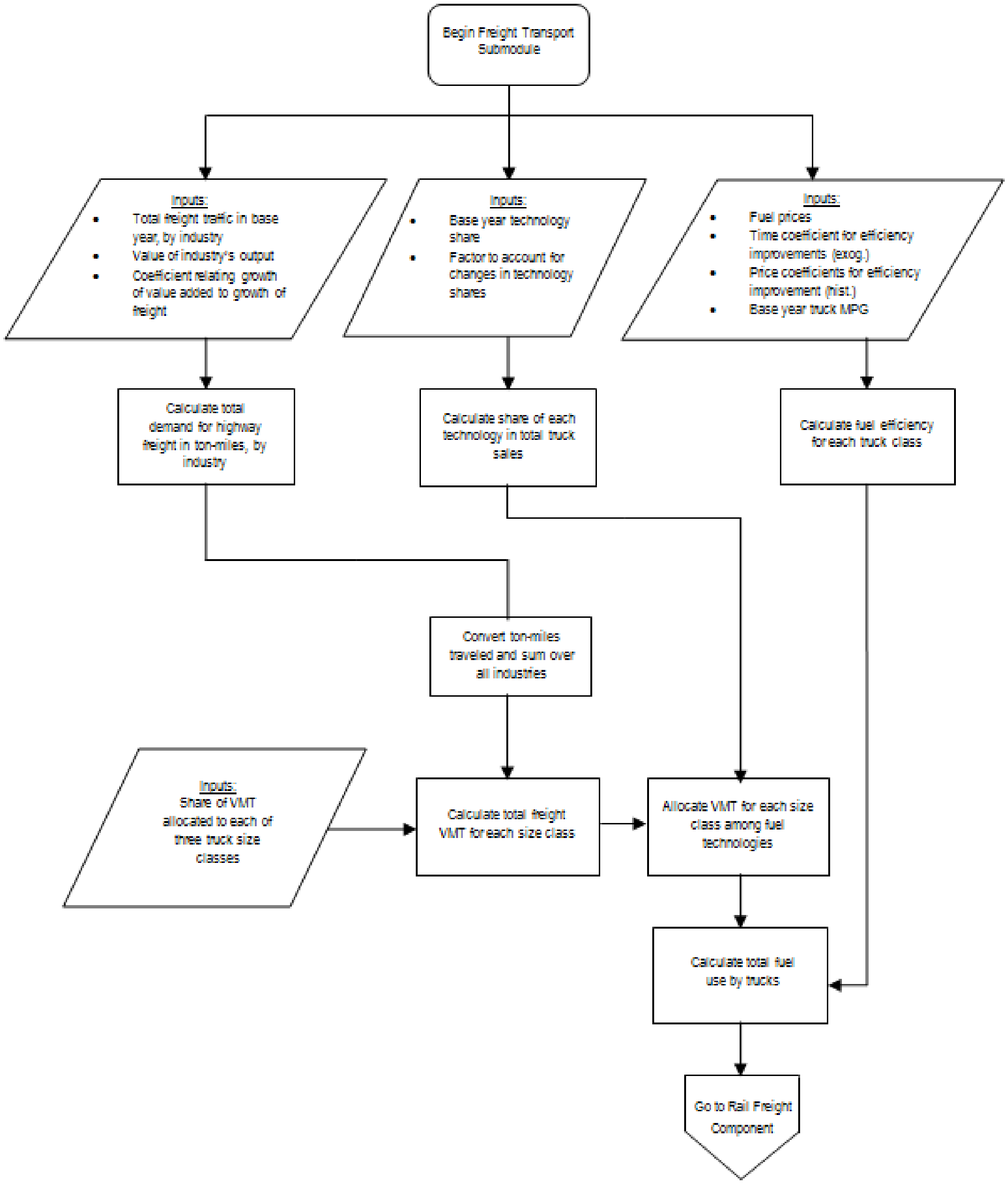
Vehicle category	Reporting size class	GVW size class	Fuel-efficiency standard market subclasses	Roof[1]
1	2b	2b	2b-3 pickup and van	-
2	2b	2b	2b-5 vocational	-
3	3	3	2b-3 pickup and van	-
4	3	3	2b-5 vocational	-
5	4-6	4	2b-5 vocational	-
6	4-6	5	2b-5 vocational	-
7	4-6	6	6-7 vocational	-
8	7-8	7	6-7 vocational	-
9	7-8	7	Tractor – day cab	Low
10	7-8	7	Tractor – day cab	Mid
11	7-8	7	Tractor – day cab	High
12	7-8	8	8 vocational	-
13	7-8	8	Tractor – day cab	Low
14	7-8	8	Tractor – day cab	Mid
15	7-8	8	Tractor – day cab	High
16	7-8	8	Tractor – sleeper cab	Low
17	7-8	8	Tractor – sleeper cab	Mid
18	7-8	8	Tractor – sleeper cab	High
19	7-8	8	Heavy-haul	-

[1]Applies to Class 7 and Class 8 day and sleeper cabs only.

1. Estimate new truck fuel economies

The first step in the FTSAC is to determine the characteristics of the incoming class of truck purchases. Estimates of new commercial light, light, medium-heavy, and heavy truck fuel economies are generated endogenously and depend on the market penetration of specific fuel-saving technologies determined by consumer preference or regulatory requirements.

Figure 14. Highway freight component



Future technologies are adapted from the joint EPA and NHTSA Final Rulemaking to establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles.[17] A second more stringent phase (Phase 2) takes effect in 2021.[18] Technologies include advanced transmissions, lightweight materials, synthetic gear lube, advanced drag reduction, advanced tires, electronic engine controls, turbo-compounding, hybrid powertrains, and direct-injection. Future technologies can enter the market throughout the component 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, CNG/LNG, flexfuel, electric, PHEV diesel, PHEV gasoline, and hydrogen fuel cell trucks.

The first step in the component is to calculate the fuel trigger price at which the technology becomes economically viable:

$$TRIGGERPRICE\_pX_{itech,icafe19,ifuel} = \frac{TECHCOST_{itech,isc19}}{\sum_{IP=1}^{PAYBACK_{icafe,itech}} \left\{ \frac{TEMP\_BTU\_pX_{isc19,ifuel} * \left(\frac{ANNVMT\_19_{icafe19,ip,ifuel}}{ANNVMT\_19_{icafe19,1,ifuel}} \right) * TECHEFF\_pX_{itech,icafe19,ifuel}}{(1 + DISCRTXG)^{ip}} \right\}} \quad (184)$$

where

TRIGGER_PRICE_pX = Fuel trigger price at which a technology, itech, becomes economically viable in phase X where X = 1 for phase 1 and x = 2 for phase 2 of the heavy duty vehicle fuel economy and greenhouse gas emission standard

PAYBACK = Payback period for a given technology and market class, in years (model increases PAYBACK to ensure compliance with minimum fuel efficiency standards)

TECHCOST = Incremental cost of a technology

TEMP_BTU_pX = Average annual truck fuel usage

ANNVMT_19 = Average VMT by vintage by 19 size classes

[17] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule," *Federal Register*, Vol. 76, No. 179 (September 15, 2011), pp. 57106-57513.

[18] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles-Phase 2; Final Rule," *Federal Register*, Vol. 81, No. 206 (October 25, 2016), pp. 57106-57513.

TECHEFF_pX = Incremental fuel economy improvement

DISCRTXG = Discount rate

ip = Index for payback periods

itech = Freight truck technologies

icafe19 = 19 market classes

ifuel = Index referring to powertrain type, where 1 = diesel, 2 = gasoline, 3 = LPG, 4 =CNG/LNG, 5 = flexfuel, 6 = electric, 7 = PHEV diesel, 8 = PHEV gasoline, and 9 = hydrogen fuel cell

isc19 = map from 4 reporting size classes to 19 market classes.

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.

The next step in the component is to calculate the average fuel price over the previous three years:

$$Avg\_Fuel\_\$_{Year,ifuel} = \frac{PRICE_{Year,ifuel} + PRICE_{Year-1,ifuel} + PRICE_{Year-2,ifuel}}{3} \quad \textbf{(185)}$$

where

Avg_Fuel_$ = Average price of fuel over three year period, in dollars per MMBtu

PRICE = Price of each fuel, in dollars per MBtu.

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:

$$PREFF\_pX_{itech,icafe19,ifuel} = 1 + TECHVAR_{itech,isc19} + \left(\frac{Avg\_fuel\_\$_{ifuel,iyr}}{TRIGGERPRICE\_pX_{itech,icafe19,ifuel}} - 1\right)$$

(186)

where

PREFF_pX = Effect of fuel price on market penetration rates for each freight technology in either phase 1 or phase 2 of the standards

TECHVAR = 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%

iyr = Model year.

For each available technology, including existing technologies, by CAFE class and fuel type, the submodule determines the share of the available market in the current year.

For each CAFE market class and technology, the market penetration over time is estimated using an S-shaped logistical equation defined as follows:

$$P_{year} = TECHSHARE\_pX + ((TECHMAX_{(itech,isc19)} - TECHBASE\_pX_{itech,icafe19,ifuel}) * \left(\frac{1}{1 + e^{-\frac{TECHPENYR\_pX_{iyr,itech,icafe19,ifuel} - TECHMID_{itech,isc19}}{TECHSHAPE_{itech,isc19}}}}\right)$$

(187)

where

P = Market penetration by year

TECHSHARE_pX = TECHSHR_pX if the technology penetration is less than the base year technology penetration or TECHBASE_pX if the technology is greater than or equal to the base share penetration

TECHSHR_pX = Market share of fuel-saving technology, by market size class and fuel type in Phase 1 and Phase 2

TECHBASE_pX = Base year market penetration paramenter

TECHMAX = Maximum market penetration parameter

TECHMID = Parameter for existing technologies

TECHPENYR_pX = Year that a technology becomes available for Phase 1 or Phase 2 of the CAFE and GHG HDV standards

TECHSHAPE = Market penetration curve for existing technologies.

If the technology is an emission control technology or if the fuel price has reached the trigger price, then the technology share is as estimated by the following:

$$TECHSHR\_pX_{iyr,itech,icafe19,ifuel} = PREFF\_pX_{itech,icafe19,ifuel} * P_{iyr}$$

(188)

However, if the technology is a fuel efficiency technology and 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 is assumed to grow at the same rate as the market penetration price sensitivity multiplier:

$$TECHSHR\_pX_{iyr,itech,icafe19,ifuel} = TECHSHR\_pX_{iyr-1,itech,icafe19,ifuel} * PREFF\_pX_{itech,icafe19,ifuel}$$

(189)

If technology A is superseded by another mutually exclusive technology B, technology A's market share must be adjusted to reflect the smaller pool of vehicles in the base market:

$$TECHSHR\_pX_{iyr,itech,icafe19,ifuel} = TECHSHR\_pX_{iyr,itech,icafe19,ifuel} * (1 - ADVSHR)$$

(190)

where

ADVSHR = 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. The MPG effects are computed as follows:

$$MPGEFF\_pX_{ifuel,icafe19} = \prod_{itech=1}^{TechpX} \left(1 - TECHEFF\_pX_{itech,icafe19,ifuel} * TECHADJSHR\_pX_{iyr,itech,icafe19,ifuel}\right)$$

(191)

where

MPGEFF_pX = Total effect of all fuel-saving technologies on new truck fuel economy in a given year and market class, icafe19

TechpX = The number of technologies in Phase 1 and Phase 2 - 37 and 83, respectively

TECHADJSHR_pX = Difference between the current tech share and the base tech share.

Fuel economy of new vintage, AGE = 1, freight trucks by market class can finally be determined as

$$NEW\_MPG\_19_{iyr,ifuel,icafe19} = \frac{BASEMPG\_pX_{ifuel,icafe19}}{MPGEFF\_pX_{ifuel,icafe19}}$$

(192)

where

NEW_MPG_19 = New truck fuel economy by 19 size classes

BASEMPG_pX = 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 each projection year's class of new trucks is the market share of each powertrain type. Market share for freight trucks is divided among nine powertrain types: diesel, gasoline, LPG, CNG/LNG, flexfuel, electric, PHEV diesel, PHEV gasoline, and hydrogren fuel cell.

Market penetration of alternative fuel freight trucks is more likely to be driven by legislative or regulatory action than by economic cost/benefit consideration. 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.

a) Market share alternative fueled vehicles

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

$$FCOST\_regn_{ifuel,iregn,icafe19,iyr} = \frac{Avg\_fuel\_\$\_regn_{ifuel,iregn}}{NEW\_MPG\_19_{iyr,ifuel,icafe19}} * HRATE_{isc19,ifuel}$$

(193)

where

FCOST_regn = Fuel cost of driving a truck by fuel type in dollar per mile

Avg_Fuel_$_regn = Average price of fuel over three-year period, in dollars per MMBtu

HRATE = Heat rate of fuel, in million Btu per gallon

iregn = index for Census Divisions.

The fuel cost of driving diesel trucks (Frt_Fuel=1) relative to LPG and CNG/LNG vehicles is then calculated as

$$DCOST_{ifuel,iregn,icafe19,iyr} = 1 - \left(\frac{FCOST\_regn_{ifuel,iregn,icafe19,iyr}}{FCOST\_regn_{fuel=1,iregn,icafe19,iyr}} - 1\right) * PRAFDFXG_{isc19,ifuel}$$

(194)

where

DCOST = Fuel cost per mile of diesel relative to alternative fueled vehicles

PRAFDFXG = Parameter representing inherent variation in AFV market share due to difference in fuel prices

ifuel = fuel type (1 = diesel, 3 = LPG, 4 = CNG/LNG, 5 = flexfuel, 6 = electric, 7 = PHEV diesel, 8 = PHEV gasoline, and 9 = hydrogren fuel cell).

The market penetration curve parameters are determined during a user-specified trigger year in the following equations:

$$SLOPE = \frac{\ln(0.01)}{0.5 * CYAFVXG_{isc19,ifuel,iflt}}$$

(195)

where

SLOPE = Logistic market penetration curve parameter

CYAFVXG = Logistic market penetration curve parameter representing number of years until maximum market penetration

iflt = index for fleet vehicles: 1 for non-fleet vehicles and 2 for fleet vehicles.

$$MIDYR = TRGSHXG_{icafe19,ifuel,iflt} + \left(0.5 * CYAFVXG_{isc19,ifuel,iflt}\right)$$

(196)

where

MIDYR = Logistic market penetration curve parameter representing "halfway point" to maximum market penetration

TRGSHXG = Year in which each alternative fuel begins to increase in market share, due to EPACT1992 or other factors.

