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

July 2014



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Update Information

This nineteenth edition of the Transportation Demand Module (TDM) of the National Energy Modeling System: Model Documentation 2014 reflects changes made to various sections of the TDM over the past year for the *Annual Energy Outlook 2014*. These changes include:

Light-Duty Vehicle (LDV) Submodule:

The LDV submodule was modified to include population projections by gender and age cohort in order to model vehicle-miles traveled by these demographic characteristics. An updated flex-fuel vehicle adoption curve based on regional data was added to the model.

Freight Transportation Submodule:

Regionalizing freight movement by mode and commodity was added to the model. Model structures representing the nine Census Divisions were added for the freight mode: truck, rail, and marine. Historical total freight ton-mile data and regional freight ton-mile data for truck, rail, and marine, freight rail efficiency, and domestic waterborne freight efficiency were updated. Liquefied natural gas, as a fuel choice for freight rail and domestic marine, was added to the model.

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Introduction

The TDM 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 TDM, 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 TDM 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 TDM 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 2040 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 TDM 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 comprises 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 TDM 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 Demand Module (TDM) as archived for the *Annual Energy Outlook 2014* (AEO2014).

Model contact

Patricia Hutchins
Energy Information Administration
EI-32/Forrestal Building
United States Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
Telephone: (202) 586-1029
E-mail: Patricia.Hutchins@eia.gov

Model Overview

The TDM 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 TDM 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 TDM 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 TDM 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 vehicles¹; 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 TDM 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.

¹ 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.

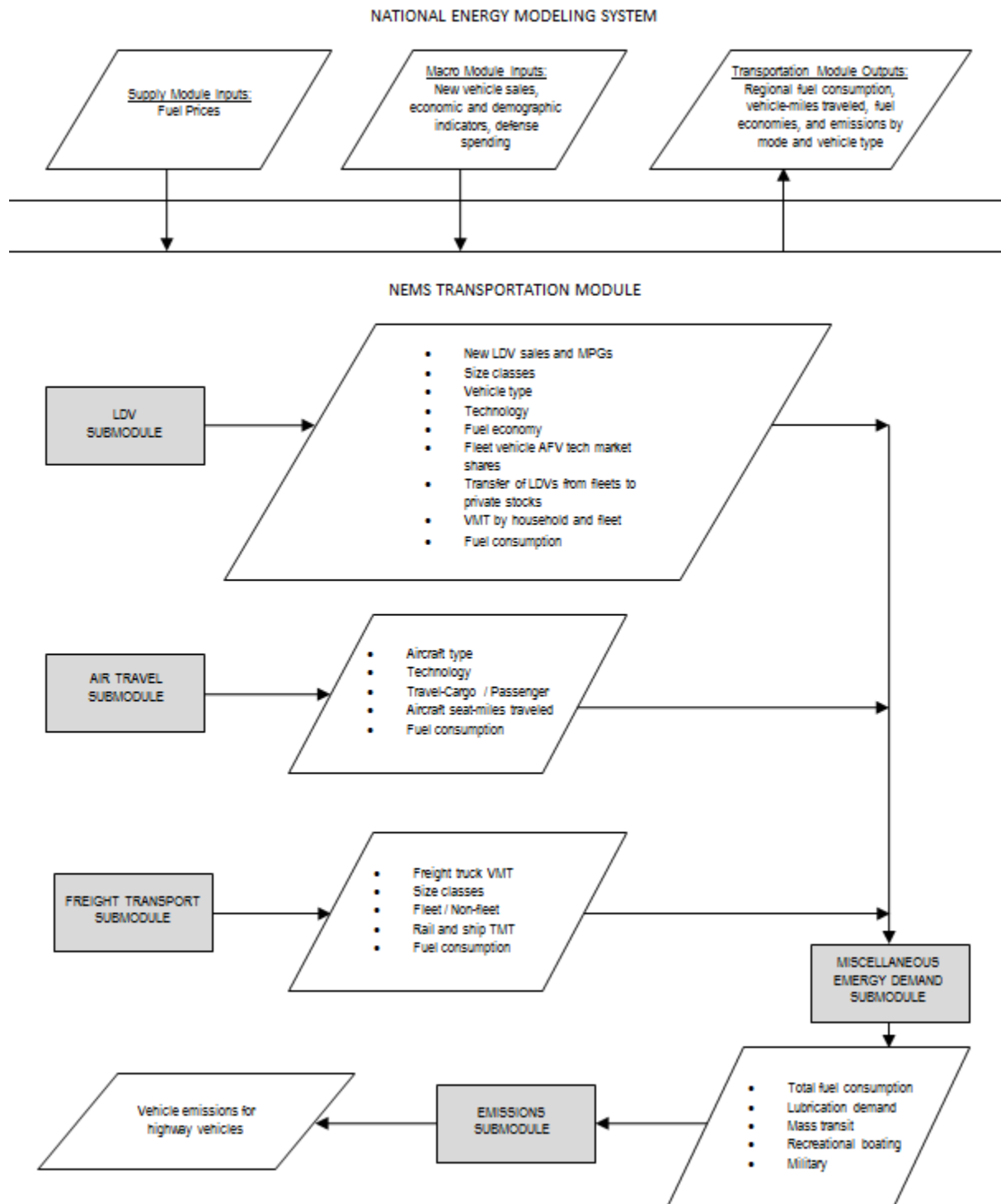
Freight Transportation Submodule

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 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 TDM 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 TDM 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 TDM 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 Demand Module Structure

As described above, the NEMS TDM 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 TDM. 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 TDM. These data sets remain unchanged throughout the projection and constitute a set of assumptions about current and future conditions.

The TDM 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:

- Manufacturers 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 class² by truck type (pickup, sport utility vehicle, and van). This leads to a total of 12 size classes, which are individually projected to 2040 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

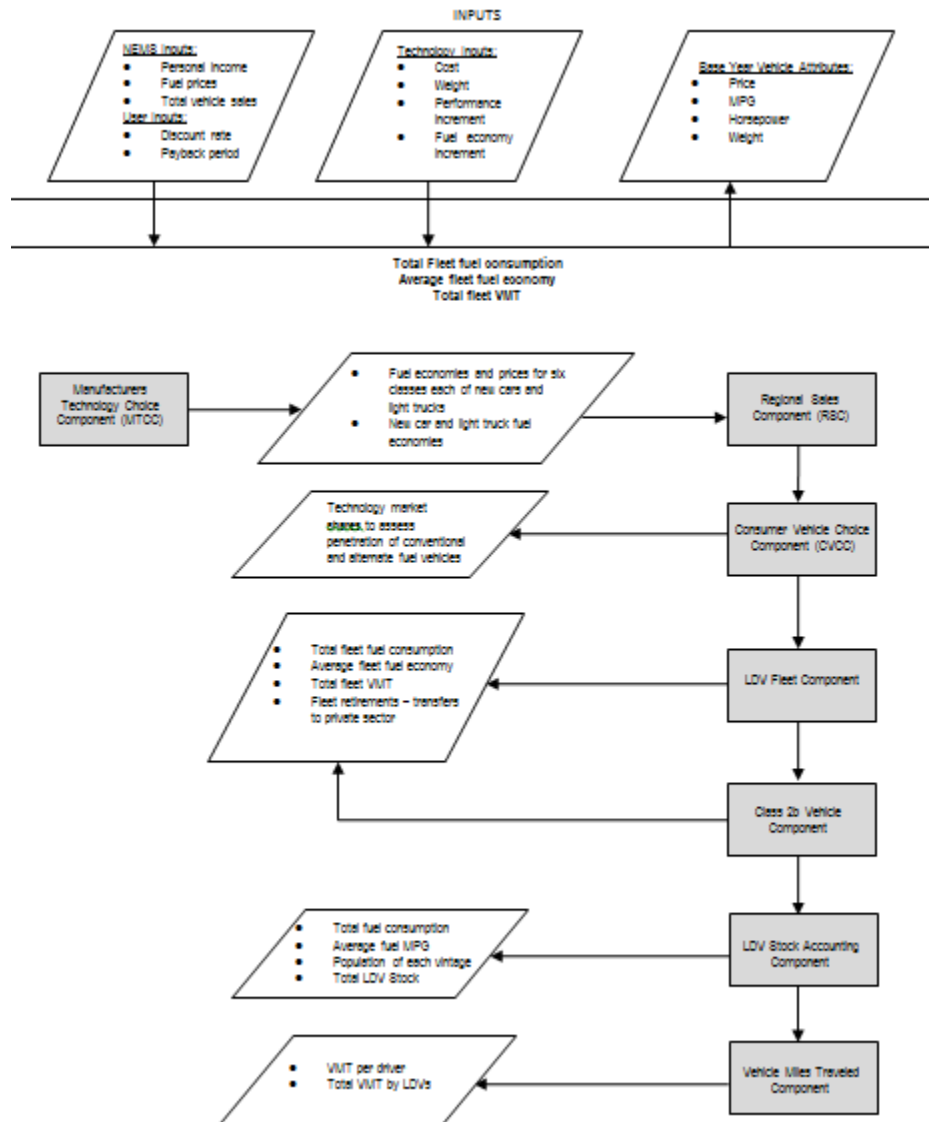
Technological improvements to each of these market classes are then projected based on the availability of new technologies to improve fuel economy as well as their cost-effectiveness under two user-specified alternative scenarios. The central assumptions involved in this technological projection are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

² 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.³ 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 all known safety and emission standards during the projection period. Emissions and safety standards increase vehicle weight and, in some cases, decrease engine efficiency. The California Low-Emission Vehicle (LEV) Program, currently enforced in Arizona, California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington, is included.

Manufacturers Technology Choice Component (MTCC)

The MTCC⁴ component in the LDV Submodule produces estimates of new light-duty vehicle fuel economy. Fuel economy is a significant aspect of the TDM 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 2010 data. Baseline vehicle attributes, describing the fuel economy, weight, horsepower, and price for each vehicle class for 2010 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

³ Goldberg, U.S. Department of Commerce, Bureau of Economic Analysis, 1998.

⁴ U.S. Department of Energy, Energy Information Administration, "Documentation of Technologies Included in the NEMS Fuel Economy Model for Passenger Cars and Light Trucks," 2002.

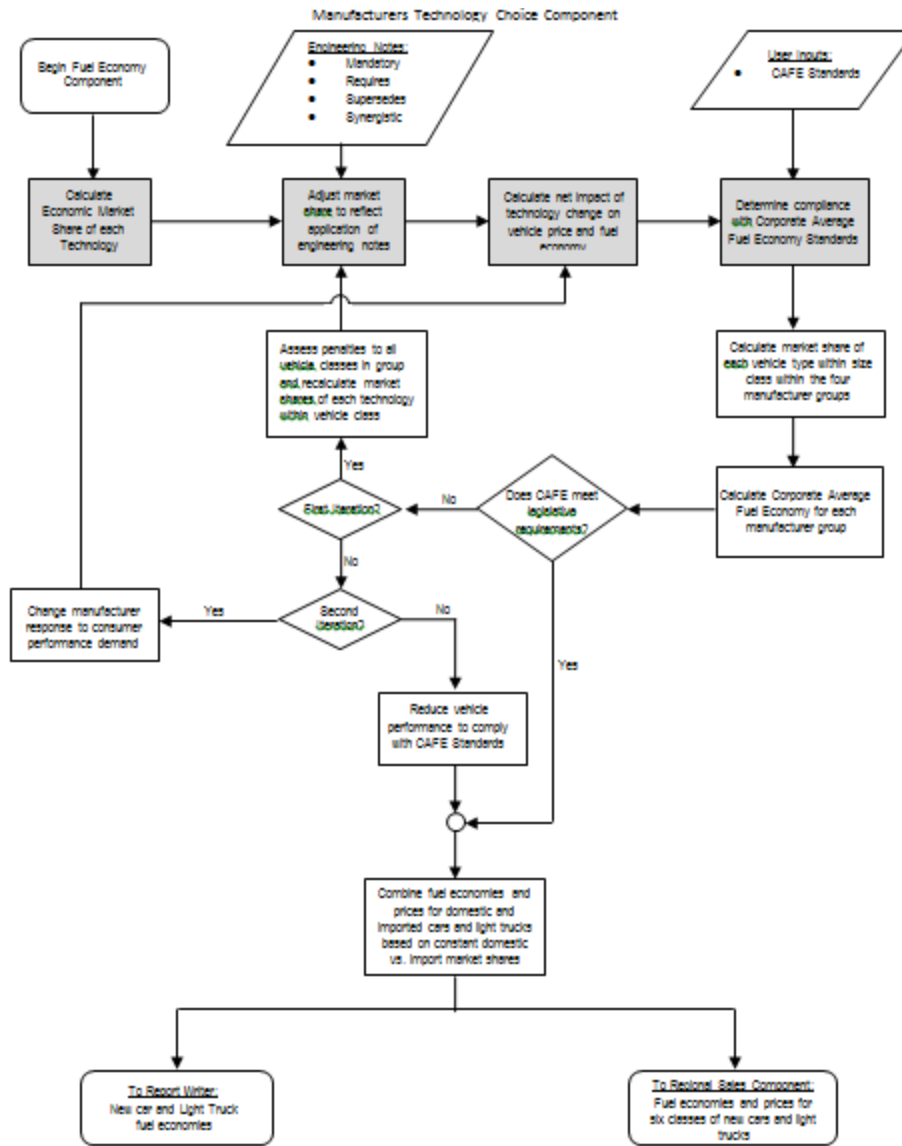
"Engineering Notes." There are four types of engineering notes: Mandatory, Supersedes, Requires, and Synergistic. These engineering notes are described in a subsequent section.

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- and 200-mile range vehicles (EV100, EV200), diesel/electric hybrid, CNG/LNG and LPG (liquefied petroleum gas) bi-fuel, dedicated CNG/LNG and LPG, methanol fuel cell, hydrogen fuel cell, gasoline 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 TDM 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:

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

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:

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

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:

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

where

AFVADJFE = Input fuel economy

b) Weight Calculation: adjustment relative to gasoline vehicles.

$$WEIGHT_{Year, FuelType} = WEIGHT_{Year, Gasoline} * (1 + AFVADJWT_{FuelType, Year}) \quad (4)$$

where

AFVADJWT = Input weight adjustment relative to gasoline vehicles.

c) Horsepower Calculation:

$$HP_{Year, FuelType} = HP_{Year, Gasoline} * (1 + AFVADJHP_{FuelType, Year}) \quad (5)$$

where

AFVADJHP = 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.⁵ If a vehicle group fails to meet CAFE after the second pass, no further adjustments to technology market shares are made. Rather, in the third pass, it is assumed that the manufacturers focus solely on CAFE compliance at the expense of increased performance.

⁵ See the variable REGCOST in Equation 12.

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 through 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:

$$\begin{aligned}
 FIVEYR_FUELCOST_1 &= \frac{1}{5} * \sum_{i=Year-8}^{Year-4} FUELCOST_i \\
 FIVEYR_FUELCOST_2 &= \frac{1}{5} * \sum_{i=Year-7}^{Year-3} FUELCOST_i \\
 PSLOPE &= MAX(0, FIVEYR_FUELCOST_1 - FIVEYR_FUELCOST_2)
 \end{aligned}
 \tag{6}$$

where

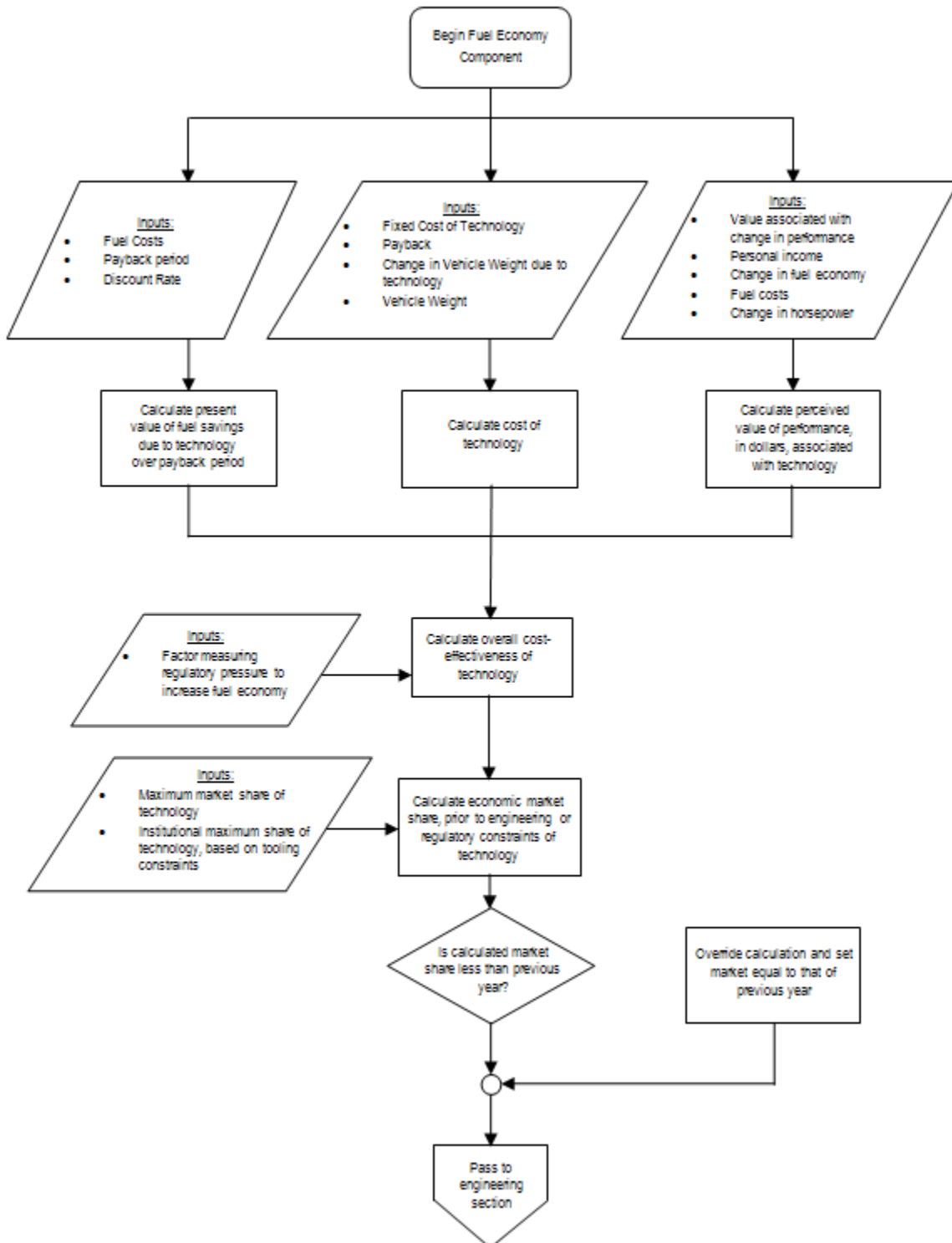
FUELCOST_{*i*} = The price of fuel year *i*.

i = Index representing the year considered.

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

$$PRICE_EX_{Year=i} = PSLOPE * (i + 2) + FIVEYR_FUELCOST_1
 \tag{7}$$

Figure 4. Economic market share calculation



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

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{Year-1}} - \left(\frac{1}{1 + DEL_FE_{itc} * FE_{Year-1}} \right) \right) * PRICE_EX_i * (1 + DISCOUNT)^{-i} \quad (8)$$

where

VMT = Annual vehicle-miles traveled.

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

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

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

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

PAYBACK = User-specified payback period.

DISCOUNT = User-specified discount rate.

a) Technology cost

Technology 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:

$$TECHCOST_{itc,Year,FuelType} = DEL_COSTABS_{itc} + DEL_COSTWGT_{itc} * \left(\begin{array}{l} ABS(DEL_WGTABS_{itc}) \\ + ABS(DEL_WGTWGT_{itc}) * WEIGHT_{Year-1,FuelType} \end{array} \right) \quad (9)$$

where

TECHCOST = Cost per vehicle of technology *itc*.

DEL_COSTABS = Absolute cost of technology *itc*.

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

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

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

WEIGHT = Original vehicle weight for different fuel type vehicles.

b) Learning cost adjustment

The technology cost is adjusted to include the multiplicative total of 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.

$$TECHCOST_{itc} = TECHCOST_{itc} * \prod_{l=1}^2 LEARN_COST_MULTIPLIER_l \quad (10)$$

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 a 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.

$$VAL_PERF_{itc,Year} = VALUEPERF * PERF_COEFF * \frac{INCOME_{Year}}{INCOME_{Year-1}} * (1 + DEL_FE_{itc}) * \frac{FUELCOST_{Year-1}}{FUELCOST_{Year}} * DEL_HP_{itc} \quad (11)$$

where

VAL_PERF = Dollar value of performance of technology *itc*.

VALUEPERF = Value associated with an incremental change in performance.

PERF_COEFF = Parameter used to constrain vehicle performance.

DEL_FE = Fractional change in fuel economy of technology *itc*.

DEL_HP = Fractional change in horsepower of technology *itc*.

FUELCOST = Actual price of fuel for the given year.

INCOME = 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:

$$COSTEF_FUEL_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + (REGCOST * FE_{Year-1} * DEL_FE_{itc})}{TEHCOST_{itc}} \quad (12)$$

$$COSTEF_PERF_{itc} = \frac{VAL_PERF_{itc} - TECHCOST_{itc}}{TEHCOST_{itc}} \quad (13)$$

$$MKT_FUEL_{itc} = \frac{1}{1 + e^{MKT_1COEFF * COSTEF_FUEL_{itc}}} \quad (14)$$

$$MKT_PERF_{itc} = \frac{1}{1 + e^{MKT_2COEFF * COSTEF_PERF_{itc}}} \quad (15)$$

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.

REGCOST⁶ = Factor representing regulatory pressure to increase fuel economy, in dollars per miles per gallon.

TECHCOST = Cost of the considered technology.

VAL_PERF = Performance value associated with technology *itc*.

MKT_FUEL = Market share based on fuel savings.

MKT_PERF = Market share based on performance.

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

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

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

$$ACTUAL_MKT_{itc,Year} = PMAX_{itc,Year} * MAX(MKT_FUEL_{itc}, MKT_PERF_{itc}) \quad (16)$$

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:

$$ACTUAL_MKT_{itc,Year} = MAX(ACTUAL_MKT_{itc,Year-1}, ACTUAL_MKT_{itc,Year}) \quad (17)$$

⁶ 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.

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

$$ACTUAL_MKT_{itc,Year} = MIN(1, MKT_MAX_{itc}, ACTUAL_MKT_{itc,Year}) \quad (18)$$

where

MKT_MAX = Maximum market share for technology *itc*.

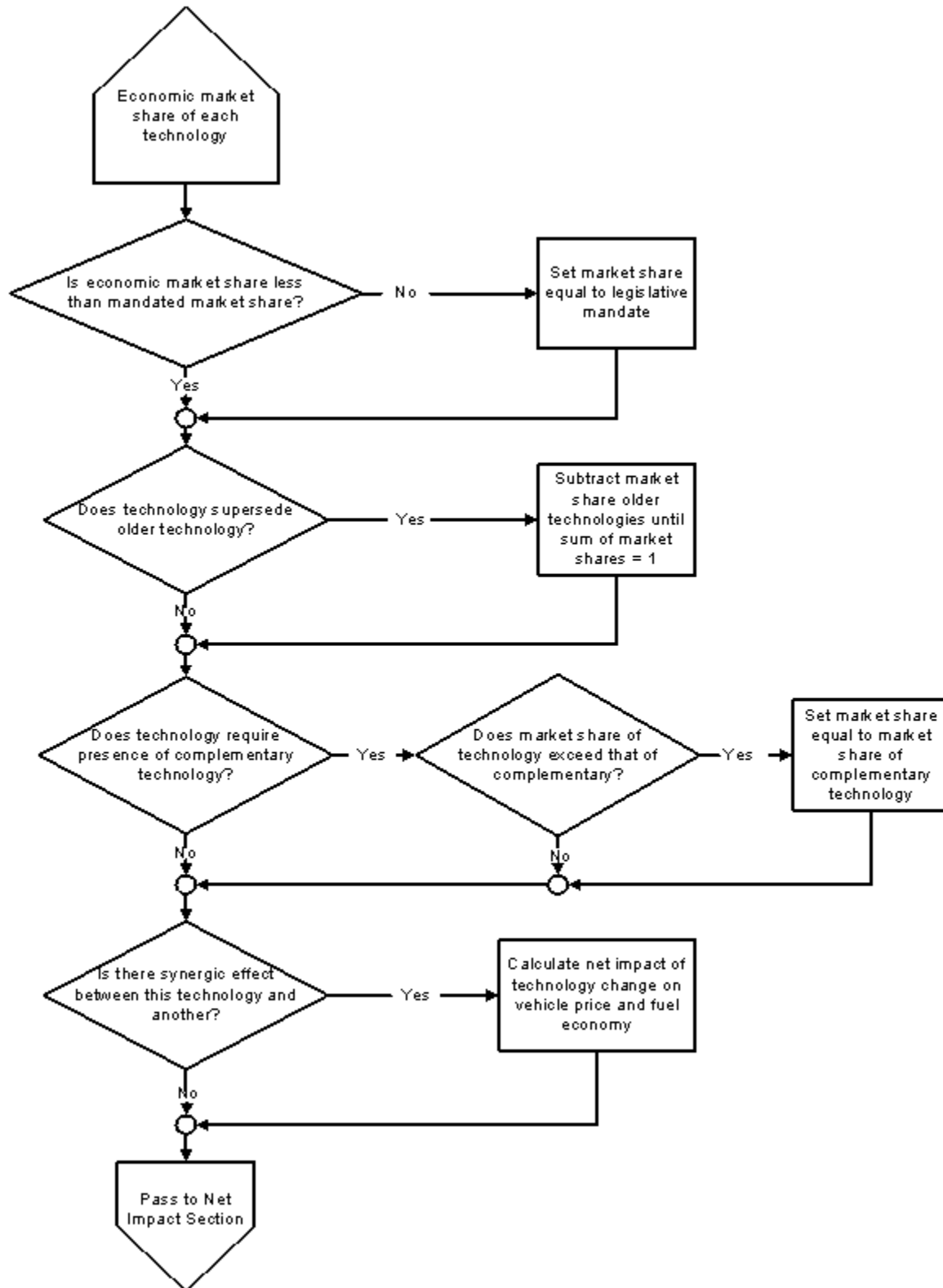
3. Apply the engineering notes

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:

$$ACTUAL_MKT_{itc,Year} = MAX\left(ACTUAL_MKT_{itc,Year}, MANDMKSH_{itc,Year}\right) \quad (19)$$

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:

$$ACTUAL_MKT_{itc,Year} = X \quad (20)$$

where

$$X = MAX\left(\begin{array}{l} ACTUAL_MKT_{itc,Year}, \\ MKT_PEN_{itc,BaseYear,FuelType} + PHASESHR_{Year} * (MKT_MAX_{itc} - MKT_PEN_{itc,BaseYear,FuelType}) \end{array}\right)$$

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:

$$ACTUAL_MKT_{itc,Year} = MIN\left(ACTUAL_MKT_{itc,Year}, MKT_MAX_{itc}\right) \quad (21)$$

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*:

$$TOT_MKT_{itc,Year} = \sum_{ino=1}^{num_sup} ACTUAL_MKT_{ino,Year} \quad (22)$$

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*:

$$MAX_SHARE = MAX(MKT_MAX_1, \dots, MKT_MAX_{num_sup}) \quad (23)$$

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:

$$DEL_MKT_{itc} = TOT_MKT_{itc,Year} - MAX_SHARE \quad (24)$$

where

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

itc = The index indicating superseded technology choice.

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

$$ACTUAL_MKT_{itc,Year} = ACTUAL_MKT_{itc,Year} - DEL_MKT_{itc} \quad (25)$$

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

$$TOT_MKT_{itc,Year} = MAX_SHARE_{itc,Year} \quad (26)$$

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

$$REQ_MKT_{Year} = MIN\left(\sum_{req} ACTUAL_MKT_{req,Year-1}, 1.0\right) \quad (27)$$

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 :

$$ACTUAL_MKT_{itc,Year} = MIN(ACTUAL_MKT_{itc,Year}, REQ_MKT) \quad (28)$$

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:

$$MKT_PEN_{itc,Year} = ACTUAL_MKT_{itc,Year} \quad (29)$$

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 improvement; however, in all cases observed in the MTCC the actual fuel economy improvement 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 SYN_R_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:

$$\begin{aligned}
 &SYNERGY_LOSS_{itc} \\
 &= \sum_{syn} \left(MKT_PEN_{itc,Year} * MKT_PEN_{syn,Year} \right) * SYN_DEL_{itc,syn} \\
 &\quad - \sum_{syn} \left(MKT_PEN_{itc,Year-1} * MKT_PEN_{syn,Year-1} \right) * SYN_DEL_{itc,syn}
 \end{aligned} \tag{30}$$

where

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

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

SYN_R_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 (DELTA_MKT) is calculated as follows:

$$DELTA_MKT_{itc} = MKT_PEN_{itc,Year} - MKT_PEN_{itc,Year-1} \quad (31)$$

DELTA_MKT *itc* is used to calculate the incremental changes in fuel economy, vehicle weight, and price due to the implementation of the considered technology.

a) Fuel economy

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

$$FE_{year} = FE_{Year} + FE_{Year-1} * \left[\sum_{itc=1}^{NUMTECH} DELTA_MKT_{itc} * DEL_FE_{itc} + SYNERGY_LOSS_{itc} \right] \quad (32)$$

where

NUMTECH = Number of newly adopted technologies.

b) Vehicle Weight

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

$$WEIGHT_{Year, FuelType} = WEIGHT_{Year-1, FuelType} + DELTA_MKT_{itc} * \left(DEL_WGTABS_{itc} + WEIGHT_{Year-1, FuelType} * DEL_WGTWGT_{itc} \right) \quad (33)$$

where

$DEL_WGTTABS$ = Change in weight (lbs) associated with technology *itc*.