After the market penetration of alternative-fuel trucks has been triggered, the AFV market trend is determined through a logistic function as follows:

$$\begin{aligned} MPATH\_regn_{icafe19,ifuel,iflt,iyr,iregn} &= DCOST_{ifuel,iregn,icafe19,iyr} \\ &* \left(BFSHXG_{isc19,ifuel,iflt} + \left(\frac{EFSHXG_{isc19,ifuel,iflt} - BFSHXG_{isc19,ifuel,iflt}}{1 + e^{SLOPE*curcalyr-MIDYR}}\right)\right) \end{aligned}$$

(197)

where

$MPATH\_regn_{icafe19,ifuel,iflt,iyr,iregn}$ = Baseline market penetration

$BFSHXG_{isc19,ifuel,iflt}$ = Base year (2010) market share

$EFSHXG_{isc19,ifuel,iflt}$ = Maximum market share

curcalyr = Current model year.

The market share of alternative fuel trucks is assumed never to dip below the previous year's level in each sector. The final projected AFV market share used in the model is therefore defined as the maximum of the historical base year share and the projected share:

$$FUEL\_SHR\_regn_{iyr,icafe19,ifuel,iflt,iregn} = \max\left[BFSHXG_{isc19,ifuel,iflt}, MPATH\_regn_{icafe19,ifuel,iflt,iregn}\right]$$

(198)

FUEL_SHR_regn = Market share of CNG freight trucks by region.

b) Economic market share of CNG and LNG

Subroutine TRUCK_STOCK performs the first step in projecting the market share of CNG and LNG freight trucks. This calculation is done by fleet, size class, VMT group, and region. VMT group, *ivmt,* is broken down into 11 separate vehicle-miles traveled categories.

First, calculate the annual fuel savings of CNG/LNG trucks as compared to diesel trucks:

$$ANN\_\$\_SAVINGS\_CNG\_regn_{ivmt,iflt,icafe19,iregn} = VMT\_VEH_{ivmt,iflt,isc19} * \left(FCOST\_regn_{fuel=f,iregn} - FCOST\_regn_{fuel=4,iregn}\right)$$

(199)

where

ANN_$_SAVINGS_CNG_regn = Annual fuel savings for CNG/LNG vehicles compared to diesel or gasoline vehicles

VMT_VEH = VMT per vehicle by fleet, non-fleet, size class, and VMT group

fuel = fuel type (1 = diesel for size classes 5-8; 2 = gasoline for size classes 2b-4; 4 = CNG/LNG).

Next, calculate the net value of these fuel savings in the projection year:

$$NPV\_ADS\_regn_{ivmt,iflt,icafe19,iregn,year} = \frac{ANN\_\$\_SAVING\_CNG\_regn_{ivmt,iflt,icafe19,iregn}}{(1 + DISCRTXG)^{year}}$$

(200)

where

NPV_ADS_regn = Net present value of the fuel savings from using CNG/LNG year = payback year spans from one to four years.

The share of vehicles by VMT group, fleet or non-fleet, and size class for the year is then weighted by a payback share distribution that accounts for the average payback periods demanded by freight truck owner/operators:

$$BUY\_CNG\_regn_{ivmt,iflt,icafe19,year,iregn} = PBACK\_SHR_{year} * VEH\_SHR_{ivt,iflt,isc19}$$

(201)

where

BUY_CNG_regn = Share of CNG vehicles brought by fleet, size sclass, and region

PBACK_SHR = Distribution of payback periods by owner/operators

VEH_SHR = Percent share of vehicle fleet and size class.

Positive purchase decisions, BUY_CNG, by fleet, size class, and VMT group, occur if the incremental cost of CNG/LNG vehicles ($17,000 for Classes 2b and 3; $40,000 for Classes 4 to 6; and $60,000 for Classes 7 to 8) is less than the net present value of fuel savings, NPV_ADS.

The shares of CNG vehicles purchased by fleet and by size class are then calculated:

$$\begin{aligned} fuel\_shr\_regn_{iyr,icafe19,fuel=4,iflt,iregn} &= fuel\_shr\_regn_{iyr,icafe19,fuel=4,iflt,iregn} \\ &+ \left(\sum_{year=1}^{4} buy\_cng\_regn_{ivmt,iflt,icafe19,year,iregn} \right. \\ &\left. * MPATH\_regn_{icafe19,fuel=4,iflt,iyr,iregn} \right) \end{aligned}$$

(202)

The market share variable FUEL_SHR_regn is then used in the following subroutine to calculate final market share for CNG trucks.

c) Market share of diesel trucks

The share of diesel, *ifuel* = 1, in conventional truck sales is projected through a time-dependent exponential decay function based on historical data that is defined by

$$\begin{aligned} MPATHregn_{icafe19,ifuel,iflt,iyr,iregn} &= BFSHXG_{isc19,ifuel,iflt} + \left(EFSHXG_{isc19,ifuel,iflt} - BFSHXG_{isc19,ifuel,iflt}\right) \\ &* \left(1 - e^{CSTDXG_{isc19,iflt} + CSTDVXG_{isc19,iflt} * curcalyr}\right) \end{aligned}$$

(203)

where

$CSTDXG_{isc19,iflt}$, $CSTDVXG_{isc19,flt}$ = 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 100%.

Diesel market share is calculated as the projected share of diesel in conventional truck sales multiplied by the share occupied by conventional trucks:

The remainder of truck purchases is assumed to be gasoline, *ifuel*=2:

$$Fuel\_Shr\_regn_{iyr,icafe19,fuel=2,iflt,iregn} = \max\left[0, 1 - \sum_{ifuel=1,3-9} Fuel\_Shr\_regn_{iyr,icafe19,ifuel,iflt,iregn}\right]$$

(204)

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 previous year's truck population estimates:

$$TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt,iregn} = TRK\_19\_regn_{iyr-1,icafe19,iage-1,ifuel,iflt,iregn} * \left(1 - SCRAP\_RATE_{isc,iage-1,ifuel}\right)$$

(205)

where

$TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt,iregn}$ = Existing stock of trucks

$SCRAP\_RATE_{isc,iage}$ = Factor representing the proportion of trucks of each vintage that are scrapped each year

iage = index for vintage of vehicle from 2-34, 1 implies new vehicle.

A number of trucks are transferred in each year from fleet to non-fleet ownership. The model assumes that only gasoline and diesel fuel vehicles are transferred. Transfers of conventional trucks are based on exogenously determined transfer rates that are defined as

$$TRF_{iyr,icafe19,iage,ifuel,iregn} = TFFXGRT_{isc,iage} * TRK19regn_{iyr,icafe19,iage,ifuel,iflt=2,iregn}$$

(206)

where

$TRF_{iyr,icafe,iage,ifuel,iregn}$ = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks

$TFFXGRT_{isc,iage}$ = Percentage of trucks of each vintage to be transferred from fleets to non-fleets.

The new estimate of the number of existing trucks is simply the existing population (after scrappage) minus fleet transfers:

$$TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt=2,iregn} = TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt=2,iregn} - TRF_{iyr,icafe19,iage,ifuel,iregn}$$

and

$$TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt=1,iregn} = TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt=1,iregn} + TRF_{iyr,icafe19,iage,ifuel,iregn}$$

(207)

4. Calculate purchases of new trucks

New truck purchases are based on Classes 2b and 3 truck sales and on the Macroeconomic Activity Module's projection of Classes 4 through 8 truck sales that is split between truck Classes 4 to 6 and Classes 7 to 8, as defined at the beginning of this section:

$$NEWTRUCKS\_regn_{iyr,isc=1,iflt=3,iregn=11} = MC\_VEHICLES_{(3,iyr)} * 1000000$$

$$NEWTRUCKS\_regn_{iyr,isc=2,iflt=3,iregn=11} = NEWCLS46_{iyr} * MC\_SUVTHAM_{iyr} * 1000000$$

$$NEWTRUCKS\_regn_{iyr,isc=3,iflt=3,iregn=11} = \left(1 - NEWCLS46_{iyr}\right) * MC\_SUVTHAM_{iyr} * 1000000$$

$$NEWTRUCKS\_regn_{iyr,isc=4,iflt=3,iregn=11} = \left(MC\_VEHICLES_{1,iyr} + MC\_VEHICLES_{2,iyr} - TEMPCLS12A_{iyr}\right) * 1000000$$

(208)

where

$NEWTRUCKS\_regn_{iyr,isc,iflt,iregn}$ = National new truck sales where isc = 1 for Class 3, isc = 2 for Classes 4-6, isc = 3 for Classes 7-8, and isc = 4 for Class 2b

$MC\_VEHICLES_{1\text{-}3,iry}$ = Sales of Class 1-3 trucks from the Macroeconomic Activity Module

$NEWCLS46_{iyr}$ = Truck classes 4 to 6 share of total truck sales

$MC\_SUVTHAM_{iyr}$ = Total new truck sales for classes 4-8, from the Macroeconomic Activity Module

$TEMPCLS12A_{iyr}$ = The total of Class 1-2 trucks that are considered light-duty vehicles *iregn* = 11 = total of all Census Divisions

The next step is to calculate the new truck sales, ***iage*** = 1,:

$$TRK\_19\_regn_{iyr,icafe19,iage=1,ifuel,iflt=2,iregn=11} = NEWTRUCKSregn_{iyr,isc,iflt=3,iregn=11} * FLEETSHR_{isc} * REGN\_SHARE_{iyr-1,iage=1,iflt,iregn}$$

$$TRK\_19\_regn_{iyr,icafe19,iage=1,ifuel,iflt=1,iregn=11} = NEWTRUCKS\_regn_{iyr,isc,iflt=3,iregn=11} * (1 - FLEETSHR_{isc}) * REGN\_SHARE_{iyr-1,iage=1,iflt,iregn}$$

(209)

where

$FLEETSHR_{isc}$ = Percent of HDV in fleet use by size class

$regn\_share_{iyr,iage,iflt,iregn}$ = Regional share of new truck sales from previous model year by fleet.

5. Calculate fuel consumption

The next stage of the component 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. The model calculates the VMT growth rate using a ratio between current year and previous year total truck ton-miles. This VMT growth rate is then applied to the previous year truck VMT, by census division and industrial sector, to calculate truck VMT:

$$TVMT_{iyr,iregn,isec} = TVMT_{iyr-1,isec,iregn} * \left(\frac{TTONMI_{iyr,iregn,isec}}{TTONMI_{iyr-1,iregn,isec}}\right)$$

(210)

where

$TVMT_{iyr,iregn,isec}$ = Freight truck vehicle miles traveled, by industrial sector and census division

$TTONMI_{iyr,iregn,isec}$ = Freight truck ton-miles by industrial sector and census division

isec = Index of economic sectors.

The model then calculates the adjustment VMT per truck:

$$VMTADJR_{iyr} = \frac{\sum_{iregn=1}^{9}\sum_{isec=1}^{10} TVMT_{iyr,iregn,isec}}{\sum_{isc,iage,ifuel,ivoc} ANNVMT_{(isc,iage,ifuel,ivoc)} * TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt,regn=11}}$$

(211)

where

$VMTADJR_{iyr}$ = Aggregate VMT adjustment factor

$ANNVMT_{isc,iage,ifuel,ivoc}$ = Base year VMT per truck by freight reporting classes

ivoc = index for vocational vehicles where 1 = non-vocational and 2 = vocational.

The model applies the VMT adjustment to obtain VMT across all sectors:

$$VMTFLTR_{cur,isc,iage,ifuel,iflt,iregn} = ANNVMT_{isc,iage,ifuel,ivoc} * VMTADJR_{iyr} * TRK\_19\_regn_{iyr,icafe19,iage,ifuel,iflt,iregn=11} * VMTSHRR_{iyr,iregn}$$

(212)

where

$VMTFLTR_{cur,isc,iage,ifuel,iflt,iregn}$ = HDV VMT

$VMTSHRR_{iyr,iregn}$ = Regional share of VMT.

Fuel consumption in gallons of gasoline equivalent is finally calculated by dividing VMT by on-road fuel economy:

$$FUELDMDR_{year,isc,ifuel,iflt,iregn} = \sum_{iage=1}^{34} \frac{VMTFLTR_{year,isc,iage,ifuel,iflt,iregn}}{HDV\_MPG_{year,isc,iage,ifuel}}$$

(213)

where

FUELDMDR = Total freight truck fuel consumption by market class and fuel type, in gallons of gasoline equivalent.

HDV_MPG = Fuel economy of freight trucks, by year, market class, fuel, and vintage.

Converting from gasoline equivalent to trillion Btu only requires multiplying by the heat rate of gasoline as shown here:

$$FUELBTUR_{isc,ifuel,iflt,iregn} = FUELDMDR_{isc,ifuel,iflt,iregn} * HRATE_{isc,ifuel} * 10^{-12}$$

(214)

where

FUELBTUR = Total fleet truck fuel consumption by market class, fuel type, and region trillion Btu.

Rail Freight Component

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. Figure 15 depicts the Rail Freight Component. 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, transfer coal ton-miles traveled (COAL_TMT) within NEMS as follows:

$$COAL\_TMT_{Year} = TTONMILE_{Year}$$

(215)

where

COAL_TMT = Ton-miles traveled for coal in a given year.

TTONMILE = Billion ton-miles by railroad for coal by coal summed over regions, from the Coal Market Module.

Then, project the growth of coal rail freight ton-miles by census division:

$$RPROJ\_CTONMI_{Year,REG} = RPROJ\_CTONMI_{Year-1,REG} * (1 + \left[\frac{COAL_{TMT_{Year}} - COAL_{TMT_{Year-1}}}{COAL_{TMT_{Year-1}}}\right]) \qquad \textbf{(216)}$$

Next, project the growth of non-coal rail freight ton-miles by census division and industrial sector:

$$RPROJ\_NCTONMI_{Year,REG,ISIC} = TSIC_{REG,ISIC} * RTM\_OUTPUT_{REG,ISIC} \qquad \textbf{(217)}$$

where

RPROJ_TONMI = Ton-miles traveled for non-coal in a given year.

RTM_OUTPUT = Ton-miles traveled per dollar of industrial ouput, *ISIC=1,16.*

TSIC = Value of output of industry *ISIC*, in base year dollars.