DEL_WGTWGT = Fractional change in vehicle weight due to technology *itc*.

$WEIGHT$ = Vehicle weight, by market class, group, and fuel type, initialized to the previous year 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:

$$PRICE_{Year} = PRICE_{Year-1} + \sum_{itc=1}^{NUMTECH} DELTA_MKT_{itc} * TECHCOST_{itc} \quad (34)$$

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

$$\begin{aligned} PRICE_{class,group,Year,FuelType} &= PRICE_{class,group,Year,FuelType} + Elec_Stor\$_{class,group,Year,FuelType} \\ PRICEHI_{class,group,Year,FuelType} &= PRICEHI_{class,group,Year,FuelType} + Elec_Stor\$_{class,group,Year,FuelType} \end{aligned} \quad (35)$$

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 TDM considers Nickel Metal Hydride (NiMH) batteries for use in HEV and initial EV applications and Lithium-ion (Li-ion) batteries for use in PHEV10, PHEV40, FC, and later EV vehicles. 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:

$$Li_ion_cost_{year} = a * (lion_prod_{year})^{-b} \quad (36)$$

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

$$Elec_Stor\$_{class,group,Year,EV} = PHEV_kWhr_{class,group,Year,EV} * EVBat\$_kWhr_{Year} * EV_sys_ \$_{class,Year} \quad (37)$$

where

$PHEV_kWhr_{EV}$ = Required battery size (kWh),

$PHEV_kWhr_{EV100}$ = $weight_{class,group,year,EV} * 0.00565$ kilowatthours per vehicle pound / EV_DOD_{year} .

$PHEV_kWhr_{EV200}$ = $weight_{class,group,year,EV} * 0.01255$ kilowatthours per vehicle pound / EV_DOD_{year} .

$$\begin{aligned}
 \text{EVBat\$_kWh} &= \text{Battery cost (\$/kWh)}, \\
 &= \text{Li_ion_cost}_{\text{year}} * \text{Lion_MktSh}_{\text{year}} + \text{NiMH_cost}_{\text{year}} * (1 - \text{Lion_MktSh}_{\text{year}}). \\
 \text{Li_ion_cost} &= \text{Cost of Lithium-ion battery (\$/kWh)}. \\
 \text{NiMH_cost} &= \text{Cost of Nickel Metal Hydride battery (\$/kWh)}. \\
 \text{Lion_MktSh} &= \text{Market share of Lithium-ion battery}. \\
 \text{EV_DOD} &= \text{Batteries maximum depth of discharge (percent)}. \\
 \text{EV_sys_\$} &= \text{EV non-battery system cost}.
 \end{aligned}$$

3) HEV – Hybrid Electric Vehicle

$$\text{Elec_Stor\$}_{\text{class,group,Year,HEV}} = \text{HEVBatPack\$}_{\text{class,group,HEV}} + \text{HEV_Sys_\$}_{\text{Year}} \quad (38)$$

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

$$\begin{aligned}
 \text{Elec_Stor\$}_{\text{class,group,Year,PHEVXX}} &= \text{PHEV_kWh}_{\text{class,group,PHEVXX}} * \text{PHEVXXBat\$kWh}_{\text{Year}} \\
 &+ \text{PHEV_Sys_\$}_{\text{Year}}
 \end{aligned} \quad (39)$$

where

for PHEV10, $\text{PHEV_kWh} = \text{weight}_{\text{class,group,year,gasoline}} * 0.000842$, kilowatthours per vehicle pound / $\text{PHEV_DOD}_{\text{year}}$.

for PHEV40, $\text{PHEV_kWh} = \text{weight}_{\text{class,group,year,gasoline}} * 0.00344$, kilowatthours per vehicle pound / $\text{PHEV_DOD}_{\text{year}}$.

$\text{PHEV_Sys_\$}$ = PHEV40 system cost adjusted for learning.

$\text{PHEV10Bat\$kW}$ = $\text{Li_Ion_Cost}_{\text{year}}$, 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

$$Elec_Stor\$_{class,group,Year,FC} = FUELCELL_{class,group,Year,FC} + BATTERY_{class,group,Year,FC} + TANKCOST_{FC} \quad (40)$$

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 (\$),

$$= weight_{class,group,year,gasoline} * 0.0005 * Li_ion_Cost_{year} \text{ kilowatthours per vehicle pound.}$$

$TANKCOST$ = 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:

$$WEIGHT_{class,group,Year,FuelType} = WEIGHT_{class,group,Year,gasoline} + Battery_Wt_{class,group,Year,FuelType} \quad (41)$$

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

$$Battery_Wt_{class,group,Year,EV} = -500 + EV_Batt_Wt_{Year} * EV_kWhr_{class,group,Year,EV} \quad (42)$$

where

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

$$= 18.72 * Lion_MktSh_{year} + 53.42 * (1 - Lion_MktSh_{year}).$$

2) HEV – Hybrid Electric Vehicle

$$Battery_Wt_{class,group,Year,HEV} = HEV_Batt_Wt_{Year} * HEV_kWh_{class,group,Year,HEV} \quad (43)$$

where

$$\begin{aligned} HEV_Batt_Wt &= \text{Average hybrid electric vehicle battery weight (lbs/kWh),} \\ &= 53.42. \end{aligned}$$

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

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

$$Battery_Wt_{class,group,Year,PHEVXX} = PHEVXX_Batt_Wt_{Year} * PHEVXX_kWh_{class,group,Year,HEV} \quad (44)$$

where

XX=10 and XX=40,

$$PHEV10_Batt_Wt = PHEV40_Batt_Wt = 18.7 \text{ lbs/kWh.}$$

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:

$$HP_{class,group,Year,FuelType} = FAC_{FuelType} * WEIGHT_{class,group,Year,FuelType} * \frac{HP_{class,group,Year,Gasoline}}{WEIGHT_{class,group,Year,Gasoline}} \quad (45)$$

where

$$\begin{aligned} FAC &= 1.0 \text{ for HEV, PHEV10, and PHEV40,} \\ &= 0.8 \text{ for EV and FC.} \end{aligned}$$

Finally, consider the vehicle fuel economy:

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

1) EV – Electric Vehicle:

$$FE_{Year, EV} = \left(\frac{1}{0.125 * (WEIGHT_{class, group, Year, EV} / 2200) / 0.8} \right) * 5253000 * (1/42) * (1/3412) \quad (46)$$

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 million barrels per day

0.8 = fuel economy degradation factor

2) FC – Fuel Cell:

$$FE_{Year, FC} = \frac{1}{GALPERMILE_{FC} * \frac{WEIGHT_{Year, Gasoline}}{1000}} \quad (47)$$

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:

$$HP_{Year, FuelType} = WEIGHT_{Year, FuelType} * \frac{HP_{Year-1, FuelType}}{WEIGHT_{Year-1, FuelType}} \quad (48)$$

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

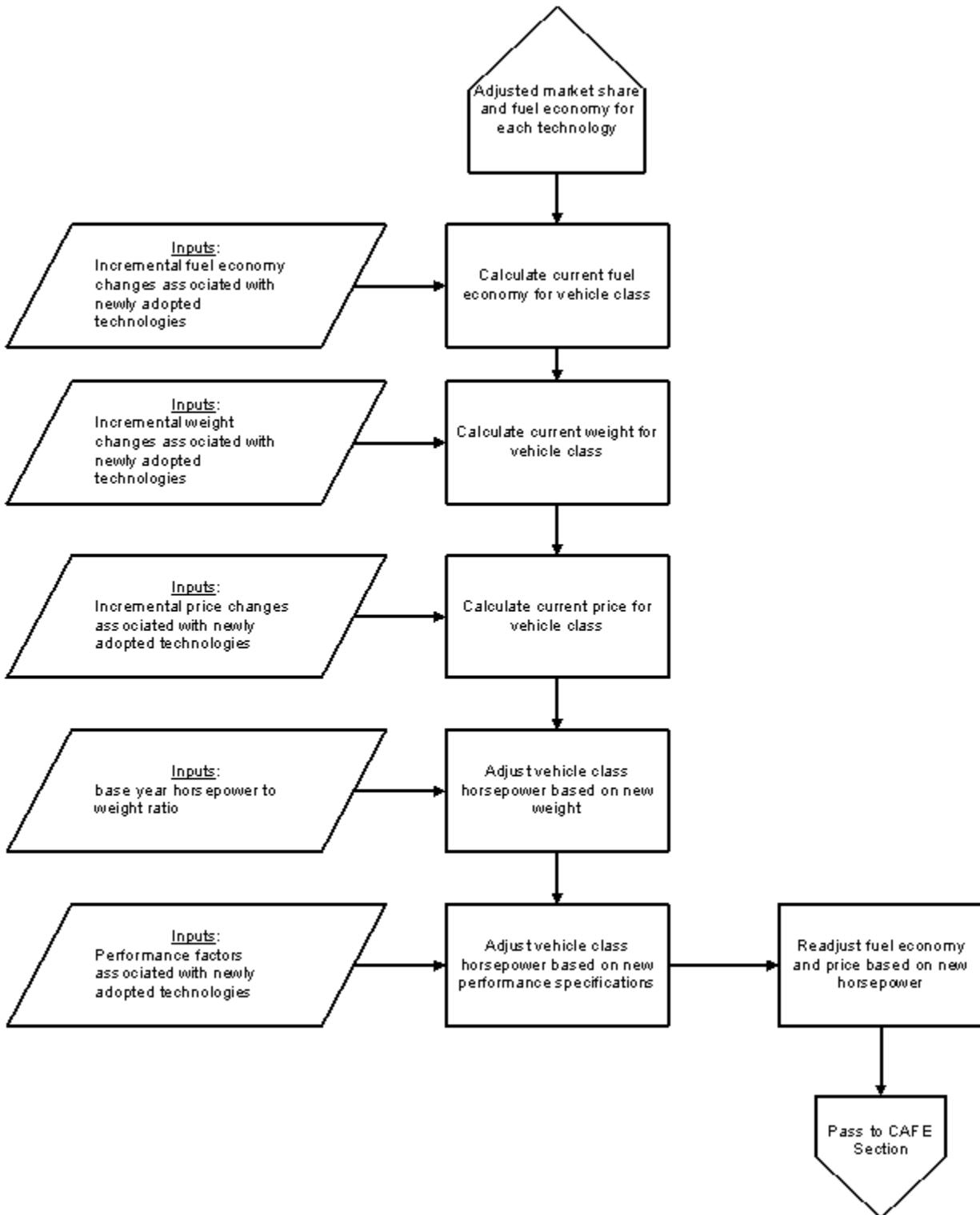
Calculate the annual horsepower adjustment due to technology introductions, which is equal to the sum of incremental changes due to newly adopted technologies:

$$TECH_ADJHP_{year} = \sum_{itc=1}^{NUMTECH} (DELTA_MKT_{itc} * DEL_HP_{itc}) \quad (49)$$

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:

$$PERF_ADJHP_{Year} = \left(\frac{INCOME_{Year}}{INCOME_{Year-1}} \right)^{0.9} * \left(\frac{PRICE_{Year-1}}{PRICE_{Year}} \right)^{0.9} * \left(\frac{FE_{Year}}{FE_{Year-1}} \right)^{0.2} * \left(\frac{FUELCOST_{Year-1}}{FUELCOST_{Year}} \right)^{0.2} - 1 \quad (50)$$

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 2010, DEMAND_USED, must be accounted for through the use of parameter USED CAP:

$$DEMAND_USED = (PERFCAP - HP_WGT_{BaseYear}) * \left(\frac{USED CAP}{1 - USED CAP} \right) \quad (51)$$

where

DEMAND_USED = Demand accrued between 1990 and 2010.

PERFCAP = Performance cap.

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

USED CAP = Input parameter.

and

$$PERF_COEFF_{Year} = 1 - \left(\frac{HP_WGT_{Year} - HP_WGT_{BaseYear} + DEMAND_USED}{PERFCAP - HP_WGT_{BaseYear} + DEMAND_USED} \right) \quad (52)$$

where

PERF_COEFF = Performance coefficient, between 0 and 1.

and

$$PERF_ADJHP_{Year} = PERF_ADJHP_{Year} * PERFFACT * PERF_COEFF_{Year} \quad (53)$$

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:

$$TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year} \quad (54)$$

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%:

$$\begin{aligned} HP_GIVEBACK_{Year} &= TTL_ADJHP_{Year} - 0.1 \\ PERF_ADJHP_{Year} &= PERF_ADJHP_{Year} - HP_GIVEBACK_{Year} \end{aligned} \quad (55)$$

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):

$$TECH_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year} \quad (56)$$

Now, calculate the modified total horsepower adjustment:

$$TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year} \quad (57)$$

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:

$$MIN_ADJHP_{Year} = \left(\frac{HP_WGT_MIN_{BaseYear} * WEIGHT_{Year} - 1}{HP_{Year}} \right)$$

$$PERF_ADJHP_{Year} = PERF_ADJHP_{Year} + MIN_ADJHP_{Year} - TTL_ADJHP_{Year} \quad (58)$$

$$TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year}$$

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.

$$EXCESS_ADJHP_{Year} = \min(TECH_ADJHP_{Year}, TTL_ADJHP_{Year} - MIN_ADJHP_{Year})$$

$$TECH_ADJHP_{Year} = TECH_ADJHP_{Year} - EXCESS_ADJHP_{Year} \quad (59)$$

$$TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year}$$

The model first computes the horsepower giveback:

$$HP_GIVEBACK_{Year} = HP_GIVEBACK_{Year} + EXCESS_ADJHP_{Year} \quad (60)$$

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

$$HP_{Year, FuelType} = HP_{Year, FuelType} * (1 + TTL_ADJHP_{Year}) \quad (61)$$

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 upward or downward 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”:

$$PERF_ADJHP_{Year} = PERF_ADJHP_{Year} - HP_GIVEBACK_{Year} \quad (62)$$

$$ADJFE_{Year} = -0.22 * PERF_ADJHP_{Year} - 0.56 * SIGN * PERF_ADJHP_{Year}^2 \quad (63)$$

where

$$SIGN = -1, \text{ if } PERF_ADJHP < 0, \text{ and } 1 \text{ otherwise.}$$

The final vehicle fuel economy is then determined as follows:

$$FE_{Year} = FE_{Year} * (1 + ADJFE_{Year}) \quad (64)$$

b) Vehicle price

Vehicle price is finally estimated:

$$PRICE_{Year} = PRICE_{Year} + PERF_ADJHP_{Year} * VALUEPERF_{Year} \quad (65)$$

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:

$$RANGE_{Year, FuelType} = TANKSIZE * FE_{Year, Gasoline} * (1 + AFVADJRN_{FuelType}) \quad (66)$$

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 80 miles and for an EV200 the range is set to 160 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:

$$\begin{aligned} DIFFLN_{Year} = & A * \ln\left(\frac{Year}{Year-1}\right) + B * \ln\left(\frac{FUELCOST_{Year}}{FUELCOST_{Year-1}}\right) \\ & + C * \ln\left(\frac{INCOME_{Year} - \$13,000}{INCOME_{Year-1} - \$13,000}\right) + D * \ln\left(\frac{PRICE_{Year, Gasoline}}{PRICE_{Year-1, Gasoline}}\right) \end{aligned} \quad (67)$$

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:

$$RATIO_LN = DIFFLN_{Year} + \ln \left(\frac{CLASS_SHARE_{class,group,nhtsalyr}}{1 - CLASS_SHARE_{class,group,nhtsalyr}} \right) \quad (68)$$

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:

$$CLASS_SHARE_{class,group,Year} = \frac{e^{RATIO_LN}}{1 + e^{RATIO_LN}} \quad (69)$$

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

$$CLASS_SHARE_{class,group,Year} = \frac{CLASS_SHARE_{class,group,Year}}{\sum_{class=1}^6 CLASS_SHARE_{class,group,Year}} \quad (70)$$

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:

$$CafeMpgWgt_{group,Year} = \frac{\sum_{class=1}^6 CLASS_SHARE_{class,group,Year} * apshr55}{\sum_{class=1}^6 Mpg_{class,group,FuelType,Year}} \quad (71)$$

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:

$$FPMpg_{class,group,Year} = \left(\left(\frac{1}{CFCoefA_{Year}} \right) + \left(\frac{1}{CFCoefB_{Year}} - \frac{1}{CFCoefA_{Year}} \right) * \right)^{-1} \frac{e^{\frac{FPrint_{class,group,Year} - CFCoefC_{Year}}{CFCoefD_{Year}}}}{1 + e^{\frac{FPrint_{class,group,Year} - CFCoefC_{Year}}{CFCoefD_{Year}}}} \quad (72)$$

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 min and max 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:

$$FPMpg_{class,group,Year} = \frac{1}{\min(\max(((CFCoefC2 * FPrint) + CFCoefD2), \frac{1}{CFCoefA2}), \frac{1}{CFCoefB2})} \quad (73)$$

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.

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

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.

$$DELTA_{class,group} = 0.0125 * CLASS_SHARE_{class,group} * SALES_{group} \quad (74)$$

where

CLASS_SHARE = Vehicle class market shares (within vehicle groups).

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:

$$AVSALES_{vt,class,11,FuelType} = AVSALES_{vt,class,11,FuelType} + DELTA_{vt,class,FuelType} \quad (75)$$

$$AVSALES_{vt,class,11,GAS} = AVSALES_{vt,class,11,GAS} - DELTA_{vt,class,GAS} \quad (76)$$

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 TDM, 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 shares⁷:

$$MPG_{vt,class} = \frac{1}{\frac{PERGRP_{dom,class}}{FE_{dom,class}} + \frac{PERGRP_{imp,class}}{FE_{imp,class}}} \quad (77)$$

$$HPW_{vt,class} = HP_{dom,class} * PERGRP_{dom,class} + HP_{imp,class} * PERGRP_{imp,class} \quad (78)$$

⁷ Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 27*, ORNL-6973, 2008. For Cars: Table 7.5, 2006 data. For Light Trucks: Table 7.6, 2006 data.

$$PRI_{vt,class} = PRICE_{dom,class} * PERGRP_{dom,class} + PRICE_{imp,class} * PERGRP_{imp,class} \quad (79)$$

$$VRNG_{vt,class} = RNG_{vt,class} = RANGE_{dom,class} * PERGRP_{dom,class} + RANGE_{imp,class} * PERGRP_{imp,class} \quad (80)$$

$$WGT_{vt,class} = WEIGHT_{dom,class} * PERGRP_{dom,class} + WEIGHT_{imp,class} * PERGRP_{imp,class} \quad (81)$$

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 TDM the capability to analyze regional differences in alternative vehicle legislation. For example, California LEV-II legislation, which requires a minimum percentage of vehicles sold to be zero emissions vehicles, earned in part through credits obtained from the sales of advanced technology partial zero emission vehicles, has been adopted by Connecticut, Massachusetts, Maine, New York, New Jersey, Pennsylvania, Maryland, Arizona, New Mexico, Oregon, Rhode Island, Washington, and Vermont, and is included in the TDM.

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 TDM. 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:

$$CARSHRT_{Year} = e^{\left\{ \begin{array}{l} \beta_0 (1-\rho) + [\rho LOG(CARSHARE_{Year-1})] + \\ \beta_1 [LOG(INC00\$16_{Year}) - \rho LOG(INC00\$16_{Year-1})] + \\ \beta_2 [LOG(PMGTR00\$C_{Year}) - \rho LOG(PMGTR00\$C_{Year-1})] + \\ \beta_3 [LOG(AHPCAR_{Year-1}) - \rho LOG(AHPCAR_{Year-2})] + \\ \beta_4 [LOG(AWTCAR_{Year-1}) - \rho LOG(AWTCAR_{Year-2})] + \\ \beta_5 [LOG(TRUEMPG_{Year-1}) - \rho LOG(TRUEMPG_{Year-2})] + \\ \beta_6 [LOG(DUMM_{Year}) - \rho LOG(DUMM_{Year-1})] \end{array} \right\}} \quad (82)$$

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:

$$NEWCARS_{Year} = (MC_SUVA_{Year} + TEMPCLS12A_{Year}) * CARSHARE_{Year}$$

and

$$NEWCLS12A_{Year} = (MC_SUVA_{Year} + TEMPCLAS12A_{Year}) * (1 - CARSHARE_{Year})$$

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:

$$NVS7SC_{group=1-4,class,Year} = CLASS_SHARE_{group=1-4,class,Year} * NEWCARS_{Year} * (1 - FLTCRAT_{Year}) * SALESHR_{group=1-4,Year}$$

and

$$NVS7SC_{group=5-9,class,Year} = CLASS_SHARE_{class,group=5-9,Year} * NEWCLS12A_{Year} * (1 - FLTTRAT_{Year}) * SALESHR_{group=5-9,Year}$$

where

NVS7SC = Non-fleet, non-commercial sales.

CLASS_SHARE = Market share for each car class, from MTCC.

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

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

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

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

$$\begin{aligned}
 NCSTSC_{class,Year} &= \sum_{group=1}^4 NVS7SC_{group,class,Year} \\
 &\text{and} \\
 NLTSTSC_{class,Year} &= \sum_{group=5}^9 NVS7SC_{group,class,Year}
 \end{aligned}
 \tag{85}$$

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:

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

and

$$LTSHRR_{class,Year} = LTSHRR_{class,Year-1} * \frac{\left(\frac{NLTSTSC_{class,Year}}{\sum_{class=1}^6 NLTSTSC_{class,Year}} \right)}{\left(\frac{NLTSTSC_{class,Year-1}}{\sum_{class=1}^6 NLTSTSC_{class,Year-1}} \right)}
 \tag{86}$$

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:

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

and

(87)

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

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 11 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:

$$SEDSHR_{FUEL,REG,Year} = \frac{SEDSHR_{FUEL,REG,Year-1} * \left(\frac{MC_YPDR_{REG,Year}}{MC_YPDR_{REG,Year-1}} \right)}{\sum_{REG=1}^9 \left(SEDSHR_{FUEL,REG,Year-1} * \left(\frac{MC_YPDR_{REG,Year}}{MC_YPDR_{REG,Year-1}} \right) \right)}$$
(88)

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 TDM 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:

$$PMGTR00\$_{REG,Year} = 0.1251 * \left(\frac{PMGTR_{REG,Year}}{MPGFLT_{Year}} \right) \quad (89)$$

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:

$$INC90\$NP_{REG,Year} = \left(\frac{MC_YPDR_{REG,Year}}{MC_N_{REG,Year}} \right) \quad (90)$$

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 demand⁸:

$$VMTLDR_{REG,Year} = e^{X+Y} \quad (91)$$

⁸ The development and estimation of the VMT equation is described in detail later, in the VMT Component (Section 3).

where

$$X = \left\{ \begin{array}{l} \rho \text{LOG}\left(\text{VMTLDR}_{REG, Year-1}\right) + \beta_0 (1 - \rho) \\ + \beta_1 \left[\text{LOG}\left(\text{VMTLDR}_{REG, Year-1}\right) - \rho \text{LOG}\left(\text{VMTLDR}_{REG, Year-2}\right) \right] \end{array} \right\}$$

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

and

$$\text{VMTEER}_{REG, Year} = \text{VMTLDR}_{REG, Year} * \text{LICDRIVER}_{REG, Year} \quad (92)$$

where

VMTEER = Total VMT in region *REG*.

VMTLDR = Regional vehicle-miles traveled per licensed driver.

LICDRIVER = Total regional licensed drivers.

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

PMGTR00\$ = Fuel price in 2000 dollars per gallon

Calculate regional VMT shares (RSHR):

$$\text{RSHR}_{REG, Year} = \frac{\text{VMTEER}_{REG, Year}}{\sum_{REG=1}^9 \text{VMTEER}_{REG, Year}} \quad (93)$$

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

$$\text{NCS}_{REG, class, Year} = \text{NCSTSC}_{class, Year} * \text{RSHR}_{REG, Year} \quad (94)$$

and,

$$\text{NLTS}_{REG, class, Year} = \text{NLSTSC}_{class, Year} * \text{RSHR}_{REG, Year} \quad (95)$$

where

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

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

NCSTSC = New car sales by market class.

NLTSTSC = New light truck sales by market class.

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 TDM. The objective of the CVCC is to estimate the market penetration of conventional and alternative-fuel vehicles during the period 1995-2040. 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:

$$\log\left(\frac{P_k}{1-P_k}\right) = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_k X_k + \varepsilon_k \quad (96)$$

where

P_k = Probability of consumer choosing vehicle (k).

β_1 = Constant term.

β_1, \dots, β_k = Coefficients of vehicle and fuel attributes.

X_1, \dots, 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:

$$S_{it} = P_{it} = \sum_{n=1}^N \frac{P_{itn}}{N}, \quad P_{itn} = \frac{e^{V_{itn}}}{\sum_{i=1}^I e^{V_{itn}}} \quad (97)$$

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.:

$$V = \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k$$

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- and 400-mile-range electric vehicles, which use NiMH batteries initially and then Li-ion batteries increasingly across the projection period. 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:

$$PSPR_{vt, FuelType, class} = PRI_{vt, FuelType, class} * MC_JPGDP \quad (98)$$

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:

$$FLCOST_{vt, FuelType, class, REG} = \frac{FPRICE_{FuelType, REG}}{MPG_{vt, FuelType, class}} \quad (99)$$

where

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

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

REG = Index referring to 9 Census regions.

MPG = Aggregate vehicle fuel economy.

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

$$ACCL_{vt, FuelType, class} = e^{-0.00275} * \left(\frac{HPW_{vt, FuelType, class}}{WGT_{vt, FuelType, class}} \right)^{-0.776} \quad (100)$$

where

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

HPW = Horsepower.

WGT = Weight.

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

$$\begin{aligned} MAINT_{1, FuelType, class, REG} &= MAINTCAR_{FuelType, REG} * TMC_PGDP \\ &\text{and} \\ MAINT_{2, FuelType, class, REG} &= MAINTTRK_{FuelType, REG} * TMC_PGDP \end{aligned} \quad (101)$$

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, gasoline 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- and 200-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:

$$PREDSTK_{hwy_fuel,Year} = LDVSTK_{FuelType,Year-1} + W * LDVSTK_{FuelType=flex:bi-fuel,Year-1} \quad (102)$$

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:

$$ALTSTAT_{hwy_fuel,Year} = ALTSTAT_{hwy_fuel,Year-1} + \frac{PREDSTK_{hwy_fuel,Year} - PREDSTK_{hwy_fuel,Year-1}}{STA_RAT_{hwy_fuel}} \quad (103)$$

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:

$$FUELVSA_{REG,hwy_fuel,Year} = NCSTECH_{REG,class,FuelType,Year-1} + NLTECH_{REG,class,FuelType,Year-1}$$

$$AFVSHREG_{REG,hwy_fuel,Year} = \frac{FUELVSA_{REG,hwy_fuel,Year}}{\sum FUELVSA_{REG,hwy_fuel,Year}} \quad (104)$$

$$ALTSTA_{REG,hwy_fuel,Year} = ALTSTAT_{hwy_fuel,Year} * AFVSHREG_{REG,hwy_fuel,Year}$$

where

NCSTECH = Regional car sales by fuel type.

NLTECH = Regional light truck sales by fuel type.

FUELVSA = 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:

$$FAVAIL_{hwy_fuel,Year,REG} = \frac{ALTSTA_{REG,hwy_fuel,Year}}{ALTSTA_{REG,Gasoline,Year}} \quad (105)$$

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:

$$FAVL_{FuelType,REG,Year} = FAVAIL_{hwy_fuel,Year,REG} \quad (106)$$

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:

$$X31XX_{vt,class} = X31_{vt,class} * \frac{X23_{vt,class}}{X22_{vt,class}} \quad (107)$$

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

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:

$$UISUM_{vt,FuelType,class,REG} = X31_{vt,class} * FLCOST_{vt,FuelType,class,REG} + X31XX * \frac{1}{VRNG_{vt,FuelType,class}} + BETAFA * e^{BETAFA2_{vt,class} * FAVL_{FuelType,REG}} \quad (108)$$

where

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

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

VRNG = Vehicle range in miles

FAVL = Fuel availability indexed relative to gasoline

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

- 3) Utility values are exponentiated and summed:

$$ESUM_{FuelType} = e^{UISUM_{FuelType}} \quad (109)$$

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

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:

$$GENCOST_{vt,class} = \frac{1}{X31_{vt,class}} * \log(ETOT) \quad (110)$$

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- and 400-mile range electric vehicles (using NiMH and Li-ion batteries). Second level market shares are estimated separately for flex and bi-fueled vehicles versus shares estimated for dedicated fuel vehicles.