Calculate aggregated rail ton-miles traveled, RTMTT, as follows:

$$RTMTT_{Year} = \sum_{REG=1}^{9} \sum_{ISIC=1}^{16} RPROJ\_NCTONMI_{Year,REG,ISIC} + \sum_{REG=1}^{9} RPROJ\_CTONMI_{Year,REG}$$

(218)

Energy consumption is then estimated using the projected rail energy efficiency as follows:

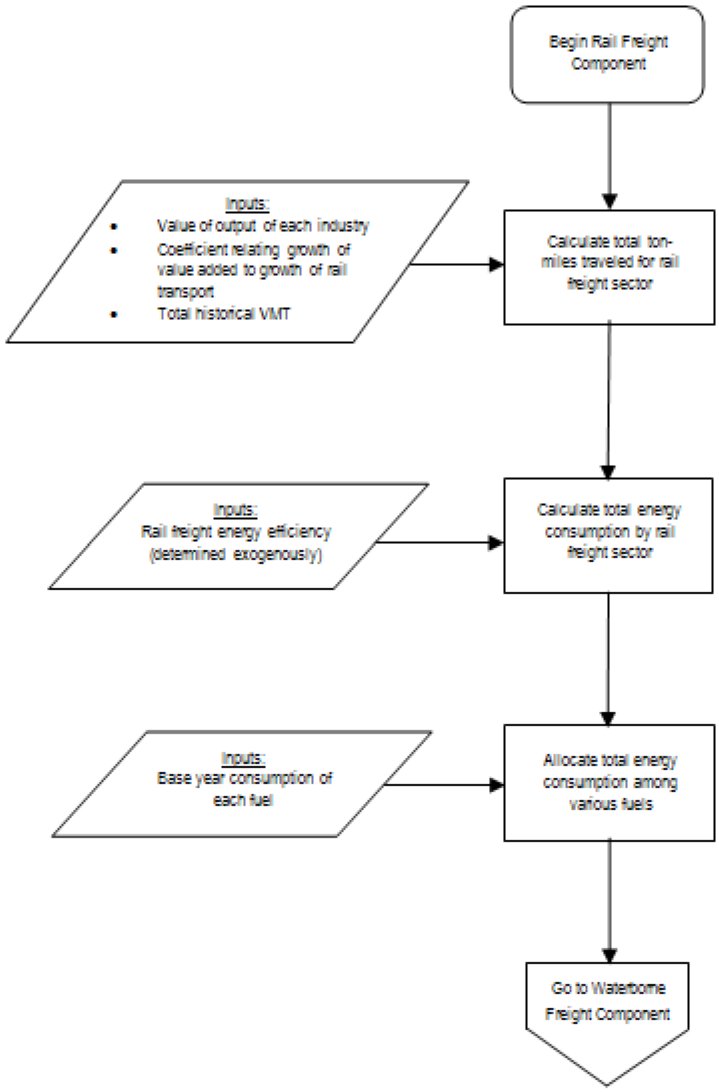
$$TQFRAILT_{Year,REG} = FREFF_{Year} * RTMTT_{Year,REG} \quad \textbf{(219)}$$

where

$TQFRAILT_{year,reg}$ = Total energy consumption by freight trains.

$FREFF_{year}$ = Freight rail energy efficiency.

Figure 15. Rail freight component



Rail efficiency gains resulting from technological development and increased system efficiency are based on an exogenous analysis of trends.

In order to estimate the demand for the various fuels used for rail transport, the potential to switch from diesel to LNG based on cost-effectiveness is calculated. The net present value of switching to LNG is calculated by the following:

$$NPV\_LNG_{Year} = \frac{ANN\_FUEL\_SAVINGS_{PAYBK=1}}{1+DISCRT} + \frac{ANN\_FUEL\_SAVINGS_{PAYBK}}{1+DISCRT^{PAYBK}} \tag{220}$$

where

NPV_LNG = Net present value of switching to LNG in year, *Year*.

ANN_FUEL_SAVINGS = Annual fuel savings from switching to LNG from diesel.

DISCRT = Discount rate for freight locomotives.

PAYBK = Payback period demanded for freight railroads.

If the net present value of switching to LNG is greater than the freight locomotive incremental cost, then the LNG fuel share is determined by the maximum LNG penetration. If the net present value is less than the incremental cost, the LNG fuel share maintains at previous year values.

Fuel consumption is then allocated to each region by:

$$TQRAILR_{Rail\_Fuel,REG,Year} = TQFRAILT_{REG,Year} * RAIL\_FUEL\_SHR_{Rail\_Fuel,Year} \tag{221}$$

where

TQRAILR = Total regional fuel consumption for each technology.

RAIL_FUEL_SHR = Share of rail freight fuel consumption, by fuel.

Waterborne Freight Component

Two classes of waterborne freight transportation are considered in this component: domestic marine traffic and freighters conducting foreign trade. This is useful because vessels that comprise freighter traffic on rivers and in coastal regions have different characteristics than those that ply international waters. Figure 16 shows a flowchart of the waterborne freight component.

Domestic marine

The estimate of total domestic waterborne transportation demand is driven by projections of industrial output and a measure of ton-mile per dollar of industrial output, as defined by:

$$STMTT_{REG,Year} = \sum_{ISIC=1}^{16} TSIC_{REG,ISIC.Year} * DSTM\_OUTPUT_{REG,ISIC} * (1 + ANN\_DECLINE_{Year})$$

(222)

where

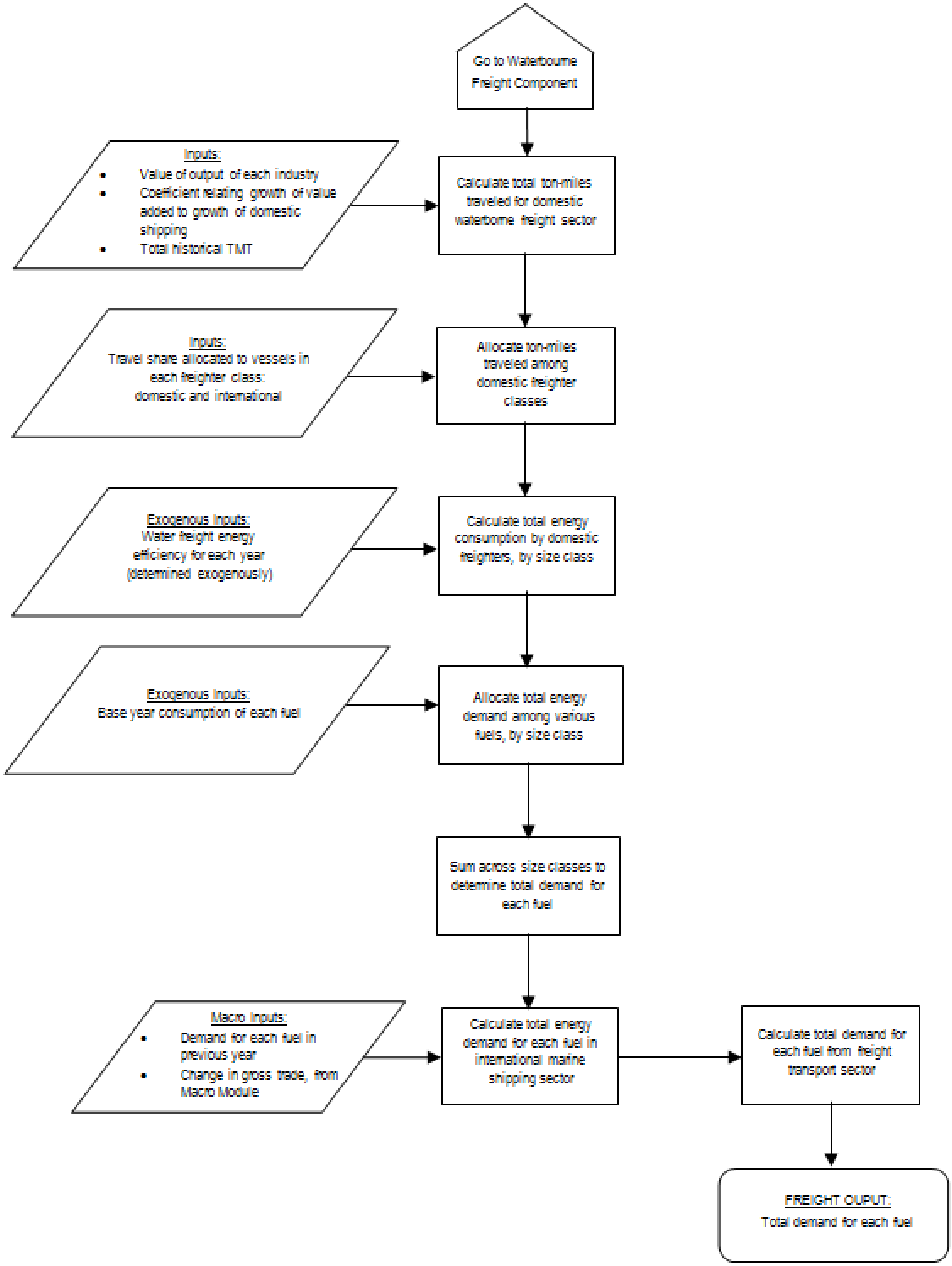
STMTT = Total ton-miles of waterborne freight by census division in year, *Year*.

TSIC = Value of industrial output, *ISIC*, in base year dollars.

DSTM_OUTPUT = Domestic marine ton-mile per dollar of industrial output.

ANN_DECLINE = Domestic marine annual rate of ton-mile per dollar output decline.

Figure 16.Waterborne freight component



Energy use is subsequently estimated, using average energy efficiency:

$$TQDSHIPT_{REG,Year} = DSEFF_{Year} * STMTT_{REG,Year} \quad \textbf{(223)}$$

where

TQDSHIPT = Domestic ship energy demand (thousand Btu) by census division.

DSEFF = Average fuel efficiency, in thousand Btu per ton-mile.

Estimated changes in energy efficiency are exogenous. The next step in the component is allocating total energy consumption among four fuel types (distillate fuel, residual fuel oil, CNG, and LNG) using domestic shipping shares:

$$TQDSHIPR_{Ship\_Fuel,REG,Year} = TQDSHIPT_{REG,Year} * DOMSHIP\_FUEL\_SHR_{Ship\_Fuel,Year} \quad \textbf{(224)}$$

where

SFD = Total regional domestic ship energy demand, by fuel and census division.

DOMSHIP_FUEL_SHR = Domestic shipping fuel share.

Ship_Fuel = Index referring to the four shipping fuel types.

The factor that allocates energy consumption among the four fuel types is based on 2006 data[19] for distillate and residual fuel. Starting in 2013, LNG is allowed to penetrate the domestic shipping fuel demand, and therefore reduces the share of both distillate and residual fuel throughout the projection period.

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:

$$ISFDT_{Year} = ISFDT_{Year-1} + 0.5 * ISFDT_{Year-1} * INTS\_B * \left[\frac{GROSST_{Year}}{GROSST_{Year-1}} - 1 \right] \quad \textbf{(225)}$$

where

ISFDT = Total international shipping energy demand in year *Year*.

INTS_B = for frozen technology case = 0.4, for high technology case = 0.6

GROSST = Value of gross trade (imports + exports), from the Macroeconomic Activity Module.

---

[19] Oak Ridge National Laboratory, *Transportation Energy Data Book Edition 28*, June 2009.

Total energy demand is then allocated among the four fuels by the following:

$$ISFD_{Ship\_Fuel,Year} = ISFDT_{Year} * INTSHIP\_FUEL\_SHR_{Ship\_Fuel,Year} \quad \textbf{(226)}$$

where

ISFD = International freighter energy demand, by fuel.

INTSHIP_FUEL_SHR = International shipping fuel share.

Regional fuel consumption is then calculated as:

$$TQISHIPR_{Ship\_Fuel,REG,Year} = ISFD_{Ship\_Fuel,Year} * SEDSHRXX_{Ship\_Fuel,REG,Year} \quad \textbf{(227)}$$

where

TQISHIPR = Total regional energy demand by international freighters.

SEDSHRXX = Regional share of fuel demand, from SEDS, by fuel, XX=DS (distillate), XX=RS (residual).

Emission Control Area (ECA) marine fuel

The North American ECAs generally extend 200 nautical miles (nm) from the U.S. and Canadian ports (50 nm for the U.S. Caribbean ECA). TDM estimates a 2012 baseline of fuel consumption (by billion British thermal units [Btus]) for ships traveling in each of the 9 U.S. census divisions and Puerto Rico. Projections include auxiliary power and are made to account for ship efficiency improvements, shipping demand changes, and fuel price fluctuations.

Baseline (2012) energy demand is estimated by the following:

$$FUELCONS_{2012,Class,CD} = TRANSITFUELCONS_{2012,Class,CD} + AUXFUELCONS_{2012,Class,CD} \quad \textbf{(228)}$$

The fleet turnover (FLEETTO) variable was computed from MARAD data to represent the rate of introduction of new vessels into the fleet moving through the North American ECA. The new vessels are assumed to be more efficient than their predecessors.

Projections of ECA energy demand is estimated by the following:

$$\begin{aligned} ECAFUELCONS_{CD,YEAR} = \sum_{Class} & FUELCONS_{2012,Class,CD} * \max[0,(1-(YEAR-2012)*FLEETTO_{Class}] \\ & + FUELCONS_{2012,Class,CD} * \{1-\max[0,(1-(YEAR-2012)*FLEETTO_{Class}]\} \\ & * (1-MEFFINC_{Class})^{\frac{YEAR-2012}{2}} * GEFFECTS_{Class,YEAR} \end{aligned} \quad \textbf{(229)}$$

where

FLEETTO = vessel fleet turnover, by vessel class.

MEFFINC = marine fuel efficiency improvement, by vessel class.

GEFFECTS = fuel consumption from the various vessel classes may be directly related to AEO scenario outputs (e.g., imports of “Petroleum and Products”), by class and year.

Class = Tanker, Container, Gas (LPG/LNG), Roll-on/Roll-off, Bulk, or General Cargo.

ECA fuel shares are revised each year based on changes in fuel prices since the base year. The fuel sharing is calculated using a logit formulation. The fuel sharing equation for each vessel CLASS is as follows:

$$FLTPROF_{MFTYPE,CD,YEAR} = \frac{P_{MFTYPE}^{Alpha} * Beta_{MFTYPE}}{\sum_{MFTYPE} P_{MFTYPE}^{Alpha} * Beta_{MFTYPE}} \quad \textbf{(230)}$$

ECA fuel demand, by fuel type, is incorporated into international marine fuel demand (TQISHIPR).

Miscellaneous Energy Demand Submodule

The Miscellaneous Energy Demand (MED) Submodule 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 Submodule.

Military Demand Component

Figure 18 is a flowchart depicting the Military Demand Component. 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:

$$MILTARGR_{Year} = \frac{MC\_GFMLR_{Year}}{MC\_GFMLR_{Year-1}} \quad \textbf{(231)}$$

where

MILTARGR = Growth in the military budget from the previous year.

MC_GFMLR = Total defense purchases in year *Year*, from the Macroeconomic Activity Module.