- 1) Second level logit model calculations for the flex and bi-fuel vehicles determine their share within the conventional vehicles, which represents the first of five groups at the first level as follows:

$$\begin{aligned}
UISUM_{jt} = & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * GENCOST \\
& + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\
& + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \quad (111) \\
& + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log(MMAVAIL_{vt,FuelType,class,Year}) \\
& + X210_{vt,FuelType}
\end{aligned}$$

where

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

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

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

X24 = Coefficient for battery replacement cost at the second level.

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

X26 = Coefficient for electric vehicle and PHEV home refueling capability.

X27 = Coefficient for maintenance cost in dollars.

X28 = Coefficient for luggage space indexed to gasoline vehicle.

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

X210 = 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.

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

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

MAINT = Maintenance cost in dollars.

LUGG = Luggage space indexed to gasoline vehicle.

MMAVAIL = Vehicle make and model diversity availability relative to gasoline exogenously determined in 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 (jt) at the first level where: $jt=2$ for hybrid vehicles; $jt=3$ for dedicated alcohol and gaseous vehicles; $jt=4$ for fuel cell vehicles; and $jt=5$ for electric vehicles.

$$\begin{aligned}
 UISUM_{jt} = & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * FLCOST \\
 & + X23_{vt,class} * \left(\frac{1}{VRNG_{vt,FuelType,class,Year}} \right) \\
 & + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \quad (112) \\
 & + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\
 & + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log(MMAVAIL_{vt,FuelType,class,Year}) \\
 & + X210_{vt,FuelType} + BETAFA2 * e^{BETAFA22_{vt,class} * FAVL_{FuelType,REG,Year}}
 \end{aligned}$$

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

$$\begin{aligned}
 ESUM_{jt} &= e^{UISUM_{jt}} \\
 ETOT_{jt} &= \sum_{jt \in jt} ESUM_{jt} \quad (113) \\
 XSHARE_{jt,jt} &= \frac{ESUM_{jt}}{ETOT_{jt}}
 \end{aligned}$$

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:

$$GCOST_{jt} = \frac{1}{X21_{vt,class}} * \log(ETOT_{jt}) \quad (114)$$

where

GCOST = Generalized cost function of the group (jt).

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

$$UISUM_{jt} = X11_{vt,class} * GCOST_{jt} \quad (115)$$

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.

$$\begin{aligned}
 ESUM_{jg} &= e^{UISUM_{jg}} \\
 YSHARE_{jg} &= \frac{ESUM_{jg}}{\sum_{jg=1}^5 ESUM_{jg}} \\
 APSHR44_{vt,class,REG,FuelType} &= XSHARE_{jg,jt} * YSHARE_{jg}
 \end{aligned}
 \tag{116}$$

where

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

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

Note, APSHR44 is used in equation (123), the vehicle sales equation in the LDV Fleet Component.

LDV Fleet Component

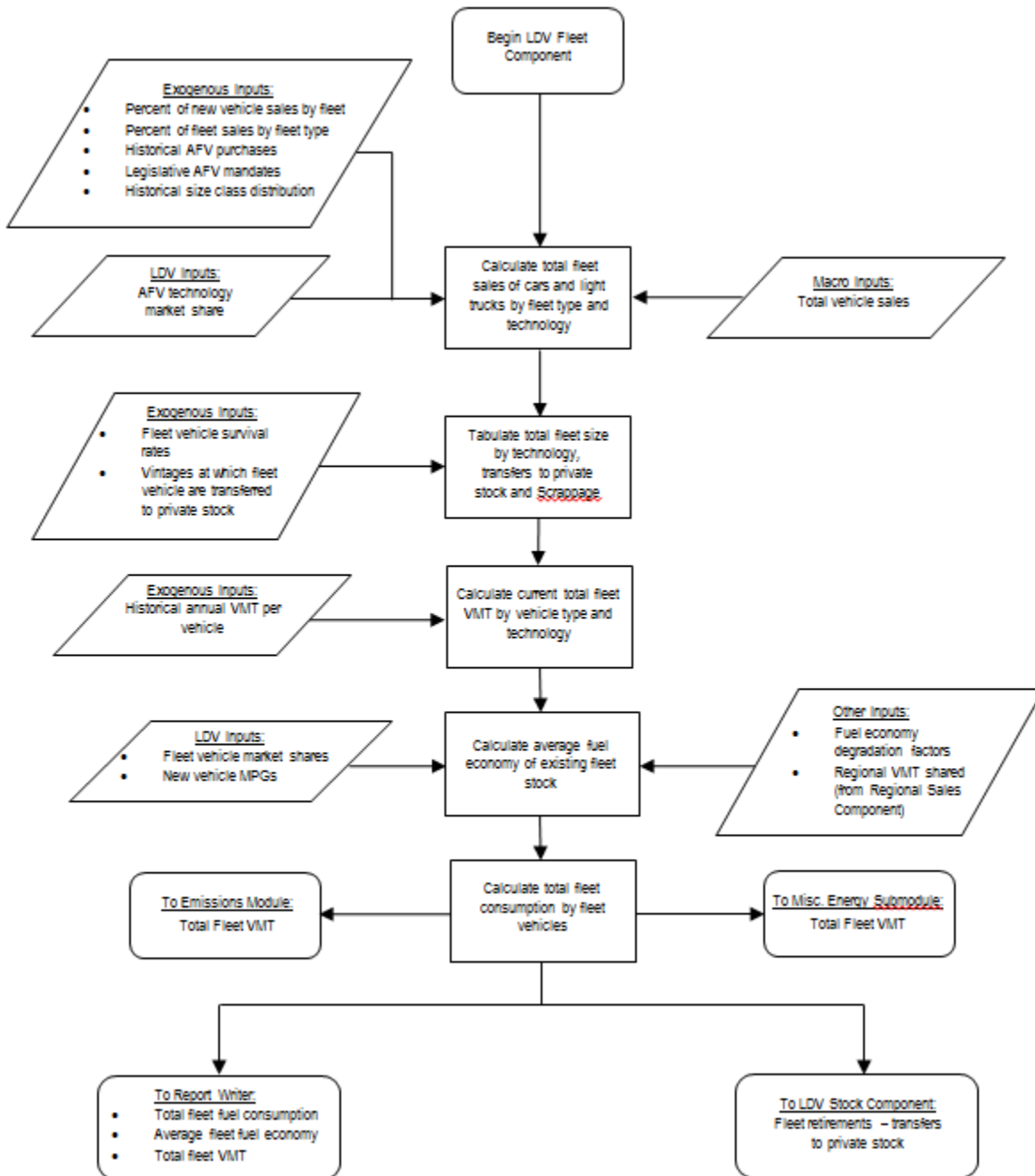
The Light-Duty Vehicle Fleet Component generates estimates of the stock of cars and trucks used in business, government, and utility fleets, and subsequently estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined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

Fleet vehicles are treated separately in the TDM 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 TLEGIS, 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, and utility 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, as seen in Figure 8:

$$\begin{aligned}
 FLTSAL_{vt=1,flt,Year} &= FLTCRAT_{Year} * NEWCARS_{Year} * FLTCSHR_{flt,Year} \\
 &\text{and} \\
 FLTSAL_{vt=2,flt,Year} &= FLTTRAT_{Year} * NEWCLS12A_{Year} * FLTTSHR_{flt,Year}
 \end{aligned}
 \tag{117}$$

where

FLTSAL = Sales to fleets by vehicle and fleet type.

FLTCRAT = Fraction of total car sales attributed to fleets.

FLTTRAT = Fraction of total truck sales attributed to fleets.

NEWCARS = Total new car sales in a given year.

NEWCLS12A = Total new light truck sales in a given year.

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

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

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

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

A new variable is then established, FLTECHSAL, disaggregating AFV sales by engine technology fuel type, *engtech*, namely E85, electric, CNG/LNG, LPG, hydrogen, methanol, diesel, and gasoline:

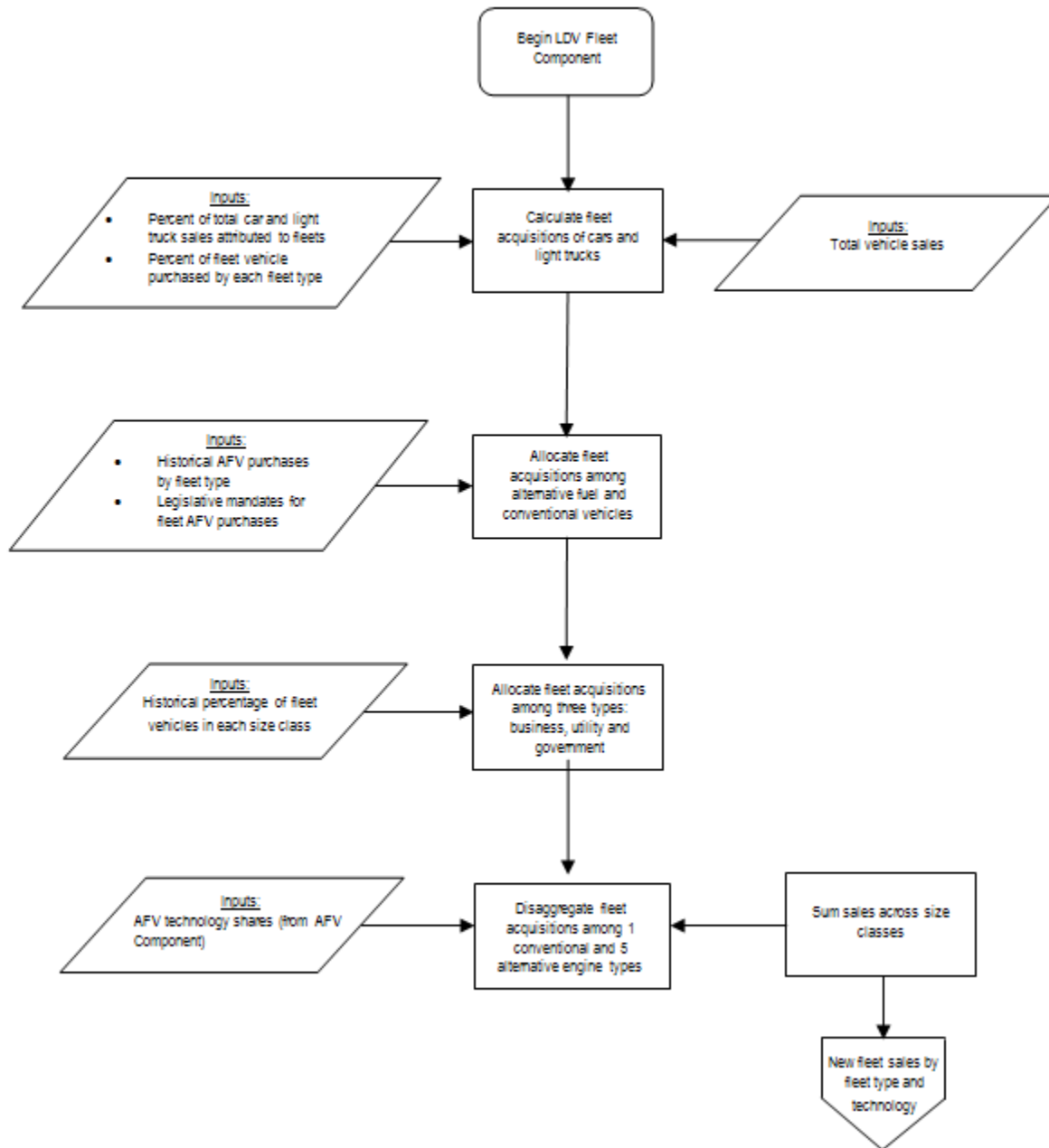
$$FLTECHSAL_{vt,flt,class,ildv} = FLTSAL_{vt,flt,Year} * FLTLDVSHR_{ildv,flt} * FLTSSHR_{flt,class,vt}
 \tag{118}$$

where

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

FLTLDVSHR = Alternative technology shares by fleet type.

Figure 8. LDV new fleet acquisitions component



Sales are then summed across market classes:

$$FLTECH_{vt,flt,engtech} = \sum_{class=1}^6 FLTECHSAL_{vt,flt,class,engtech} \quad (119)$$

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

$$FLTSTKVN_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint-1,Year-1} * SURVFLTT_{vt,vint-1}$$

and

$$FLTSTKVN_{vt,flt,engtech,vint=1,Year} = FLTECH_{vt,flt,engtech} \quad (120)$$

where

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

SURVFLTT = Survival rate of a given vintage.

vint = Index referring to vintage of fleet vehicles.

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

$$OLDFSTK_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint,Year} \quad (121)$$

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, as shown in Table 3.

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{vt,flt,engtech,Year} = \sum_{vint=1}^{20} FLTSTKVN_{vt,flt,engtech,vint,Year} \quad (122)$$

where

TFLTECHSTK = Total stock, by technology and fleet type

Figure 9. Determine characteristics of existing LDV fleets

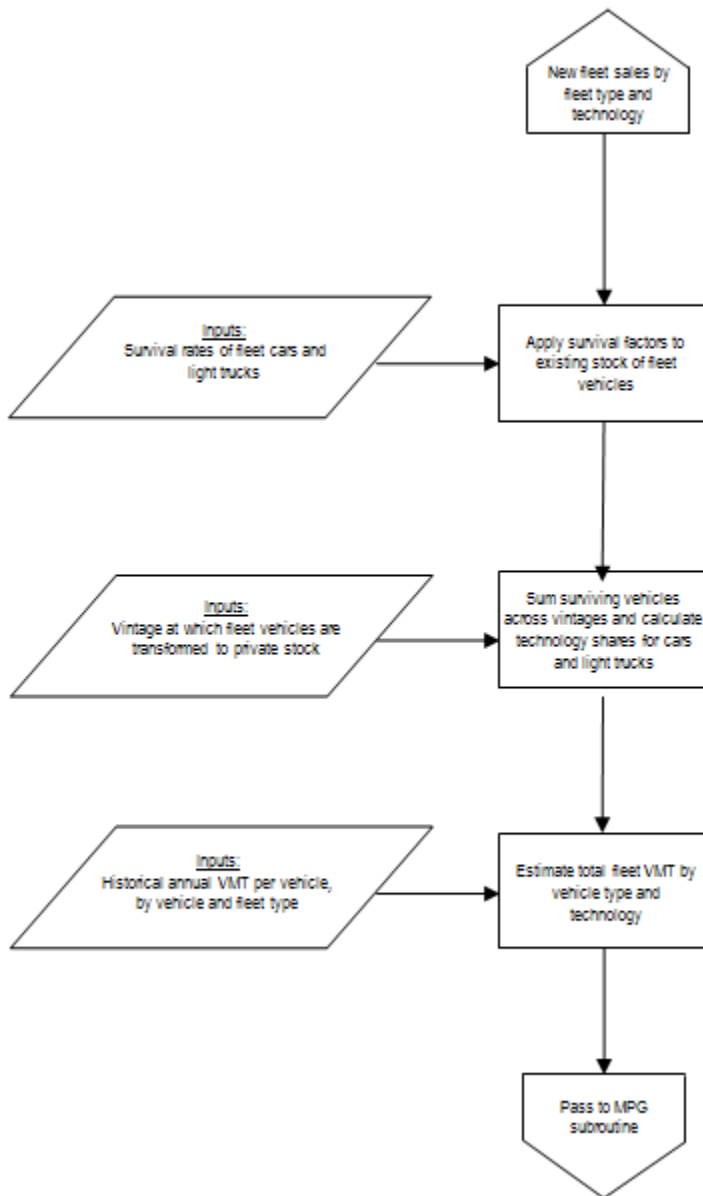


Table 3. Transfer vintage of fleet vehicles

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
Light Truck (vt = 2)	Business	3
Light Truck	Government	6
Light Truck	Utility	5

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

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

$$\begin{aligned}
 VSALES_{vt=1,class,REG,FuelType,Year} &= APSHR44_{vt=1,class,REG,FuelType,Year} * NCS_{REG,class,Year} \\
 &\text{and} \\
 VSALES_{vt=2,class,REG,FuelType,Year} &= APSHR44_{vt=2,class,REG,FuelType,Year} * NLTS_{REG,class,Year}
 \end{aligned}
 \tag{123}$$

where

APSHR44 = Share calculated from equation 116.

NCS = Regional non-fleet car sales by market class, calculated in equation 94.

NLTS = Regional non-fleet light truck sales by market class, calculated in equation 95.

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

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

REG = Census region 1 (participating state Massachusetts), 2 (participating state New York), and 9 (participating state California).

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

$$ZEVCD_{Year,rg} = TTLZEV_{Year} * \left(COEF1_{rg} * NEWCARS_{Year} + COEF2_{rg} * NEWCLS12A_{Year} \right)
 \tag{124}$$

where

ZEVCD = State-mandated sales of ZEVs.

rg = Region index of participating states:

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

= 2 = New York, New Jersey, Pennsylvania, and Maryland.

= 9 = California, Arizona, New Mexico, Oregon, and Washington.

TTLZEV = Total percent of mandated sales of ZEVs, from input file, trnldv.xml.

= ATPZEV + ZEV + ZFCV, found in equations 127, 128, and 129.

NEWCARS = Total new car sales.

NEWCLS12A = Total new light truck sales.

COEF1 = Fraction of total new car sales by participating state.

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

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

$$TOTCRED_{REG} = \sum_{vt=1}^2 (VSALES_EVGH_{vt,REG} + VSALES_FCM_{vt,REG} + VSALES_FCG_{vt,REG}) \quad (125)$$

where

TOTCRED = Total ZEV sales for gasoline hybrid and methanol and gasoline fuel cell vehicles.

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

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

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

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

First, set AVSALES = VSALES:

$$AVSALES_{vt,class,REG,Gasoline} = VSALES_{vt,class,REG,Gasoline} \quad (126)$$

- a) If the total sales of gasoline hybrid and fuel cell (excluding hydrogen) vehicles, TOTCRED, is less than required by the Low-Emission Vehicle Program (LEVP), then increase the vehicle sales to meet the mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSales_{REG,Year} * ATPZEV_{Year}}{TOTCRED_{REG,Year}} \right] \quad (127)$$

where

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

ZEVSales = Total ZEV sales that are mandated in census region, REG=1, 2, and 9.

= REG=1 (Maine, Massachusetts, Vermont, Connecticut, and Rhode Island).

= REG=2 (New York, New Jersey, Pennsylvania, and Maryland).

= REG=9 (California, Arizona, New Mexico, Oregon, and Washington).

ATPZEV = Percent of total mandated sales associated with sale of gasoline hybrid, methanol and gasoline fuel cell vehicles, from trnldv.xml.

If the total sale of electric vehicles, TZEVSAL, is less than required by the LEV Program, then increase the resulting electric vehicle sales to meet these mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSales_{REG,Year} * ZEV_{Year}}{TZEVSAL_{REG,Year}} \right] \quad (128)$$

where

AVSALES = New total vehicle sales, adjusted for electric vehicles.

TZEVSAL = Total available ZEV sales of electric vehicles:

= VSALES_EV_{vt=1,REG} + VSALES_EV_{vt=2,REG}

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

ZEV = Percent of total mandated sales associated with sale of electric vehicles, from trnldv.xml.

- b) If the total sale of hydrogen fuel cell vehicles, TZFC SAL, is less than required by the LEV Program, then increase the resulting hydrogen fuel cell vehicle sales to meet these mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSALES_{REG,Year} * ZFCV_{Year}}{TZFC SAL_{REG,Year}} \right] \quad (129)$$

where

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

TZFC SAL = Total available ZEV sales from hydrogen fuel cell vehicles:

$$= VSALES_FCH_{vt=1,REG} + VSALES_FCH_{vt=2,REG}$$

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

ZFCV = Percent of total mandated sales associated with the sale of hydrogen fuel cell vehicles, in trnldv.xml.

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

$$AVSALES_{vt,class,REG,Gasoline} = AVSALES_{vt,class,REG,Gasoline} - DEL_TECH_{vt,class,REG,FuelType} \quad (130)$$

where

DEL_TECH = Additional vehicle sales needed to meet requirement:

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

FuelType = Gasoline hybrid, methanol and gasoline fuel cell, and electric vehicle fuel technologies.

Sum the adjusted vehicle sales across technologies:

$$AVSALEST_{vt,class,REG} = \sum_{FuelType=1}^{16} AVSALES_{vt,class,REG,FuelType} \quad (131)$$

where

AVSALEST = Total regional adjusted vehicle sales by market class.

Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{vt,class,REG,FuelType} = \frac{AVSALES_{vt,class,REG,FuelType}}{AVSALEST_{vt,class,FuelType}} \quad (132)$$

where

APSHR55 = Absolute regional market shares of adjusted vehicle sales.

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

$$\begin{aligned}
 NCSTECH_{REG,class,FuelType} &= NCS_{REG,class} * APSHR55_{vt=1,class,REG,FuelType} \\
 &\text{and} \\
 NLTECH_{REG,class,FuelType} &= NLTS_{REG,class} * APSHR55_{vt=2,class,REG,FuelType}
 \end{aligned}
 \tag{133}$$

where

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

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

2. Calculate Fleet VMT

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

$$FLTVMT_{Year} = \sum_{vt=1}^2 \sum_{flt=1}^3 \sum_{engtech=1}^{16} (TFLTECHSTK_{vt,flt,engtech,Year} * FLTVMTYR_{flt,Year,vt})
 \tag{134}$$

where

FLTVMT = Total VMT driven by fleet vehicles.

FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type, from trnldv.xml.

TFLTECHSTK = Total stock within each technology and fleet type, calculated in equation 122.

Total VMT is then disaggregated by vehicle type and technology:

$$FLVMTECH_{vt,flt,engtech,Year} = TFLTECHSTK_{vt,flt,engtech} * FLTVMTYR_{flt,engtech,Year}
 \tag{135}$$

where

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

3. Calculate Fleet Stock MPG

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

$$FLTMPG_{vt,flt,engtech} = \left[\frac{\sum_{class=1}^6 FLTECHSAL_{vt,flt,class,engtech}}{\sum_{class=1}^6 \frac{FLTECHSAL_{vt,flt,class,engtech}}{MPG_{vt,FuelType,class}}} \right] \quad (136)$$

where

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

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

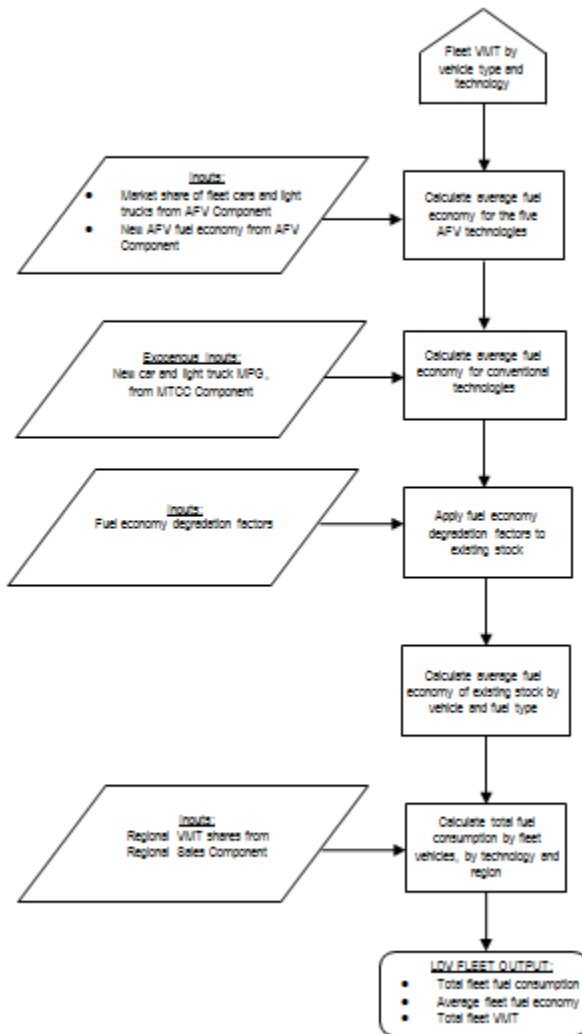
Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{vt} = \left[\frac{\sum_{flt=1}^3 \sum_{engtech=1}^6 FLTECH_{vt,flt,engtech}}{\sum_{flt=1}^3 \sum_{engtech=1}^6 \frac{FLTECH_{vt,flt,engtech}}{FLTMPG_{vt,flt,engtech}}} \right] \quad (137)$$

where

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

Figure 10. Determine fuel economy and consumption for LDV fleets



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

For $vint=1$:

$$\begin{aligned}
 CMPGFSTK_{flt,engtech,vint,Year} &= FLTMPG_{vt=1,flt,engtech,Year} \\
 &\text{and} \\
 TMPGFSTK_{flt,engtech,vint,Year} &= FLTMPG_{vt=2,flt,engtech,Year}
 \end{aligned}
 \tag{138}$$

where

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

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

For $vint=2, 3, \dots, 7$:

$$\begin{aligned}
 CMPGFSTK_{flt,engtech,vint,Year} &= CMPGFSTK_{flt,engtech,vint-1,Year-1} \\
 &\text{and} \\
 TMPGFSTK_{flt,engtech,vint,Year} &= TMPGFSTK_{flt,engtech,vint-1,Year-1}
 \end{aligned}
 \tag{139}$$

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

$$\begin{aligned}
 MPGFLTSTK_{vt=1,flt,engtech} &= \left[\frac{\sum_{vint=1}^{\max vint} FLTSTKVN_{vt=1,flt,engtech,vint}}{\sum_{vint=1}^{\max vint} \frac{FLTSTKVN_{vt=1,flt,engtech,vint}}{CMPGFSTK_{flt,engtech,vint} * CDFRFG}} \right] \\
 &\text{and} \\
 MPGFLTSTK_{vt=2,flt,engtech} &= \left[\frac{\sum_{vint=1}^{\max vint} FLTSTKVN_{vt=2,flt,engtech,vint}}{\sum_{vint=1}^{\max vint} \frac{FLTSTKVN_{vt=2,flt,engtech,vint}}{TMPGFSTK_{flt,engtech,vint} * LTDFRFG}} \right]
 \end{aligned}
 \tag{140}$$

where

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

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

CDFRFG = Degradation factor for cars.

LTDFRFG = Degradation factor for light trucks.

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

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

$$FLTTOTMPG_{vt} = \left[\frac{\sum_{flt=1}^3 \sum_{engtech=1}^6 TFLTECHSTK_{vt,flt,engtech}}{\sum_{flt=1}^3 \sum_{engtech=1}^6 \frac{TFLTECHSTK_{vt,flt,engtech}}{MPGFLTSTK_{vt,flt,engtech}}} \right] \quad (141)$$

where

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

4. Calculate Fuel Consumption by Fleet Vehicles

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

$$FLTLDVC_{vt,flt,engtech} = \frac{FLTVMTECH_{vt,flt,engtech,Year}}{MPGFLTSTK_{vt,flt,engtech}} * QBTU_{engtech} \quad (142)$$

where

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

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

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

$$FLTFCLDVBTU_{vt,engtech,Year} = \sum_{flt=1}^3 FLTLDVC_{vt,flt,engtech} \quad (143)$$

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:

$$FLTFCLDVBTUR_{REG,engtech,Year} = \sum_{w=1}^2 FLTFCLDVBTU_{engtech,Year} * RSHR_{REG} \quad (144)$$

where

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology.

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

REG = Index of Census regions.

Class 2b Vehicle Component

The Class 2b Vehicle Component provides an accounting of sales, stock, fuel economy, and energy use for vehicles weighing 8,500 to 10,000 pounds GVWR.⁹ The component tracks travel and fuel efficiency for twenty vehicle vintages. The primary purpose of this component is to provide a mechanism to allocate the stock and new sales of Class 2b vehicles among the various major-use groups considered in this component, which includes five industrial categories (agriculture, mining, construction, total manufacturing, and utility) and one household segment (personal travel or personal VMT). Historical stock numbers are derived from an Oak Ridge National Laboratory study using Polk data,¹⁰ and new sales are obtained from the Macroeconomic Activity Module. The shares used for allocating the stock and new sales information are derived from the 2002 Vehicle Inventory and Use Survey (VIUS). VIUS provides data to use in distributing the VMT by major-use group that allows estimation of the total annual miles traveled within each category.

Calculate the new Class 2b vehicle sales:

$$NEWCLS2B_{Year} = MC_VEHICLES_{1,Year} + MC_VEHICLES_{2,Year} - TEMPCLS12A_{Year} \quad (145)$$

where

NEWCLS2B = New Class 2b vehicle sales.