Total consumption of each of four fuel types is then determined by

$$MFD_{Mil\_Fuel,Year} = MFD_{Mil\_Fuel,Year-1} * MILTARGR_{Year} \quad \textbf{(232)}$$

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:

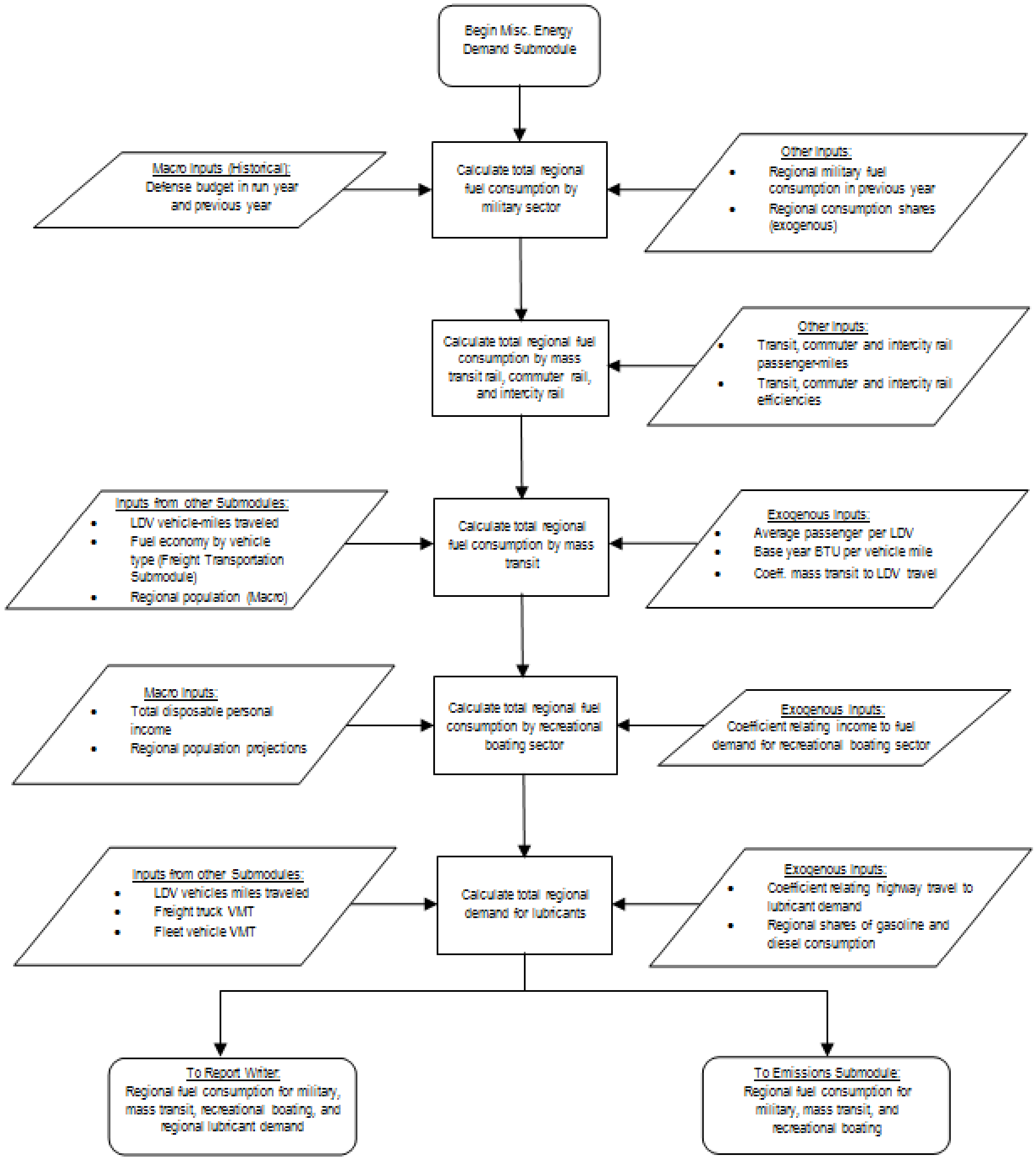
$$QMILTR_{Mil\_Fuel,REG,Year} = MFD_{Mil\_Fuel,Year} * MILTRSHR_{Mil\_Fuel,REG,Year} \quad \textbf{(233)}$$

where

QMILTR = Regional fuel consumption, by fuel type, in Btu.

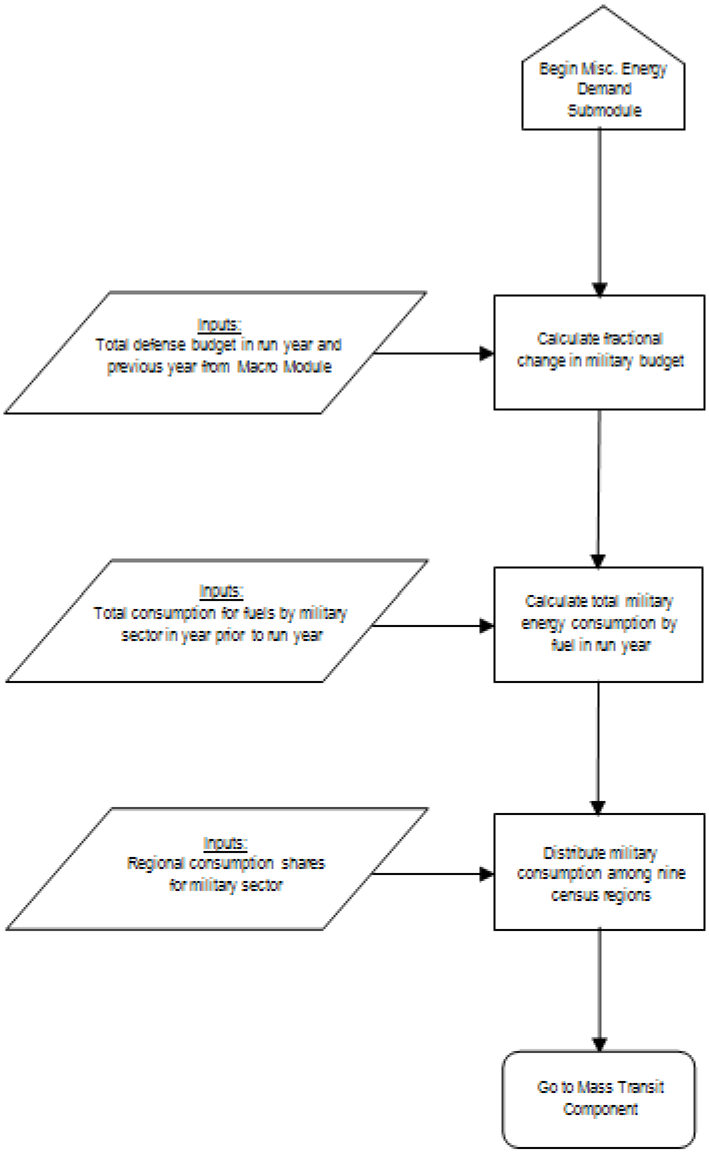
MILTRSHR = Regional consumption shares, from 1991 data, held constant.

Figure 17. Miscellaneous energy demand submodule



Note: The Emissions Submodule is currently inactive.

Figure 18. Military demand component



Mass Transit Demand Component

Figure 19 depicts the Mass Transit Demand Component. 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. Changes have been made to the Mass Transit Demand Component 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, and travel demand log of income are read in. The sum of the three rail modes is captured by the following equation:

$$QMTRR_{Ifuel,Region,Year} = TRED_{Region,Year} + CREDE_{Region,Year} + IREDER_{Region,Year} \tag{234}$$

where

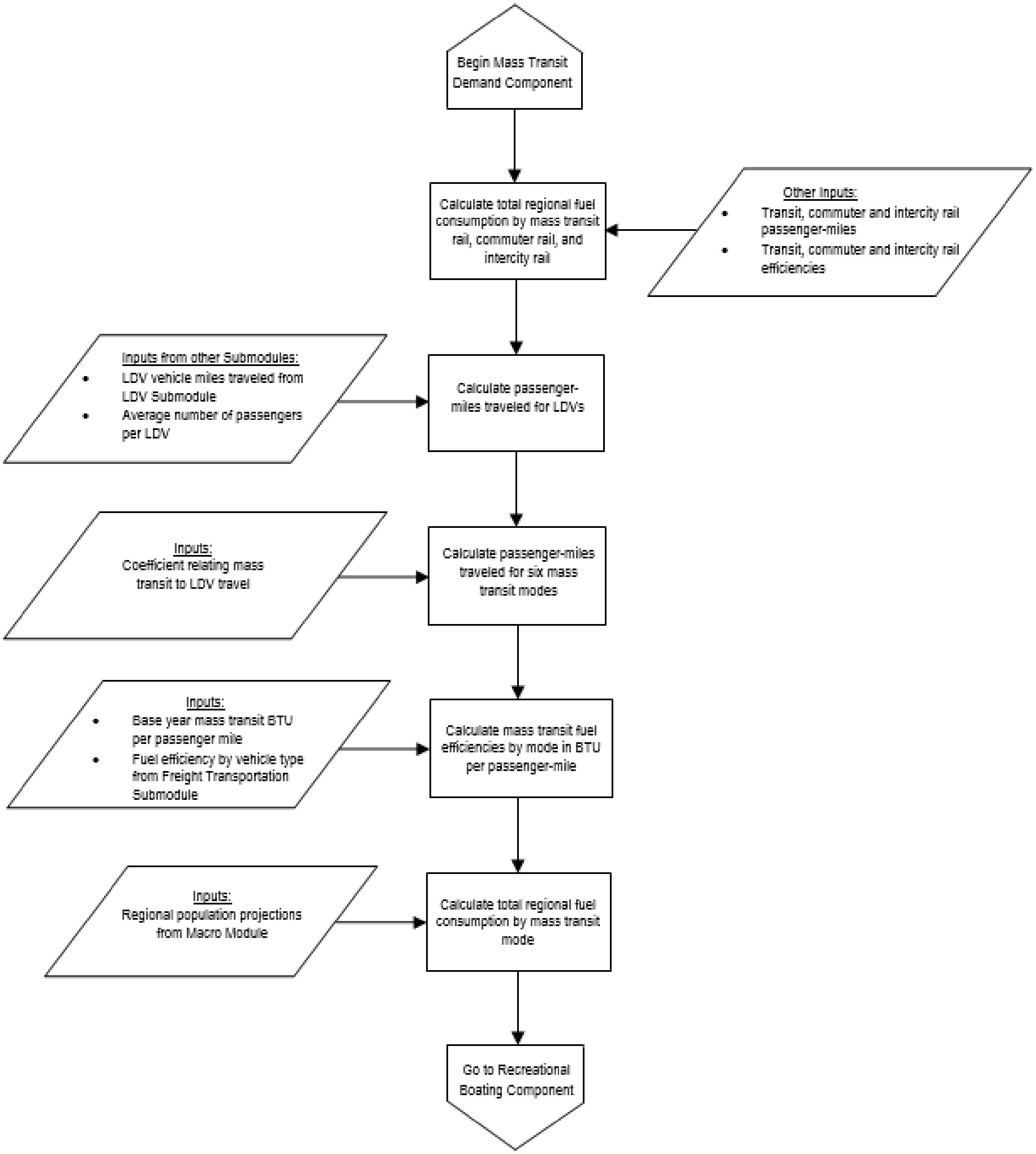
QMTRR = Passenger rail energy demand by fuel by Census division.

TRED = Transit rail energy demand by Census division.

CREDE = Commuter rail energy demand by Census division.

IREDER = Intercity rail energy demand by Census division.

Figure 19. Mass transit demand component



The first set of equations describes the bus segment of the component for the transit bus mode, IM=1:

$$TMPMT_{iregn,n} = TBPMTPC_{iregn,n} * MC_{NP16A_{iregn,n}} - CAVADJ_{iregn,n} \tag{235}$$

where

TBPMT = Passenger-miles traveled for the transit bus mode.

TBPMTPC = Passenger-miles traveled per capita for the transit bus mode.

MC_NP16A = U.S. population 16 and older from the Macroeconomic Activity Module.

CAV_ADJ = Change in travel demand due to ride hailing.

Fuel efficiencies, in Btu per vehicle-mile, are obtained from the Freight Submodule for buses and rail. Mass transit efficiencies, in Btu per passenger-mile, are calculated as:

$$\begin{aligned} TBBTUPM_{REG,Year} = {} & TBBTUPM_{REG,Year-1} * TBSYSEF_{REG} \\ & *1-((1-\left(\frac{TRFTMPG_{Year-1}}{TRFTMPG_{Year}}\right)*TBFSHR_{REG,Fuel=diesel,Year})) \\ & *1+((TBFSHR_{REG,Fuel=CNG,Year} - TBFSHR_{REG,Fuel=CNG,Year-1})*0.25) \end{aligned} \tag{236}$$

where

TBBTUPM = Btu per passenger-mile for the transit bus mode.

TRFTMPG = Freight MPG, by vehicle type, from the Freight Transportation Module.

TBSYSEF = Bus system efficiency for the transit bus mode, in Btu per passenger.

TBFSHR = Projected fuel share for transit buses, by fuel type.

Total fuel consumption is calculated and distributed among regions according to their populations based on the following:

$$QMTBR_{im,ifuelx,iregn,n} = TBPMT_{iregn,year} * TBBTUPM_{iregn,year} * TBFSHR_{iregn,ifuelx,year} \tag{237}$$

where

QMTBR = Regional consumption of fuel, by mode.

The following equations describe the bus segment of the model for intercity and school buses:

$$TMOD_{IM,Year} = TMPASMIL_{IM} * MC\_NP_{Year} \tag{238}$$

where

TMOD = Passenger-miles traveled, by mode.

TMPASMIL = Passenger-miles per capita, by bus mode.

MC_NP = U.S. population from the Macroeconomic Activity Module (adult population for intercity, child population for school).

IM = Index of transportation mode: 1 = Intercity Bus, 2 = School bus.

Fuel efficiencies, in Btu per vehicle-mile, are obtained from the Freight Transportation Submodule for buses and rail and mass transit efficiencies, in Btu per passenger-mile, are calculated as:

$$TMEFF_{IM,Year} = TMEFF_{IM,Year-1} * BUSSYSEF_{IM} \\ *1-((1-\left(\frac{TRFTMPG_{Year-1}}{TRFTMPG_{Year}}\right)*QMODFSHR_{IM,2,Year})) \\ *1+((QMODFSHR_{IM,3,Year} - QMODFSHR_{IM,3,Year-1})*0.25) \quad \textbf{(239)}$$

where

TMEFF = Btu per passenger-mile, by mass transit mode.

BUSSYSEF = Bus system efficiency by mode, in Btu per passenger.