MC_VEHICLES = Sales of light-duty trucks from Macroeconomic Activity Module.

TEMPCLS12A = Sales of class 1 and 2a trucks.

⁹ As defined in NEMS, light commercial trucks are a subset of Class 2 vehicles (vehicles weighing 6,001 to 10,000 pounds GVW) and are often referred to as Class 2b vehicles (8,500 to 10,000 pounds GVW). Class 2a vehicles (6,001 to 8,500 pounds GVW) are addressed in the Light-Duty Vehicle Submodule.

¹⁰ Oak Ridge National Laboratory, Memorandum on the Distribution of Trucks by Age and Weight: 2000 Truck Population, Stacy C. Davis, November 2001.

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

$$CLTSTK_{fuel,vint=1,Year} = NEWCLS2B_{Year}$$

and

$$CLTSTK_{fuel,vint,Year} = CLTSTK_{fuel,vint-1,Year-1} * CLTSURV_{vint-1} \quad (146)$$

where

CLTSTK = Class 2b vehicle stock, by vintage.

CLTSURV = Percentage of stock carried over from previous year.

vint = Vintage, or age, of vehicle = 2,..., 20.

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

$$CLTVMT_{fuel,vint,Year} = CLTSTK_{fuel,vint,Year} * CLTVMTV_{vint,1995} * \left(\frac{growth2_{Year}}{growth1_{Year}} \right)^{Year-1995} \quad (147)$$

where

CLTVMT = Class 2b VMT, by vintage.

CLTVMTV = Class 2b vehicle-miles traveled per truck for 1995, from trnldv.xml.

growth1 = Annual growth in Class 2b vehicle-miles traveled.

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

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

Estimate Class 2b vehicle fuel economy by vintage:

$$CLTMPG_{fuel,vint,Year} = CLTMPGV_{fuel,vint}, vint = 1, \dots, 20, Year = 1995$$

and

$$CLTMPG_{fuel,vint,Year} = CLTMPG_{fuel,vint,Year-1}, vint = 1, Year \geq 1996 \quad (148)$$

and

$$CLTMPG_{fuel,vint,Year} = CLTMPG_{fuel,vint-1,Year-1} * \left[1 + \left(\frac{MPG_{fuel,Year} - MPG_{fuel,Year-1}}{MPGT_{fuel,Year-1}} \right) \right], vint \geq 2, Year \geq 1996$$

where

CLTMPG = Class 2b vehicle fuel economy, by vintage.

CLTMPGV = Base year light-duty truck MPG.

MPG = Light-duty truck MPG, for gasoline and diesel vehicles, from the LDV Stock Component.

fuel = Gasoline or diesel.

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

$$CLTGAL_{fuel,Year} = \sum_{vint=1}^{20} \frac{CLTVMT_{fuel,vint,Year}}{CLTMPG_{fuel,vint,Year}}$$

and

$$CLBTUT_{fuel,Year} = CLTGAL_{fuel,Year} * \frac{5.253}{42}$$

(149)

where

CLTGAL = Commercial light truck fuel consumption in gallons.

CLBTUT = Commercial light truck fuel consumption in Btu.

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

$$CLTMPGT_{Year} = \frac{\sum_{vint=1}^{20} CLTVMT_{vint,Year}}{CLTGAL_{Year}}$$

(150)

where

CLTMPGT = Commercial light truck average fuel economy, by vintage.

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:

$$\begin{aligned}
 \mathit{TECHNCS}_{FuelType,Yr} &= \sum_{class=1}^6 \sum_{REG=1}^9 \mathit{NCSTECH}_{REG,class,FuelType,Yr} \\
 &\quad \text{and} \\
 \mathit{TECHNLT}_{FuelType,Yr} &= \sum_{class=1}^6 \sum_{REG=1}^9 \mathit{NLTECH}_{REG,class,FuelType,Yr}
 \end{aligned}
 \tag{151}$$

where

$\mathit{TECHNCS}$ = Total new car sales, by engine technology fuel type.

$\mathit{TECHNLT}$ = Total new light truck sales, by engine technology fuel type.

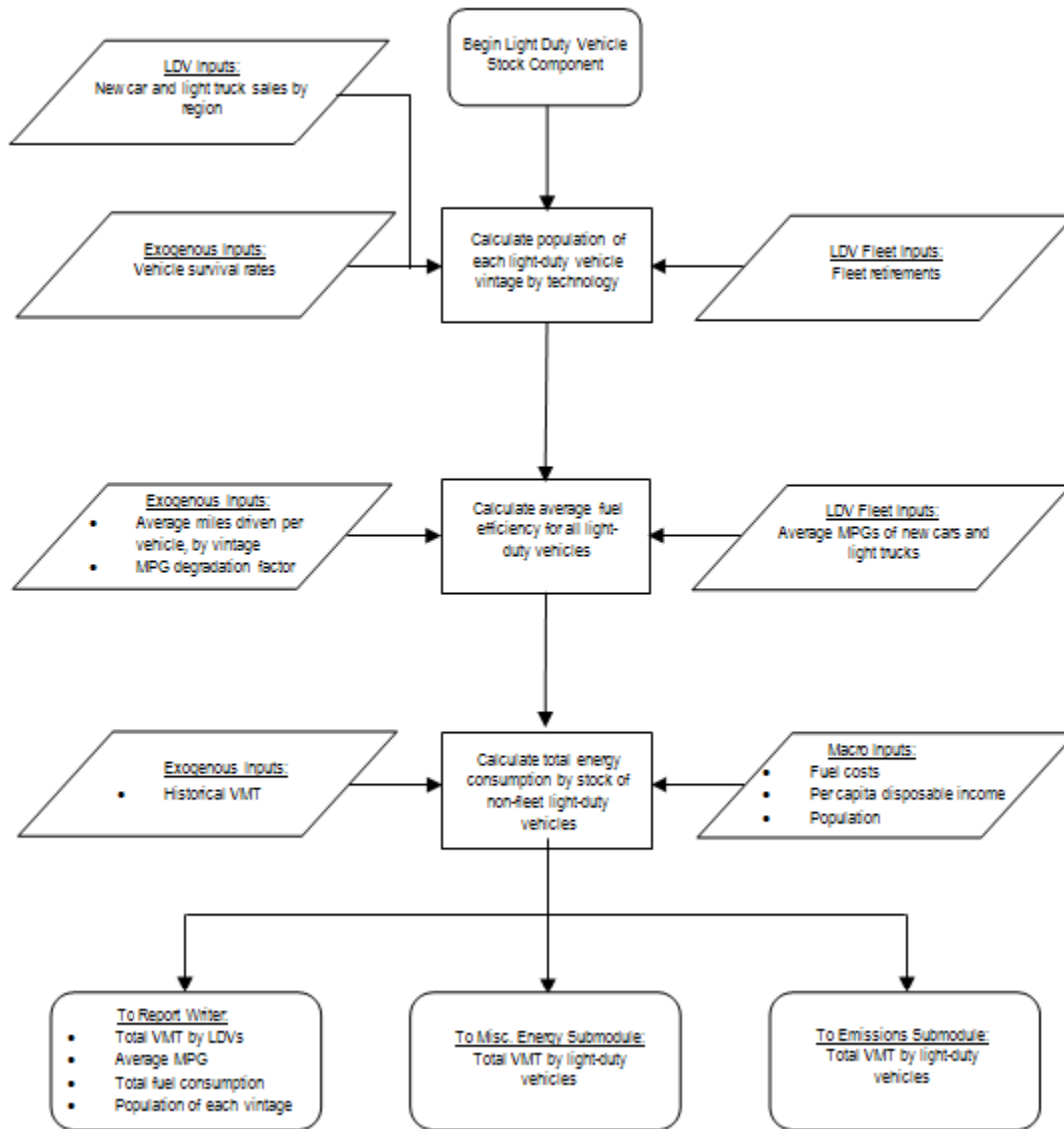
$\mathit{NCSTECH}$ = New car sales, by region, market class, and technology, from the CVCS.

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

$FuelType$ = Engine technology fuel types (1 to 16).

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 $vint = 2, 3, \dots, 24$:

$$\begin{aligned}
 PASSTK_{FuelType, vint, Year} &= PASSTK_{FuelType, vint-1, Year-1} * SSURV25_{vint-1} \\
 &\text{and} \\
 LTSTK_{FuelType, vint, Year} &= LTSTK_{FuelType, vint-1, Year-1} * SSURV25_{vint-1}
 \end{aligned}
 \tag{152}$$

For $vint = 25$:

$$\begin{aligned}
 PASSTK_{FuelType, vint=25, Year} &= A * B * C \\
 &\text{and} \\
 LTSTK_{FuelType, vint=25, Year} &= X * Y * Z
 \end{aligned}
 \tag{153}$$

where

$$A = PASSTK_{FuelType, vint=24, Year-1}$$

$$B = SSURV25_{vint=24} + PASSTK_{FuelType, vint=25, Year-1}$$

$$C = SSURV25_{vint=25}$$

$$X = LTSTK_{FuelType, vint=24, Year-1}$$

$$Y = SSURV25_{vint=24} + LTSTK_{FuelType, vint=25, Year-1}$$

$$Z = SSURV25_{vint=25}$$

PASSTK = Surviving car stock, by technology and vintage.

LTSTK = Surviving light truck stock, by technology and vintage.

SSURV25 = Fraction of a given vintage's cars/trucks that survive.

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.

$$\begin{aligned}
 PASSTK_{FuelType,vint,Year} &= PASSTK_{FuelType,vint,Year} + OLDFSTK_{car,flt,FuelType,vint,Year} \\
 &\text{and} \\
 LTSTK_{FuelType,vint,Year} &= LTSTK_{FuelType,vint,Year} + OLDFSTK_{truck,flt,FuelType,vint,Year}
 \end{aligned}
 \tag{154}$$

where

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

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

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

$$\begin{aligned}
 STKCAR_{Year} &= \sum_{vint=1}^{25} \sum_{FuelType=1}^{16} PASSTK_{FuelType,vint,Year} \\
 &\text{and} \\
 STKTR_{Year} &= \sum_{vint=1}^{25} \sum_{FuelType=1}^{16} LTSTK_{FuelType,vint,Year}
 \end{aligned}
 \tag{155}$$

where

STKCAR = Total stock of non-fleet cars.

STKTR = Total stock of non-fleet light trucks.

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

$$VSPLDV_{FuelType,Year} = \frac{\sum_{vint=1}^{25} (PASSTK_{FuelType,vint,Year} + LTSTK_{FuelType,vint,Year})}{STKCAR_{Year} + STKTR_{Year}}
 \tag{156}$$

where

VSPLDV = Light-duty vehicle shares of each of the 16 vehicle technologies.

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

1. Calculate Stock Efficiencies for Cars and Light Trucks

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

Sum new car and light truck sales across regions:

$$\begin{aligned}
 NVSALES_{vt=1,class,FuelType,Year} &= \sum_{REG=1}^9 NCSTECH_{REG,class,FuelType,Year} \\
 &\text{and} \\
 NVSALES_{vt=2,class,FuelType,Year} &= \sum_{REG=1}^9 NLTECH_{REG,class,FuelType,Year}
 \end{aligned}
 \tag{157}$$

The harmonic average efficiencies of the 15 non-gasoline technologies are calculated as follows:

$$\begin{aligned}
 MPGC_{FuelType,Year} &= \left[\frac{\sum_{class=1}^6 \frac{NVSALES_{vt=1,class,FuelType,Year}}{MPG_{vt=1,FuelType,class}}}{\sum_{class=1}^6 NVSALES_{vt=1,class,FuelType,Year}} \right]^{-1} \\
 &\text{and} \\
 MPGT_{FuelType,Year} &= \left[\frac{\sum_{class=1}^6 \frac{NVSALES_{vt=2,class,FuelType,Year}}{MPG_{vt=2,FuelType,class}}}{\sum_{class=1}^6 NVSALES_{vt=2,class,FuelType,Year}} \right]^{-1}
 \end{aligned}
 \tag{158}$$

where

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

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

The overall fuel efficiency of cars and light trucks is then calculated across the 25 vintages addressed in the component.¹¹ Since older vehicles are driven less than newer vehicles, it is necessary to weight the fuel efficiencies of each vintage according to the average number of miles driven. This is done by summing the total number of miles driven across all vintages and technologies:¹²

¹¹ Initial values for on-road car and light truck fleet MPG are obtained from the Federal Highway Administration, *Highway Statistics, 2007*, U.S. Department of Transportation (2008).

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

$$TOTMICT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{25} PASSTK_{FuelType,vint,Year} * PVMT_{vint}$$

and

$$TOTMITT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{25} LTSTK_{FuelType,vint,Year} * LVMT_{vint}$$

(159)

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:

$$CMPGT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{25} \frac{PASSTK_{FuelType,vint,Year} * PVMT_{vint}}{CMPGSTK_{FuelType,vint,Year} * CDFRFG}$$

and

$$TMPGT_{Year} = \sum_{FuelType=1}^{16} \sum_{vint=1}^{25} \frac{LTSTK_{FuelType,vint,Year} * LVMT_{vint}}{TTMPGSTK_{FuelType,vint,Year} * LTDFRFG}$$

(160)

where

CMPGT = Car stock MPG.

TMPGT = Light truck stock MPG.

CMPGSTK = Car fuel economy.

CDFRFG = Car fuel efficiency degradation factor.

LTDFRFG = Light truck fuel efficiency degradation factor.

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

$$STMPG_{Year} = \frac{TOTMITT_{Year}}{TMPGT_{Year}}$$
(161)

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:

$$MPGFLT_{Year} = \frac{TOTMICT_{Year} + TOTMITT_{Year}}{CMPGT_{Year} + TMPGT_{Year}}$$
(162)

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

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

$$CMPG_{IT_{FuelType,Year}} = \left[\frac{\sum_{vint=1}^{25} \frac{PASSTK_{FuelType,vint,Year} * PVMT_{vint}}{CMPGSTK_{FuelType,vint,Year} * CDFRFG}}{\sum_{vint=1}^{25} PASSTK_{FuelType,vint,Year} * PVMT_{vint}} \right]^{-1}$$

and

$$TMPG_{IT_{FuelType,Year}} = \left[\frac{\sum_{vint=1}^{25} \frac{LTSTK_{FuelType,vint,Year} * LVMT_{vint}}{TTMPGSTK_{FuelType,vint,Year} * LTDFRFG}}{\sum_{vint=1}^{25} LTSTK_{FuelType,vint,Year} * LVMT_{vint}} \right]^{-1}$$
(163)

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 TDM 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 are available from the Federal Highway Administration (FHWA). All macroeconomic inputs are calculated based on a chain-weighted average. These data are used to estimate the VMT equation in the NEMS VMT Component:

$$\begin{aligned} \text{LOG}(\text{VMTLD}_{\text{Year}}) - \rho \text{LOG}(\text{VMTLD}_{\text{Year}-1}) = & \alpha + \beta_1 [\text{LOG}(\text{INC00\$16}_{\text{Year}})] + \\ & \beta_2 [\text{LOG}(\text{COSTMI}_{\text{Year}})] + \beta_3 [\text{LOG}(\text{VPLD}_{\text{Year}})] + \beta_4 [\text{LOG}(\text{EMP}_{\text{Year}})] \end{aligned} \quad (164)$$

where

VMTLD = VMT per licensed driver for the driving age population.