Total fuel consumption is calculated and distributed among regions according to their population shares:

$$QMTBR_{IM,Fuel,REG,Year} = TMOD_{IM,Year} * TMEFF_{IM,Year} \\ * \frac{MC\_NP_{REG,Year}}{\sum_{REG=1}^{9} MC\_NP_{REG,Year}} * QMODFSHR_{IM,Fuel,Year} \quad \textbf{(240)}$$

where

MC_NP = Regional population projections, from the Macroeconomic Activity Module.

QMODFSHR = Projected fuel share for intercity and school buses, by fuel type

Recreational Boating Demand Component

Figure 20 depicts the Recreational Boating Demand Component. 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:

$$RBEDPC_{Fuel,Year} = X1_{Fuel} + X2_{Fuel} * LOG(INC00\$NPT_{Year}) + X3_{Fuel} * PRICE04_{Fuel} \quad \textbf{(241)}$$

where

RBEDPC = Recreational boating 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.

INC00$NPT = 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 boating fuel consumption for each year with the following equation:

$$RECFD_{Fuel,Year} = RBEDPC_{Fuel,Year-1} * \sum_{REG=1}^{9} MC\_NP_{REG,Year} \quad \textbf{(242)}$$

where

RECFD = National recreational fuel consumption in year, Year, Fuel (where 1=Gasoline and 2 = Diesel).

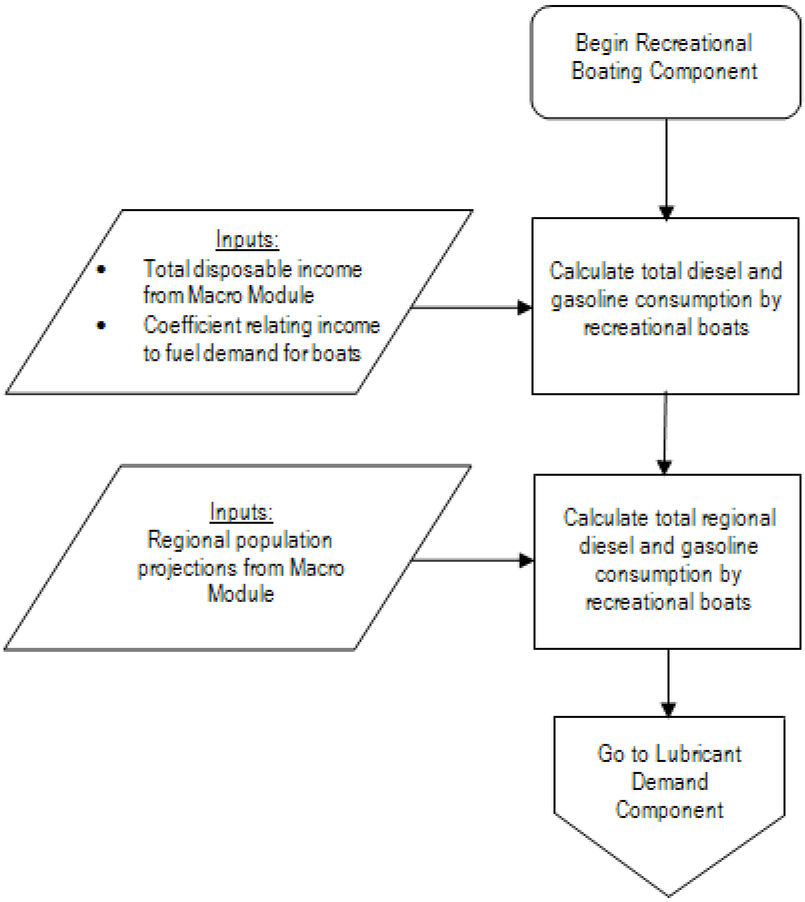
Following this, the regional consumption is calculated according to population, as for mass transit:

$$QRECR_{Fuel,REG,Year} = RECFD_{Fuel,Year} * \frac{MC\_NP_{REG,Year}}{\sum_{REG=1}^{9} MC\_NP_{REG,Year}} \quad \textbf{(243)}$$

where

QRECR = Regional fuel consumption by recreational boats in Year, Fuel (where 1=Gasoline and 2 = Diesel).

Figure 20. Recreational boating demand component



Lubricant Demand Component

Figure 21 shows a flowchart depicting the Lubricant Demand Component. 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 (VMT) is first determined as:

$$HYWAY_{Year} = VMTEE_{Year} + FTVMT_{Year} + FLTVMT_{Year} \quad \textbf{(244)}$$

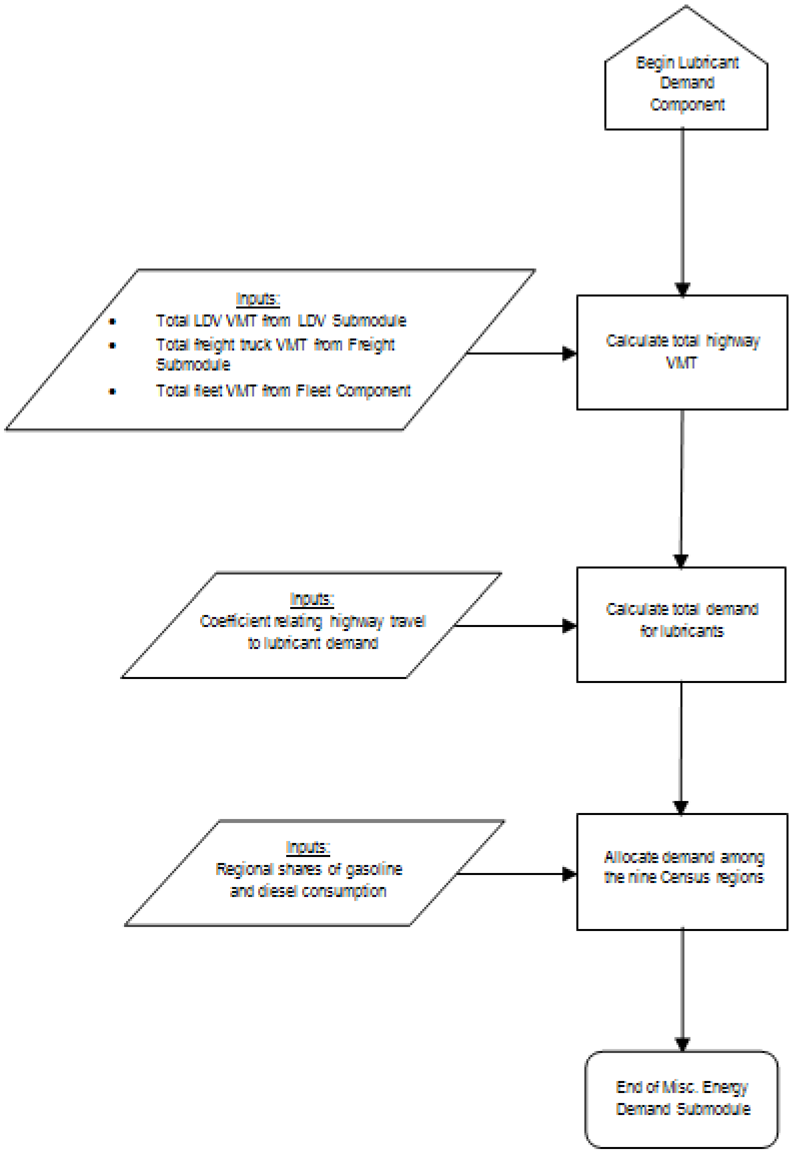
where

HYWAY = Total highway VMT.

FTVMT = Total freight truck VMT, from the Freight Transportation Submodule.

FLTVMT = Total fleet vehicle VMT, from the LDV Fleet Component.

Figure 21. Lubricant demand component



Lubricant demand is then estimated based on the following:

$$LUBFD_{Year} = LUBFD_{Year-1} * \left[\frac{HYWAY_{Year}}{HYWAY_{Year-1}} \right]^{BETALUB} \quad \textbf{(245)}$$

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 follows:

$$QLUBR_{REG,Year} = LUBFD_{Year} * \left[\frac{(VMTEE_{Year} + FLTVMT_{Year}) * SHRMG_{REG,Year} + FTVMT_{Year} * SHRDS_{Year}}{HYWAY_{Year}} \right] \quad \textbf{(246)}$$

where

QLUBR = Regional demand for lubricants in year,*Year*, in Btu.

VMTEE = Total household light-duty vehicle miles traveled.

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 Demand Module

Model acronym

TRAN

Description

The Transportation Sector Demand 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 submodules: Light-Duty Vehicles (including Light-Duty Fleet Vehicles, Light-Duty Stock, and Commercial Light Trucks), Air Travel, Freight Transportation (truck, rail, and marine), and Miscellaneous Energy Demand (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 2050) 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 2017 Model Interfaces

Receives inputs from the Electricity Market Module, Liquid Fuels Market Module, Natural Gas Transmission and Distribution Module, and the Macroeconomic Activity Module.

Documentation

Model Documentation Report: Transportation Sector Demand Module of the National Energy Modeling System, DOE/EIA-M070(2018), June 2018.

Energy system described

Domestic transportation sector, and international aviation and marine energy consumption.

Coverage

- Geographic: Nine Census Divisions: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific.
- Time Unit/Frequency: Annual, 1995 through 2050.
- Products: motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG/LNG, methanol, ethanol, hydrogen, lubricants, and pipeline fuel.
- 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 2015 (SEDS), June 2017, www.eia.gov/states/seds .
- *Short-Term Energy Outlook*, October 2017, www.eia.gov/forecasts/steo .
- Macroeconomic Activity Module 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, 2009, March, 2010.

- Jet Information Services Inc., World Jet Inventory: Year-End 2015.
- Federal Highway Administration, https://www.fhwa.dot.gov/policyinformation/statistics.cfm.
- National Highway Traffic Safety Administration, Final Model Year Fuel Economy Report, 2016.
- Oak Ridge National Laboratory, Transportation Energy Data Book Ed. 35, ORNL-6987, October 2016.
- Department of Commerce, Bureau of the Census, Vehicle Inventory and Use Survey 2002, December 2004.
- U.S. Environmental Protection Agency, Engines and Vehicles Compliance Information System, various years.
- 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards, October, 2012, http://www.nhtsa.gov/fuel-economy.
- IHS Markit Polk, National Vehicle Population Profile, various years.
- IHS Markit Polk, Trucking Industry Profile, various years.

Appendix B. Acronyms

Acronym	Definition
ATV	Advanced Technology Vehicle
AFV	Alternative Fuel Vehicle
AFVADJ	Alternative Fuel Vehicle Adjustment Subroutine
ASM	Available Seat-Miles
AEO2018	Annual Energy Outlook 2018
CNG/LNG	Compressed/Liquefied Natural Gas
CVCC	Consumer Vehicle Choice Component
CAFE	Corporate Average Fuel Economy
RPMD	Domestic Revenue Passenger-Miles
EPACT1992	Energy Policy Act of 1992
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FFV	Flex Fuel Vehicle
FTSAC	Freight Truck Stock Adjustment Component
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
MTCC	Manufacturers Technology Choice Component
MPG	Miles Per Gallon
MEDS	Miscellaneous Energy Demand Submodule
NEMS	National Energy Modeling System
NHTSA	National Highway Traffic Safety Administration
NiMH	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
VMTC	Vehicle-Miles Traveled Component
ZEV	Zero-Emission Vehicle

Appendix C. Details of Subroutines Used in the Model

A flowchart of the calls made by the Transportation Sector Demand Module is provided in 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 subroutine are only called once. These include subroutines such as READNHTSA, READHIST, and READSTOCK.

SUBROUTINE: TRAN

Description: The NEMS transportation model encompasses a series of semi-independent modules 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 sector demand module consists of four submodules 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 submodules include: Light-Duty Vehicle, Air Travel, Freight Transportation (Heavy Truck, Rail, and Marine), and Miscellaneous Energy Demand.

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- 256

SUBROUTINE: READLDV

Description: Reads the spreadsheet input file TRNLDV.XML.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: READSTOCK

Description: Reads the spreadsheet input file TRNSTOCK.XML.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: TMAC

Description: This subroutine reassigns MACRO data to TRAN subroutine local variables.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: NEWLDV

Description: This subroutine segments new light vehicle sales by cars, light trucks less than 8,500 pounds GVWR and light trucks from 8,500 pounds GVWR to 10,000 pounds GVWR.

Called by: TRAN

Calls: None

Equations: None

SUBROUTINE: TMPGNEW

Description: This subroutine starts the fuel economy module, AFV module, and loads data inputs. After

completion, the average price of vehicles is computed.

Called by: TRAN

Calls: READNHTSA ; READHIST; AFVADJ; FEMCALC; CGSHARE; TREG; TLDV; CAFECALC; CAFETEST

Equations: 1-144

SUBROUTINE: READNHTSA

Description: This subroutine reads the NHTSA calibration data file.

Called by: TMPGNEW

Calls: None

Equations: None

SUBROUTINE: READHIST

Description: This subroutine reads data for 1990 through the year prior to the MTCC 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: This subroutine establishes alternative 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 MTCC. 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, trnldv.xml. 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/LNG 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; HEVCALC; PHEV10CALC; PHEV40CALC; FCCALC

Equations: 1- 81

SUBROUTINE: FEMCALC

Description: This subroutine determines the cost-effective market shares of technologies for each vehicle class. The resulting fuel economy, weight, horsepower, and price are calculated. This 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. This 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 and plug-in 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 NiMH and Li-ion batteries. Consumer performance demand is adjusted downward as HP/Weight ratio increases so that performance gains cannot continue indefinitely. This 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; HEVCALC; PHEV10CALC; PHEV40CALC; FCCALC; FEMRANGE; CALIBNHTSA;

Equations: 1-144

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 TRNLDV.XML 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: This subroutine calculates battery costs and related quantities for electric vehicles. It applies learning curves to battery prices and aggregates battery price based on NiMH, and Li-ion market share and adds to vehicle price. This subroutine also calculates vehicle weight as a function of battery weight, market share, and vehicle fuel economy as a function of vehicle weight.

Called by: FEMCALC

Calls: None

Equations: 1- 144

SUBROUTINE: HEVCALC

Description: This subroutine calculates battery costs and related quantities for hybrid electric vehicles. It applies learning curves to battery prices and aggregates battery price based on NiMH and Li-ion market share and adds to vehicle price. This 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- 144

SUBROUTINE: LIONCOSTCALC

Description: This subroutine calculates Lithium-ion Battery cost ($/kWh) for PHEV10s, PHEV40s, and EVs, for the three phases of the cost curve, the revolutionary, evolutionary, and mature phases. Lithium-ion capacity additions are calculated, and then the battery costs are calculated.

Called by: AFVADJ

Calls: None

Equation: 36

SUBROUTINE: PHEV10CALC

Description: This subroutine calculates battery costs and related quantities for plug-in hybrid electric vehicles with a 10-mile all-electric range. It applies learning curves to battery prices and aggregates battery price based on NiMH and Li-ion market share and adds to vehicle price. This 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- 144

SUBROUTINE: PHEV40CALC

Description: This subroutine calculates battery costs and related quantities for plug-in hybrid electric vehicles with a 40-mile all-electric range. It applies learning curves to battery prices and aggregates battery price based on NiMH and Li-ion market share and adds to vehicle price. This 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- 144

SUBROUTINE: FCCALC

Description: This subroutine 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. This subroutine 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- 144

SUBROUTINE: CALIBNHTSA

Description: This subroutine calibrates 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: This subroutine calculates vehicle range estimates.

Called by: FEMCALC

Calls: None

Equations: 1-144

SUBROUTINE: CGSHARE

Description: This subroutine calculates light vehicle market class shares, average horsepower, and weight for cars and light trucks. It sets domestic and import shares of total cars and light trucks using historic NHTSA sales data. It then calculates non-fleet non-commercial sales of cars and light trucks by market class and overall non-fleet, and non-commercial class shares for cars and light trucks. The domestic and import groups are combined to calculate market class shares and sales of conventional vehicles. This subroutine also estimates average horsepower and weight for new cars and light trucks.

Called by: TMPGNEW

Calls: None

Equations: 1-144

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: 1-144

SUBROUTINE: TLDV

Description: This subroutine initiates the vehicle choice routine.

Called by: TMPGNEW

Calls: TATTRIB; TALT2; TALT2X; TFLTSTKS; TLEGIS

Equations: 1-144

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. This 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-volume production price or rise above low-volume production price). It then combines domestic and 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: 1-144

SUBROUTINE: FLEXSHR

Description: This subroutine 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 ratios for minimum alternative fuel use which are used to fill the alternative fuel station availability array. This subroutine uses an alternative fuel choice logit model based on fuel price and fuel availability. It can also simulate an aggressive E-85 vehicle 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 PHEVs 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: 1-144

SUBROUTINE: TALT2

Description: This subroutine calculates regional fuel availability for highway fuels that include gasoline, diesel, ethanol, methanol, CNG/LNG, LPG, electricity, and hydrogen. It estimates the vehicle stocks used to calculate the number of refueling stations by weighting flex-fuel and bi-fuel at 25%. It calculates the total number of refueling stations needed based on an historic ratio of vehicle stock per refueling station. It regionalizes the predicted stations by regional vehicle sales and estimates fuel availability.

Called by: TLDV

Calls: None

Equations: 1-144

SUBROUTINE: TALT2X

Description: This subroutine calculates level 1 and level 2 light vehicle market penetration estimates in the AFV model. It 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: TALT314; TALT315;TALT316

Equations: 1-144

SUBROUTINE: TALT314

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for ethanol flex vehicles.

Called by: TALT2X

Calls: None

Equations: 1-144

SUBROUTINE: TALT315

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for CNG/LNG bi-fuel vehicles.

Called by: TALT2X

Calls: None

Equations: 1-144

SUBROUTINE: TALT316

Description: This subroutine calculates fuel cost, vehicle range, and fuel availability for LPG bi-fuel vehicles.

Called by: TALT2X

Calls: None

Equations: 1-144

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. This subroutine also adjusts vehicle sales and market shares to reflect legislative mandates on sales of Zero Emission Vehicles (ZEV), including Transitional Zero Emission Vehicles (TZEV) and Advanced Technology Partial Zero Emission Vehicles (ATPZEV). Participating states include California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont. 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: 1-163

SUBROUTINE: TLEGIS

Description: This subroutine adjusts vehicle sales and market shares to reflect legislative mandates on sales of Zero Emission Vehicles (ZEV), including Transitional Zero Emission Vehicles (TZEV) and Advanced Technology Partial Zero Emission Vehicles (ATPZEV). Participating states include California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont. 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: 1-163

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: 1-163

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.

Called by: TMPGNEW

Calls: None

Equations: 1-144

SUBROUTINE: TFLTVMTS

Description: This subroutine calculates VMT for fleets.

Called by: TRAN

Calls: None

Equations: 1-165

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. This subroutine 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: 1-163

SUBROUTINE: TMPGSTK

Description: This subroutine calculates light vehicle stock MPG by technology and also calculates new car and light truck sales for six 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: 1-163

SUBROUTINE: TCURB

Description: This subroutine calculates the stock average weight (by vintage) of cars and light trucks.

Called by: TRAN

Calls: None

Equations: 1-163

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. This subroutine then calculates overall fleet average MPG by fuel technology.

Called by: TRAN

Calls: None

Equations: 1-163

SUBROUTINE: TFLTCONS

Description: This subroutine calculates fuel consumption of fleet vehicles by regions.

Called by: TRAN

Calls: None

Equations: 1-144

SUBROUTINE: TRANFRT

Description: This subroutine calculates fuel consumption for freight trucks, classes 2b-8. It applies scrappage rates to truck populations, excluding new trucks. It then calculates stock transfers from fleet to non-fleet ownership and processes new truck sales from the Macroeconomic Activity Module 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; TRUCK_NEW; TRUCK_STOCK; TRUCK_VMT; TRUCK_FUEL

Equations: 196-253

SUBROUTINE: TFRTRPT

Description: This subroutine writes reports that support the freight model.

Called by: TRANFRT

Calls: None

Equations: None

SUBROUTINE: INIT

Description: This subroutine initializes variables in TRANFRT and assigns variables for each run. It copies inputs for prices and macroeconomic output from NEMS global data call for each year. It 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, and 12) government.

Called by: TRANFRT

Calls: CFREAD

Equations: 196-253

SUBROUTINE: CFREAD

Description: This subroutine reads input for the freight model from spreadsheet input file trnhdv.xlm, including variables such as non- fleet VMT per truck by fuel and vintage, new truck sales, and Class 4-6 shares of Class 4-8 trucks, etc.

Called by: INIT

Calls: None

Equations: 196-253

SUBROUTINE: CFREADSTOCK

Description: This subroutine reads input for the freight model from spreadsheet input file trnstock.xlm, including variables such as fleet stocks by fuel, vintage, gross vehicle weight, and vocational vs. non-vocational.

Called by: INIT

Calls: None

Equations: None

SUBROUTINE: WR_FSHFLT

Description: This subroutine calculates fuel shares of the entire truck stock, excluding new trucks, for comparison with the fuel shares assigned in subroutine TRUCK_NEW.

Called by: TRUCK_STOCK

Calls: None

Equations: 196-227

SUBROUTINE: TRUCK_VMT

Description: This subroutine 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. It calculates aggregate VMT growth based on growth in real economic output by sector.

Called by: TRANFRT

Calls: FAC

Equations: 196-227

SUBROUTINE: FAC

Description: This subroutine 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: 196-253

SUBROUTINE: TRUCK_FUEL

Description: This subroutine calculates 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 of gasoline equivalent and passes VMT to TRAN for benchmarking. This subroutine summarizes personal and fleet light-duty 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: TRANFRT

Calls: None

Equations: 1-256

SUBROUTINE: TRUCK_NEW

Description: This subroutine 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. This subroutine implements fuel-saving technologies that include various technologies that are adopted when commercially available and cost-effective. It 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. It 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. This subroutine implements the market penetration equation: s-shaped logistical equation to estimate market penetration over time. It outputs the market penetration fraction.

Called by: TRANFRT

Calls: None

Equations: 1-256

SUBROUTINE: TRUCK_STOCK

Description: This subroutine estimates new vehicle sales, stocks, and fuel economy. This subroutine determines 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. This subroutine returns SLOPE and Mid-Point on Logistic penetration curve. This subroutine determines the market share of CNG freight trucks purchased by fleet, size, and VMT groups. Purchase decisions are estimated by calculating the net present value of annual fuel savings as compared to diesel trucks, weighted by a payback share distribution. This subroutine calculates total personal light vehicle VMT. It 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: TRANFRT

Calls: WR_FSHFLT

Equations: 1-256

SUBROUTINE: TRAIL

Description: This subroutine calculates energy consumption by rail by region and fractional change in fuel efficiency.

Called by: TRAN

Calls: None

Equations: 228-234

SUBROUTINE: TSHIP

Description: This subroutine calculates energy use for shipping. It calculates the international shipping fuel use (including use within Emission Control Areas of North America) split by the fuel types: distillate fuel oil, LNG, and residual fuel oil. It calculates ton-miles traveled for domestic shipping and the fractional change in fuel efficiency.

Called by: TRAN

Calls: None

Equations: 235-240

SUBROUTINE: TRANAIR

Description: This subroutine calls the air freight subroutines TAIRT and TAIREFF.

Called by: TRAN

Calls: TAIRT; TAIREFF

Equations: 166-195

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 the variables representing aircraft sales, active aircraft, and stock for narrow-body, wide-body, and regional jets, it calculates the yield (ticket price), load factors, and 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: TRANAIR

Calls: None

Equations: 166-195

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 and 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: TRANAIR

Calls: None

Equations: 166-195

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-mile, bus energy demand by segment, and regionalizes commuter bus energy demand by regional population. It also calculates demand growth and regional recreational boating energy demand by population. It calculates regional lubricant demand by summing VMT shares for freight and light-duty vehicles.

Called by: TRAN

Calls: None

Equations: 241-256

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/LNG, 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: 1-163

SUBROUTINE: TINTEG

Description: This subroutine calculates total transportation energy consumption by fuel type for all modes.

Called by: TRAN

Calls: None

Equations: 1-256

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: 1-256

SUBROUTINE: TEMISS

Description: This subroutine calculates vehicle emissions by the three criteria pollutants: hydrocarbons, carbon monoxide, and nitrous oxides. This routine sums up total VMT across market classes, reads emission factors in grams per mile, and initializes emissions variables. It aggregates emissions by age (or vintage) for the model's report writer by converting the weight of emissions in grams to million metric tons.

Called by: TRAN

Calls: TRANFRT

Equations: 1-256

SUBROUTINE: TREPORT

Description: This subroutine generates the parameters used in the model's 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: 1-256

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 miles per gallon by taking the reciprocal.

Called by: TRANFRT; TRUCK_STOCK; TFRTRPT

Calls: None

Equations: 196-227

Figure 22. Flowchart of calls made by TRAN subroutine

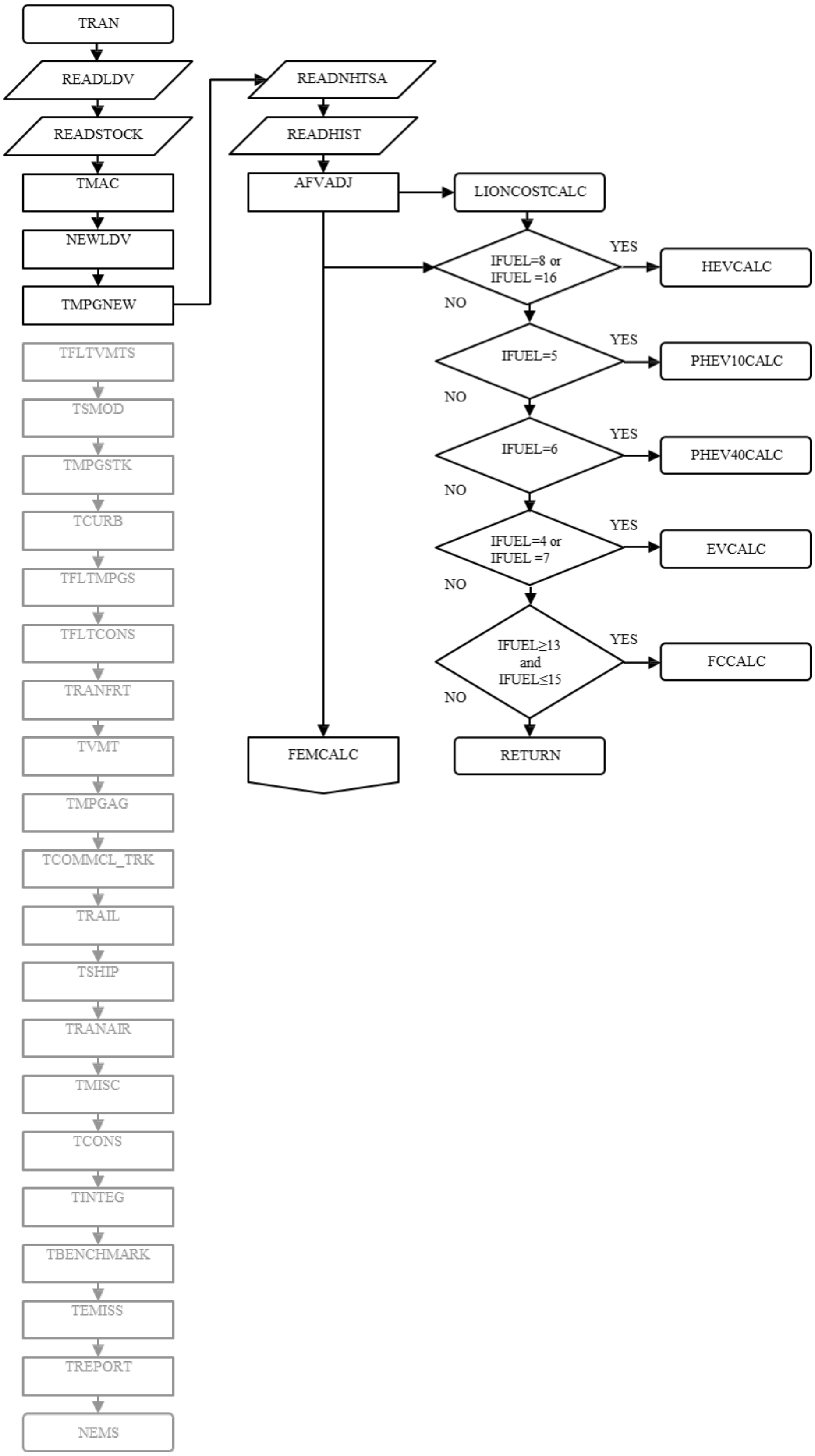


Figure 22. Flowchart of calls made by TRAN subroutine (cont.)

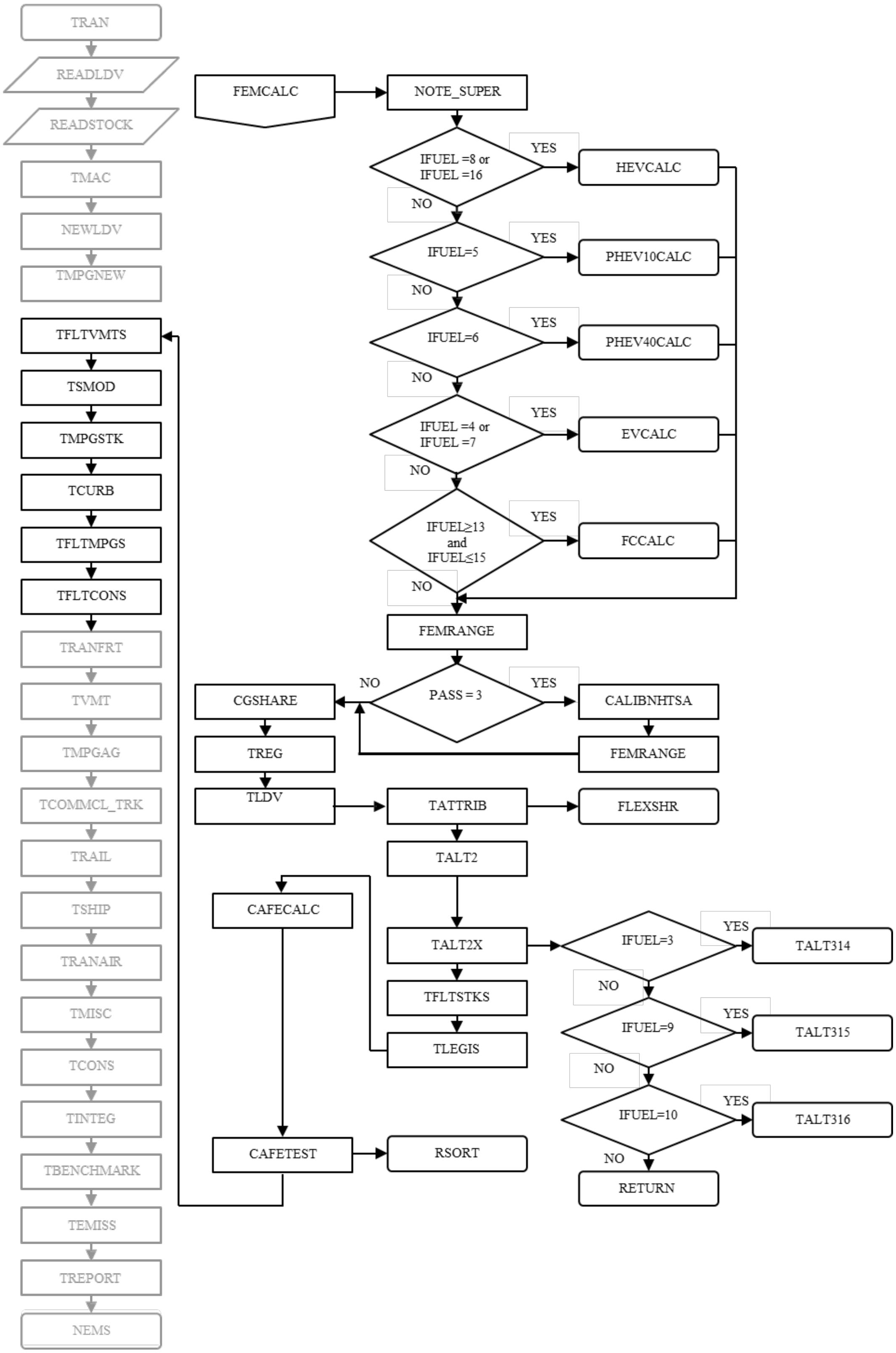
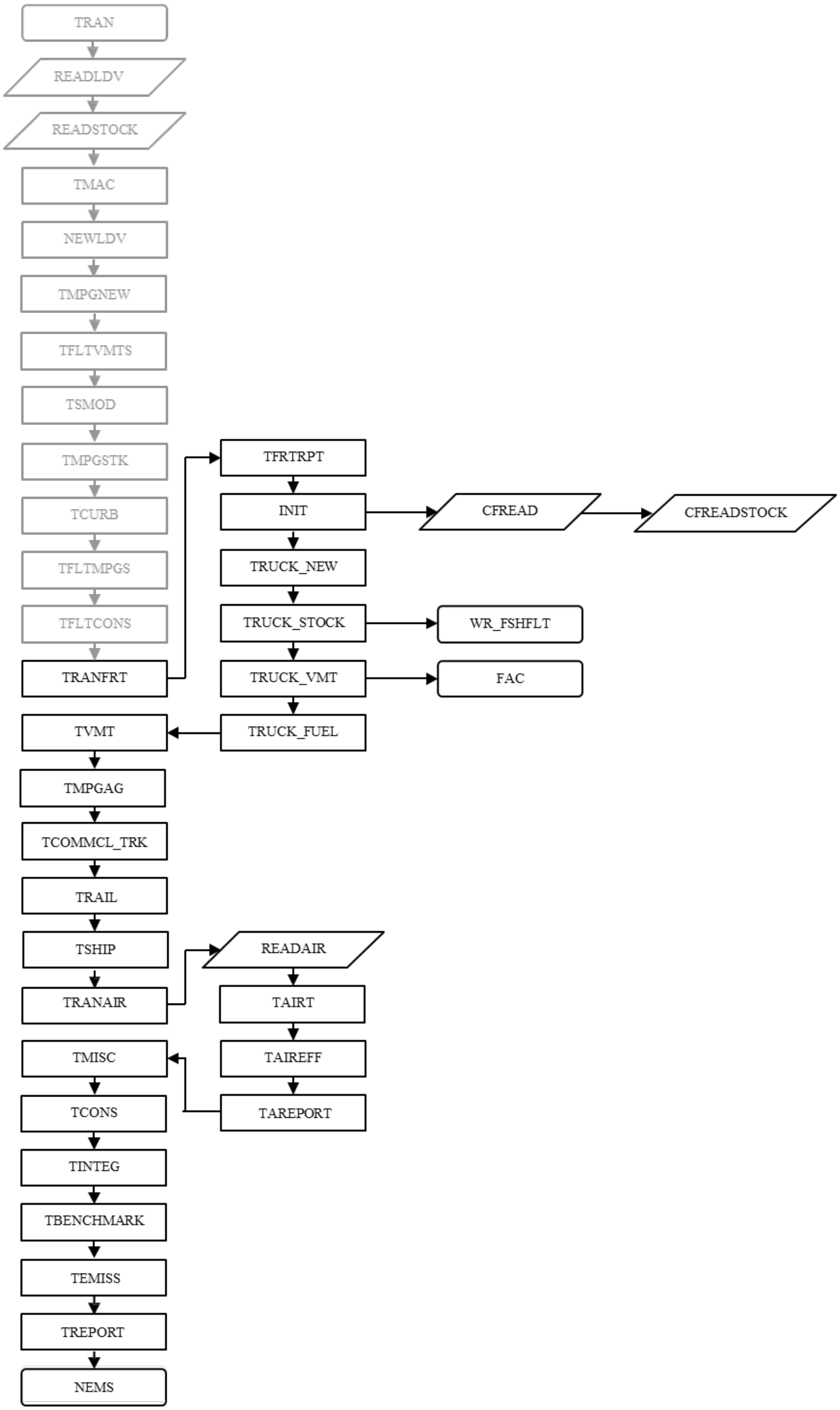


Figure 22. Flowchart of calls made by TRAN subroutine (cont.)



Appendix D. Input/Output Variables in Transportation Model

Variable Name	Variable Description
Transportation Specific Macro Variables	
INC00$16	Disposable income per capita for population 16+ (2000$)
INC00$NPT	Disposable income per capita (1000s of 2000$)
INC90$NP	Disposable income per capita (1990 $) - fuel economy component
MC_GFMLR	Federal government purchases - defense
MC_SUVTHAM	Total new truck sales for classes 4-8, from the Macroeconomic Activity Module
NEWCARS	New car sales
NEWCLS12A	New light truck sales, class 1-2a
TMC_PGDP	GDP deflator
Global definitions	
ACCL	Vehicle acceleration - 0 to 60 mph
ACTUAL_MKT	Technology market share = MKT_PEN
AFVADJFE	ATV fuel economy differential
AFVADJHP	ATV horsepower differential
AFVADJPR	ATV price differential (1/2 low volume car/truck,3/4 High volume car/truck)
AFVADJPRH	ATV high volume price differential
AFVADJRN	ATV range differential
AFVADJWT	ATV weight differential
AHPCAR	Average car horsepower
APSHR44	Percent of total light-duty vehicles sales by technology type
APSHR55	Absolute regional market shares of adjusted vehicle sales
ATPZEV	Total (%) mandated gas hybrid and methanol/gas fuel cell vehicles
AVSALES	Total adjusted vehicle sales
AVSALEST	Total regional adjusted vehicle sales by market class
AWTCAR	Average car weight
AWTTRUCK	Average light truck weight
BASE	FEM attribute index value for the base year
BATTERY	Weighted average battery cost
BETAFA2	ATV NMLM level 2, fuel availability 1
BRCOST25	Battery replacement cost - currently set to zero
CAFE_STAND	CAFE standards
CDCARSHR	Share of total cars by region
CDFREG	Car fuel efficiency degredation factor
CDLTSHR	Share of total light trucks by region
CDFRFG	Car fuel efficiency degradation factor
CFCoefA, CFCoefA2,CFCoefB, CFCoefB2, CFCoefC, CFCoefC2, CFCoefD, CFCoefD2	Car coefs
CLASS_SHARE	Vehicle class market shares (within vehicle groups)
CMPGSTK	Car fuel economy
CMPGT	Car stock MPG

Variable Name	Variable Description
CMPGT_IT	Average fuel efficiency of cars by powertrain
COSTEF_FUEL	Cost effectiveness of mpg improvement of a subsystem technology
COSTEF_PERF	Cost effectiveness of performance improvement of a subsystem technology
CURRENT	FEM attribute index value for the current year
DEL_COSTABS	Absolute incremental change in cost ($)
DEL_COSTWGT	Relative incremental change in cost ($/lb)
DEL_FE	Incremental fractional change in fuel economy
DEL_HP	Incremental fractional change in horsepower
DEL_WGTABS	Absolute incremental change in weight (lb)
DEL_WGTWGT	Relative incremental change in weight (lb/base vehicle lb)
DELTA_MKT	Incremental increase in subsystem technology market share
DISCOUNT	Discount rate
DOMCAR = 1	Vehicle group index value for a domestic car
Elec_Stor$	Cost of on-board electricity systems and storage
EV_Batt_Wt	EV battery weight (lbs) per kWhr
EV_DOD	EV battery depth of discharge (percentage)
EV_kWhr	EV battery size (kWhr)
FAVAIL	Fuel availability by technology, region, year
FAVL	Fuel availability index relative to gasoline
FLCOST	Fuel cost per mile
FLT	Fleet indices
FLTCRAT	Fraction of total car sales attributed to fleets
FLTCSHR	Fraction of fleet cars purchased by a given fleet type
FLTECH	Vehicle purchases by fleet type and technology
FLTECHSAL	Fleet sales by size, technology, and fleet type
FLTFCLDVBTUR	Regional fuel consumption by fleet vehicles, by technology
FLTLDVC	Fuel consumption by technology, vehicle and fleet type
FLTLDVSHR	Percent of fleet vehicles by fleet type and size
FLTMPG	New fleet vehicle fuel efficiency, by fleet type and vehicle technology type
FLTMPGTOT	Overall fuel efficiency of new fleet cars and light trucks
FLTSAL	Sales to fleets by vehicle and fleet type
FLTSSHR	Percent of fleet vehicles by fleet type, size class, and vehicle type
FLTSTKVN	Fleet stock, by fleet type, technology, and vintage
FLTTOTMPG	Total fleet mpg
FLTTRAT	Fraction of total truck sales attributed to fleets
FLTTSHR	Fraction of fleet trucks purchased by a given fleet type
FLTVMTECH	Fleet VMT by technology, vehicle type, and fleet type
FLTVMTYR	Annual miles of travel per fleet vehicle
FPMpg	
FPMpgGrp	
FPRICE	Fuel price by region
FPrint	
FUELCELL	Incremental fuel cell cost
FuelCell$kW	Fuel cell cost ($/kW)
FUELSAVE	Expected fuel savings of advanced subsystem technology

Variable Name	Variable Description
GAS	Vehicle fueling configuration index value for gasoline
HEV_Batt_Wt	HEV battery weight (lbs) per kWhr
HEV_kWhr	HEV battery size (kWhr)
HEV_Sys_$	HEV non-battery system cost
HFUEL	Home refueling
HP	Vehicle class base horsepower
I,J,K	Miscellaneous indices
IAGE	Age indices
IATV	ATV type indices
ICL	Index for six size classes
IFUEL	Fuel engine technology
ILDV	Index for light-duty vehicle powertrains
IREGN,IRAILREGN	Region indices
ITECH	Technology type
IVTYP	Vehicle type
LEARN_COST_MULTIPLIER	Technology learning curve parameters
LDVSTK	Vehicle stock, by engine technology fuel type, 1 ... 16, using above mapping
Li_ion_Cost	Lithium-ion battery cost ($/kWhr)
LION_MKTSH	Lithium-ion battery market share for Electric Vehicles
LTDFRFG	Degradation factor for light trucks
LTSHRR	Light truck market shares by class
LTSTK	Light-duty vehicle light trucl stock by fuel type and vintage
LTSTKREGN	Light-duty vehicle light truck stock by fuel type, vintage and region
LUBFD	Transportation lubricant demand
LUGG	Vehicle luggage space
LVMT	Average miles driven by each vintage of light truck
MAINT	Vehicle maintenance cost
MAINTCAR	Car maintenance cost by technology, market class
MAINTTRK	Truck maintenance cost by technology, market class
MANDMKSH	Mandatory engineering note parameters
MAX_SHARE	Maximum technology market share = MMAX
MAXAGE	Vintage 25 for light-duty vehicles
MFD	Total military use by fuel type
MKT_FUEL	Subsystem technology market share based on efficiency cost effectiveness
MKT_MAX	Technology market share cap
MKT_PEN	Technology market share
MKT_PENF	Technology penetration aggregated over class
MKT_PERF	Subsystem technology market share based on performance cost effectiveness
MMAVAIL	ATV make/model availability
MMAX	Maximum technology market share = MKT_MAX
MPG	New car fuel efficiency, by size class
MPGC	New car fuel efficiency, by engine technology fuel type
MPGFLT	Average fuel efficiency for all light-duty vehicles
MPGFLTSTK	MPG Fleet

Variable Name	Variable Description
MPGT	New light truck fuel efficiency, by engine technology fuel type
N	Trans variable for curiyr
NCS	New car sales, by market class and region
NCSTECH	Regional car sales by fuel type
NCSTSC	Car sales by class
NHTSALYR	Last year of NHTSA data
NiMH_Cost	Nickel metal hydride battery cost ($/kWhr)
NLTECH	Regional light truck sales by fuel type
NLTS	New light truck sales, by market class and region
NLTSTSC	Light truck sales by class
NUM_SUP	Engineering note counters
NUMTECH	Actual number of input technologies
NVSALES	Total new LDV sales by size class
NVS7SC	Non-fleet, non-commercial sales
OLDFSTK	Old fleet stocks of given types and vintages, transferred to the private sector
OLDFSTKT	Total transfered vehicles from fleets to households
PASSHRR	Car market shares by class
PASSTK	Light-duty vehicle car stock by fuel type and vintage
PASSTKREGN	Light-duty vehicle car stock by fuel type, vintage and region
PAYBACK	Payback period
PERFCAP	Vehicle class performance cap
PERFFACT	Vehicle class base performance factor
PERGRP	Manufacture share of sales by size class
PHASESHR	Fraction of total mandatory share by year
PHEV_DOD	PHEV battery depth of discharge
PHEV10_Batt_Wt	PHEV10 battery weight (lbs) per kWhr
PHEV40_Batt_Wt	PHEV40 battery weight (lbs) per kWhr
PHEV40Bat$kWh	PHEV40 battery cost per kWhr
PRICE	Vehicle class base price (low volume)
PRICE_EX	Expected fuel price used in cost effectiveness calculation
PRICEHI	Vehicle class base price (high volume)
PSLOPE	Expected rate of change in future fuel price
PSPR	Average vehicle price
RANGE	Vehicle driving range
RATIO_LN	Used to determine size class shares
REG_COST	CAFE non-compliance fine
REGCOST	CAFE Fine
REQ_MKT	Required market share - see engineering notes
REQUIRES	Required engineering note parameters
RSHR	
SALESHR	Car and light truck sales shares by group
SCMPG	On-road stock mpg household cars
SIGN	Positive or negative indicator
SSURV25	Survival rate of cars and light trucks by vintage
STA_RAT	Refuel stations per vehicle stock
STKCAR	Total stock of non-fleet cars

Variable Name	Variable Description
STKTR	Total stock of non-fleet light trucks
STMPG	On-road stock mpg household light trucks
SUPERSEDES	Supersedes engineering note parameters
SURVFLTT	Survival rate of given vintage
SYNERGY	Synergy engineering note parameters
SYNR_DEL	Synergy engineering note parameters
TANKSIZE	Vehicle class base fuel tank size
TECHCOST	First cost of subsystem technology - cost adjustments (economies of scale, etc) made to this value
TECHNCS	Total new car sales, by engine technology fuel type
TECHNLT	Total new light truck sales, by engine technology fuel type
TFLTECHSTK	Total stock, by technology and fleet type
TMPASMIL	Passenger miles per capita by bus type
TMPGT	Light truck stock MPG
TMPGT_IT	Average fuel efficiency of light trucks by powertrain
TOT_MKT	Total market share of subsystem technology
TOTMICT	Total miles driven by cars
TOTMITT	Total miles driven by light trucks
TTLZEV	Total (%) mandated ZEV sales
TTMPGSTK	Truck fuel economy
USEDCAP	Fraction of vehicle class performance cap used
VAL_PERF	Value of performance improvement to consumer
VALUEPERF	Vehicle class base performance value
VMT	Annual VMT by vintage
VRNG	Vehicle range
VSPLDV	Light-duty vehicle shares of each of the sixteen vehicle technologies
VT	Vehicle type, car and light truck
WEIGHT	Vehicle class base curb weight
WGT	Light-duty vehicle weight
X21	ATV NMLM level 2, vehicle price
X210	ATV calibration coefficients
X211	ATV calibration coefficients'
X212	ATV calibration coefficients
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
X31	ATV NMLM level 3, multi-fuel generation cost
ZEV	Total (%) mandated electric vehicles
ZFCV	Total (%) mandated hydrogen fuel cell vehicles
LDV Submodule	

Variable Name	Variable Description
LDV Stock Accounting Component	
PVMT	Car VMT per vintage
LDV VMT Stock Component	
COSTMI	Fuel cost of driving one mile (2004 cents per gallon)
EMP_RATE	Employment rate
LICDRIVER	Licensed drivers by region, gender and age cohorts
VMTEE	Total household LDV VMT
VMTEER	Sum of regional VMT
VMTLD	VMT per licensed driver
VMTLDR	Regional vehicle-miles traveled per licensed driver
New LDV	
CARSHRT	Non-normalized projected car share
Air Demand Submodule	
Aircraft Efficiency	
ASMAC	ASM per aircraft by type
ASMPGT	Aircraft efficiency after technology addition (1=new, 2=Stock)
ASMPGD	Domestic aircraft efficiency. By type and vintage
ASMPGI	International aircraft efficiency. By type and vintage
Aircraft Technology Penetration	
BASECONST	Base constant
EFFIMP	Fractional improvement associated w/ a given technology
TIMECONST	Time constant
TRIGPRICE	Jet fuel price in $/gal necessary for cost effectiveness
TRIGYEAR	Year of technology introduction by aircraft type
Available Seat Miles (ASM)	
ASM_DOM	Total domestic available seat miles
ASM_INT	Total international available seat miles
SMDEMD	Total available seat miles
Aircraft Sales	
SHR_NEW_STK	Share of new aircraft sales by type
Aircraft Stocks	
STK_SUP_TOT	Aircraft stock (passenger +cargo) total by aircraft type
STKPASS_ACTIVE_TOT	Passenger aircraft total active stock by aircraft type
SURVAC	Aircraft survival curves by aircraft type
Yield	
YIELD	Revenue per passenger mile
Freight Transportation Submodule	

Variable Name	Variable Description
Rail Freight Model	
DISCRT	Discount rate applied by freight railroads
FREFF	Freight rail efficiency (1000 Btu/ton-mile)
PAYBK	Payback period demanded by freight railroads
RAIL_FUEL_SHR	Historic rail fuel shares
RTM_OUTPUT	Freight rail ton-miles per dollar industrial output
RTMTT	Freight rail travel (billion ton-miles)
TQFRAILT	Total energy demand
Waterborne Freight Component	
Domestic Waterborne	
ANN_DECLINE	Annual rate of ton-mile per dollar output decline
DOMSHIP_FUEL_SHR	Domestic shipping fuel share
DSEFF	Domestic marine vessel efficiency
DSTM_OUTPUT	Domestic marine ton-miles per dollar industrial output
STMTT	Domestic marine Travel (billion ton-miles)
International Waterborne	
GROSST	Gross tons shipped
INTSHIP_FUEL_SHR	International shipping fuel share
ISFD	Energy demand by fuel type (1-diesel, 2-residual,3-CNG,4-LNG)
ISFDT	Total international shipping energy demand in year
TQISHIPR	Regional energy demand by fuel type
Miscellaneous Energy Demand Submodule	
Transit Rail Submodule	
TRED	Transit rail energy demand by CD
Commuter Rail Submodule	
CREDE	Commuter rail electricity demand by CD
Intercity Rail Submodule	
IREDER	Intercity rail electricity demand by CD
Bus Mass Transit	
BUSSYSEF	Bus system efficiency by mode, in Btu per passenger
QMODFSHR	Bus fuel shares
TMEFF	Bus efficiency (Btu/passenger mile)
TMOD	Bus passenger miles
Recreational Boating Demand Component	
RBEDPC	Energy demand per capita by fuel type
RECFD	Energy demand by fuel type (gasoline, diesel)

Variable Name	Variable Description
Miscellaneous Transportation Energy Variables	
QLUBR	Lubricant energy demand by region
QMILTR	Military energy demand by fuel by region
QMTBR	Bus energy demand by fuel by region
QMTRR	Passenger rail energy demand by fuel by region
QRECR	Recreational boat energy demand by region
Car light truck sales shares	
CARSHARE	Projected car share of LDV sales
DUMM	Car share dummy
Variables in TRANFRT Submodule	
AGE	Number of vintages for truck stocks 1-34
CAFE19	Number of truck classes with CAFE breakout for classes 7-8 tractors
CUR	Current year subscript (= 2)
CURCALYR	Current model year
FLT	Fleet vehicles: 1 – non-fleet, 2 - fleet
FUEL	Number of powertrain types: 1 – diesel, 2 – gasoline, 3 – LPG, 4 – CNG/LNG, 5 – flexfuel, 6 – electric, 7 – PHEV diesel, 8 – PHEV gasoline, 9 – hydrogren fuel cell
LAG	Lag year subscript (= 1)
SC	Number of Truck Market classes:1 - Medium Light, Class 3, 2 - Medium Heavy, Classes 4-6, 3 - Heavy, Classes 7-8, 4 – commercial light truck, class 2b
SEC	Number of Industrial sectors
TECH	Technologies available in Phase 1 of the heavy-duty CAFE and greenhouse gas emission standards
TECHP2	Tehcnologies available in Phase 2 of the heavy-duty CAFE and greenhouse gase emission standards
VOC	Vocational truck: 1 – non-vocational, 2 – vocational
Subscripts	
IAGE	Index for vintage
ICAFE19	Index for size classes for fuel consumption standard
IFLT	Index for fleet
IFUEL	Index for fuel type
IGVW	Index for full size classes: 1 – blank, 2 – class 2b, 3 – class 3, 4 – class 4, 5 – class 5, 6 – class 6, 7 – class 7, 8 – class 8
IP	Index for payback periods
IREGN	Index for census divisions
ISC	Index for size class
ISEC	Index for industrial sector
ITECH	Index for technology
ITR	Index for NEMS iteration
IVOC	Index for vocation
IYR	Index for year
Mapping	

Variable Name	Variable Description
ISC19	Map 19 CAFE classes back to 4 size classes (SC)
Variables	
ADVSHR	Superseding effect, equal to the market share of the superseding technology
ANN_$_SAVINGS_CNG_regn	Annual fuel savings for CNG/LNG vehicles compared to diesel or gasoline vehicles
ANNVMT	Average annual VMT per vehicle by 4 reporting classes
ANNVMT_19	Average VMT by vintage by 19 size classes
AVG_FUEL_$	Average price of fuel over 3 years
AVG_FUEL_$_REGN	Average price of fuel over 3 years by region
BASEMPG_p1, BASEMPG_p2	Fuel economy of new freight trucks with no fuel-saving technologies for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
BFSHXG	Base year(2010) Market share of each fuel
BUY_CNG_regn	Share of CNG vehicles brought by fleet, size sclass, and region
CSTDVXG	Market penetration curve parameter for diesel
CSTDXG	Market penetration curve parameter for diesel
CYAFVXG	Logistic market penetration curve parameter
DCOST	Fuel cost per mile of diesel relative to alternative fueled vehicles
DISCRTXG	Discount rate
EFSHXG	Final market share of each fuel
FCOST_regn	Fuel cost of driving a truck by fuel type in $ per mile
FLEETSHR	Percent of HDV in fleet use by size class
FUEL_SHR_regn	Fuel shares for New trucks by size class, fleet/nonfleet by region
FUELBTUR	Total truck fuel consumption in trillion Btu by region
FUELDMDR	Frieght truck fuel consumption by region
HDV_MPG	Fuel economy size class, vintage, and fuel in mpg miles/cubic cng
HRATE	Heat rate by fuel type
MIDYR	Logistic market penetration curve parameter representing “halfway point” to maximum market penetration
MPGEFF_p1, MPGEFF_p2	Total effect of all fuel-saving technology on new truck fuel efficiency for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
NEW_MPG_19	New truck fuel economy by 19 size classes
NEWCLS46	Share of truck sales in class 4-8 that are class 4-6, by year
NEWTRUCKS_regn	Sales of new trucks by market class, region, and fleet/non-fleet + total
NPV_ADS_regn	Net present value of the fuel savings from using CNG/LNG
P	Market penetration by year
PAYBACK	Payback period for each technology by CAFE size class and fuel
PRAFDFXG	Parameter: variation AFV Market share due to different fuel prices
PREFF_p1, PREFF_P2	Market Penetration Price sensitivity multiplier for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
SCRAP_RATE	Truck scrappage rate

Variable Name	Variable Description
SLOPE	Logistic market penetration curve parameter
TECHADJSHR_p1, TECHADJSHR_p2	Difference between the current tech share and the base tech share for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHBASE_p1, TECHBASE_p2	Base year market penetration paramenter for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHEFF_p1, TECHEFF_p2	Percentage improvement in fuel economy by technology for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHMAX, TECHMAX_p2	Maximum market share for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHMID, TECHMID_p2	Number of years to 50% penetration for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHPENYR_p1, TECHPENYR_p2	Year that a technology becomes available for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHSHAPE, TECHSHAPE_p2	Market penetration shape constant for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHSHARE_p1, TECHSHARE_p2	TECHSHR_pX if the technology penetration is less than the base year technology penetration or TECHBASE_pX if the technology is greater than or equal to the base share penetration for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHSHR_p1, TECHSHR_p2	Market share of fuel-saving technology, by market size class and fuel type in Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TECHVAR	Fuel price sensitivity parameter
TEMP_BTU_p1, TEMP_BTU_p2	Average annual truck fuel usage for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
TEMPCLS12A	The total of Class 1-2 trucks that are considered light-duty vehicles
TFFXGRT	Exogenous % of trucks/vintage transferred from fleet to non-fleet
TRF	Trucks trans fleet to non-fleet w/ no restrictions
TRGSHXG	Logistics parameter: 1/2 way to maximum Market penetration
TRIGGER_PRICE_p1, TRIGGER_PRICE_P2	Trigger price when technology becomes economical
TRK_19_regn	Existing stock of trucks by 19 size classes and regions
TTONMI	Freight truck ton-miles by industrial sector and census division
TVMT	Freight truck vehicle miles traveled, by industrial sector and census division
VEH_SHR	Percent share of vehicle fleet and size class
VMT_VEH	VMT per vehicle by fleet and size class for Phase 1 and Phase 2 of the HDC CAFE and GHG standards, respectively
VMTADJR	Aggregate VMT adjustment factor
VMTFLTR	HDV VMT

Appendix E. Bibliography

The Transportation Sector Demand Module is documented along with a series of other NEMS model documentation reports, available on the Internet at www.eia.doe.gov/reports/. Most of the references in the Bibliography refer to the model documentation reports and their publication numbers or other EIA reports providing data inputs to the model. The references listed below are available (or will soon be available) and reflect changes incorporated for *AEO2018*.

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