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

COSTMI = fuel cost of driving.

VPLD = light-duty vehicles per licensed driver.

EMP = employment rate of population age 16+.

Of greater significance are 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 separately, 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:

$$\begin{aligned} \text{VMTLD}_{\text{Year}} = & e^{\left\{ \alpha + \beta_0 \text{LOG}[\text{VMTLD}_{\text{Year}-1}] + \beta_1 \text{LOG}[\text{INC00\$16}_{\text{Year}}] + \beta_2 \text{LOG}[\text{COSTMI}_{\text{Year}}] \right\}} \\ & * e^{\left\{ \beta_3 \text{LOG}[\text{VPLD}_{\text{Year}}] + \beta_4 \text{LOG}[\text{EMP}_{\text{Year}}] \right\}} \end{aligned} \quad (165)$$

where

VMTLD = Vehicle-miles traveled per licensed driver.

COSTMI = Fuel cost of driving a mile, expressed in 2004 cents per mile.

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

VPLD = Vehicles per licensed driver.

EMP_RATE = U.S. employment rate, from the Macroeconomic Activity Module.

Air Travel Submodule

The Air Travel Submodule of the NEMS TDM 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 13 world regions (Table 4) on a per capita basis, expressed 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, Costa Rica, Cuba, Dominican Republic, El Salvador, Guadeloupe, Guatemala, Honduras, Jamaica, Mexico, Netherlands Antilles, Panama, 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, Syria, 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 logistic functions estimated over the period 1950 to 2009 for the United States and 2000 to 2009 for the non-U.S. regions. 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. Key model relationships are presented below. Where numbers appear in place of variable names, parameters have been estimated statistically from historical 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:

$$\begin{aligned}
 RPMT_PC_{wreg=1,di,Year} &= max_rpm_{wreg=1,di} + \\
 &\left[\left(max_rpm_{wreg=a,di} - min_rpm_{wreg=a,di} \right)^{-1} \right. \\
 &\left. + \left(\epsilon \left(constant_rpm_{wreg=1,di} + share_rpm_{wreg=1,di} * \frac{inc00\$np_{Year}}{inc00\$np_{Base_Year}} \right) \right) \right]^{-1} \quad (166)
 \end{aligned}$$

Twelve non-U.S. regions:

$$\begin{aligned}
 RPMT_PC_{wreg,di,Year} &= max_rpm_{wreg,di} + \\
 &\left[\left(max_rpm_{wreg,di} - min_rpm_{wreg,di} \right)^{-1} \right. \\
 &\left. + \left(\epsilon \left(constant_rpm_{wreg,di} + share_rpm_{wreg,di} * \frac{per_capita_gdp_{wreg,Year}}{per_capita_gdp_{wreg,Base_Year}} \right) \right) \right]^{-1} \quad (167)
 \end{aligned}$$

where

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

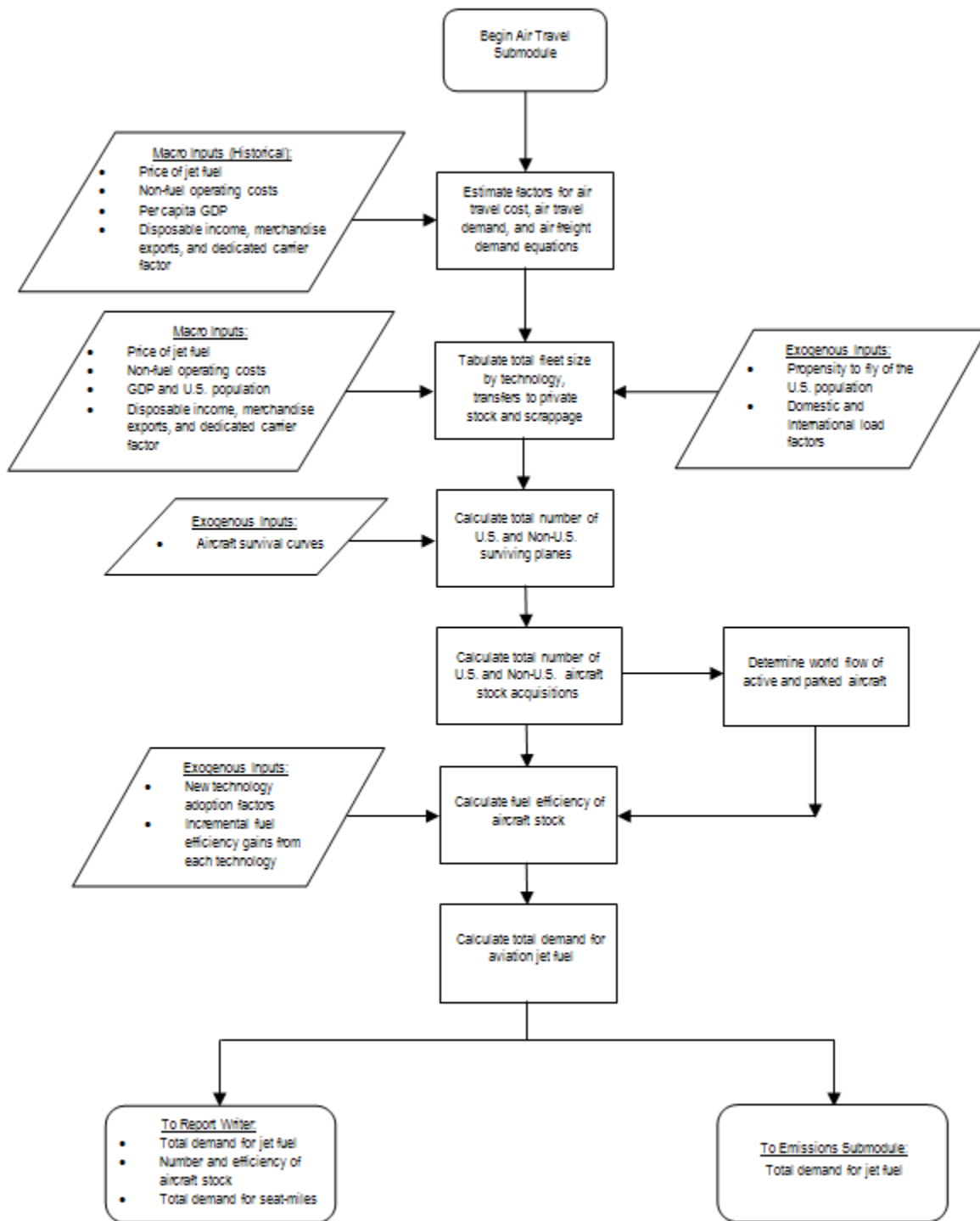
inc00\$np = U.S. per capita personal disposable income in chain-weighted 2005 dollars.

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

wreg = World region = 1 through 13.

Base_Year = First Year for the historic per capita GDP time series by region.

Figure 12. Air travel submodule



Note: The Emissions Submodule is currently inactive.

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

$$RPM_{wreg,di,Year} = RPMT_PC_{wreg,di,Year} * WLD_POP_{wreg,Year} \quad (168)$$

where

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

wld_pop = World regional population for the 13 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,¹³

$$RPM_{wreg,di,atyp,Year} = RPMT_{wreg,di,Year} * SHR_RPM_{wreg,di,atyp} \quad (169)$$

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:

$$RTM_{us,Year} = \alpha + (\beta_1 * PJFTR_{Year} * MC_JPGDP_{Year-1}) + (\beta_2 * MC_XGR_{Year})$$

and

$$RTM_{wreg,Year} = RTM_{wreg,Year-1} * \frac{WLD_GDP_{wreg,Year}}{WLD_GDP_{wreg,Year-1}} \quad (170)$$

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

where

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

$$SMDEMD_{wreg,Year} = \sum_{di=1}^2 \sum_{atyp=1}^3 ASM_{wreg,di,atyp,Year} \quad (171)$$

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 2040.

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.

$$STKPASS_SALES_{wreg=US,Year} = \alpha + \beta_1 * (MC_GDPR_{Year-1})$$

and (172)

$$STKPASS_SALES_{wreg,Year} = STKPASS_SALES_{wreg,Year-1} * \frac{WLD_GDP_{wreg,Year}}{WLD_GDP_{wreg,Year-1}}, wreg = 2, \dots, 13$$

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_GDPR = 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:

$$STK_PASS_{wreg,atyp,age=1,Year} = STKPASS_SALES_{wreg,Year} * SHR_NEW_STK_{wreg,atyp,Year} \quad (173)$$

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.¹⁴ 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:

$$STK_PASS_{wreg,atyp,age,Year} = STK_PASS_{wreg,atyp,age-1,Year-1} * SURVAC_{atyp,age} \quad (174)$$

where

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:

$$STK_CARGO_{wreg,atyp,age,Year} = STK_CARGO_{wreg,atyp,age-1,Year-1} * SURVAC_{wreg,atyp,age} \quad (175)$$

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

$$STK_CARGO_{wreg,atyp,age,Year} = STK_CARGO_{wreg,atyp,age-1,Year-1} + STK_PASS_{wreg,atyp,age,Year} * CARGO_PCT_{age} \quad (176)$$

¹⁴ Jet Inventory Services, *World Jet Inventory: Year-End 2009*, (March 2010).

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:

$$STK_PASS_{wreg,atyp,age,Year} = STK_PASS_{wreg,atyp,age,Year} * (1 - CARGO_PCT_{age}) \quad (177)$$

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

$$STK_SUP_TOT_{wreg,atyp,Year} = \sum_{age} STK_PASS_{wreg,atyp,age,Year} \quad (178)$$

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

$$STKPASS_DMD_{wreg,atyp,Year} = \frac{ASMDEMD_{wreg,atyp,Year}}{ASMAC_{wreg,atyp,Year}} \quad (179)$$

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

$$STKPASS_ACTIVE_{wreg,atyp,age,Year} = STK_PASS_{wreg,atyp,age,Year} - STKPASS_PARKED_{wreg,atyp,age,Year} \quad (180)$$

where

$STKPASS_ACTIVE$ = Active stock of passenger aircraft, for each of the 13 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:

$$STKPASS_ACTIVE_TOT_{wreg,atyp,Year} = \sum_{age} STKPASS_ACTIVE_{wreg,atyp,age,Year} \quad (181)$$

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:

$$DEL_STKPASS_{wreg,atyp,Year} = STKPASS_DMD_{wreg,atyp,Year} - STKPASS_ACTIVE_TOT_{wreg,atyp,Year} \quad (182)$$

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 are 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, $ifx = 1, 2, \dots, 9$. 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:

$$TIMEFX_{ifx, atyp, Year} = TIMEFX_{ifx, atyp, Year-1} + (TIMECONST_{atyp} * TPN_{ifx, atyp} * TYRN_{ifx, atyp}) \quad (183)$$

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:

$$COSTFX_{ifx, atyp, Year} = \left[\frac{TPJFGAL_{Year} - TRIGPRICE_{ifx, atyp}}{TPJFGAL_{Year}} \right] * TPN_{ifx, atyp} * TYRN_{ifx, atyp} * TPZ_{ifx, atyp} \quad (184)$$

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

$$TOTALFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year} + COSTFX_{ifx,atyp,Year} - BASECONST \quad (185)$$

where

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

For each technology, a technology penetration function is defined as

$$TECHPEN_{ifx,atyp,Year} = \left[1 + e^{-TOTALFX_{ifx,atyp,Year}} \right]^{-1} \quad (186)$$

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

$$FRACIMP_{atyp,Year} = 1.0 + \sum_{ifx=1}^9 EFFIMP_{ifx} * TECHPEN_{ifx,atyp,Year} \quad (187)$$

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

$$\begin{aligned}
 ASMPGD_{atyp,age=1,Year} &= ASMPGD_{atyp,age=1,Year=2008} * FRACIMP_{atyp,Year} \\
 &\text{and} \\
 ASMPGI_{atyp,age=1,Year} &= ASMPGI_{atyp,age=1,Year=2008} * FRACIMP_{atyp,Year}
 \end{aligned}
 \tag{188}$$

where

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

ASMPGI = International aircraft fuel efficiency in available seat-mpg.

Second, stock efficiency is assumed to remain unchanged over time and is defined as

$$\begin{aligned}
 ASMPGD_{atyp,age,Year} &= ASMPGD_{atyp,age-1,Year-1} \\
 &\text{and} \\
 ASMPGI_{atyp,age,Year} &= ASMPGI_{atyp,age-1,Year-1}
 \end{aligned}
 \tag{189}$$

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.

$$\begin{aligned}
 ASMPGT_{atyp,age,Year} &= \\
 &\left[\frac{ASM_DOM_{Year} + ASM_INT_{Year}}{(ASM_DOM_{Year} / ASMPGDT_{atyp,age,Year}) + (ASM_INT_{Year} / ASMPGIT_{atyp,age,Year})} \right]
 \end{aligned}
 \tag{190}$$

where

ASM_DOM = Available domestic seat 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:

$$SMD_TOT_{wreg,Year} = SMDEMD_{wreg,Year} + (RTM_{wreg,Year} * EQSM)
 \tag{191}$$

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

$$JFGAL_{wreg,Year} = \frac{SMDTOT_{wreg,Year}}{ASMPGT_{Year}} \quad (192)$$

The demand for aviation gasoline is calculated as

$$AGD_{Year} = BASEAGD + GAMMA * e^{-KAPPA*(Year-1979)} \quad (193)$$

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:

$$JFBTU_{Year} = JFGAL_{Year} * \frac{5.670MMBtu / bbl}{42 gal / bbl} \quad (194)$$

and

$$AGDBTU_{Year} = AGD_{Year} * \frac{5.048MMBtu / bbl}{42 gal / bbl}$$

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

$$QJETR_{REG,Year} = JFBTU_{Year} * SEDSHR_{JetFuel,REG,Year} \quad (195)$$

and

$$QAGTR_{REG,Year} = AGDBTU_{Year} * SEDSHR_{AvGas,REG,Year}$$

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. Census Bureau Commodity Flow Survey. 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.

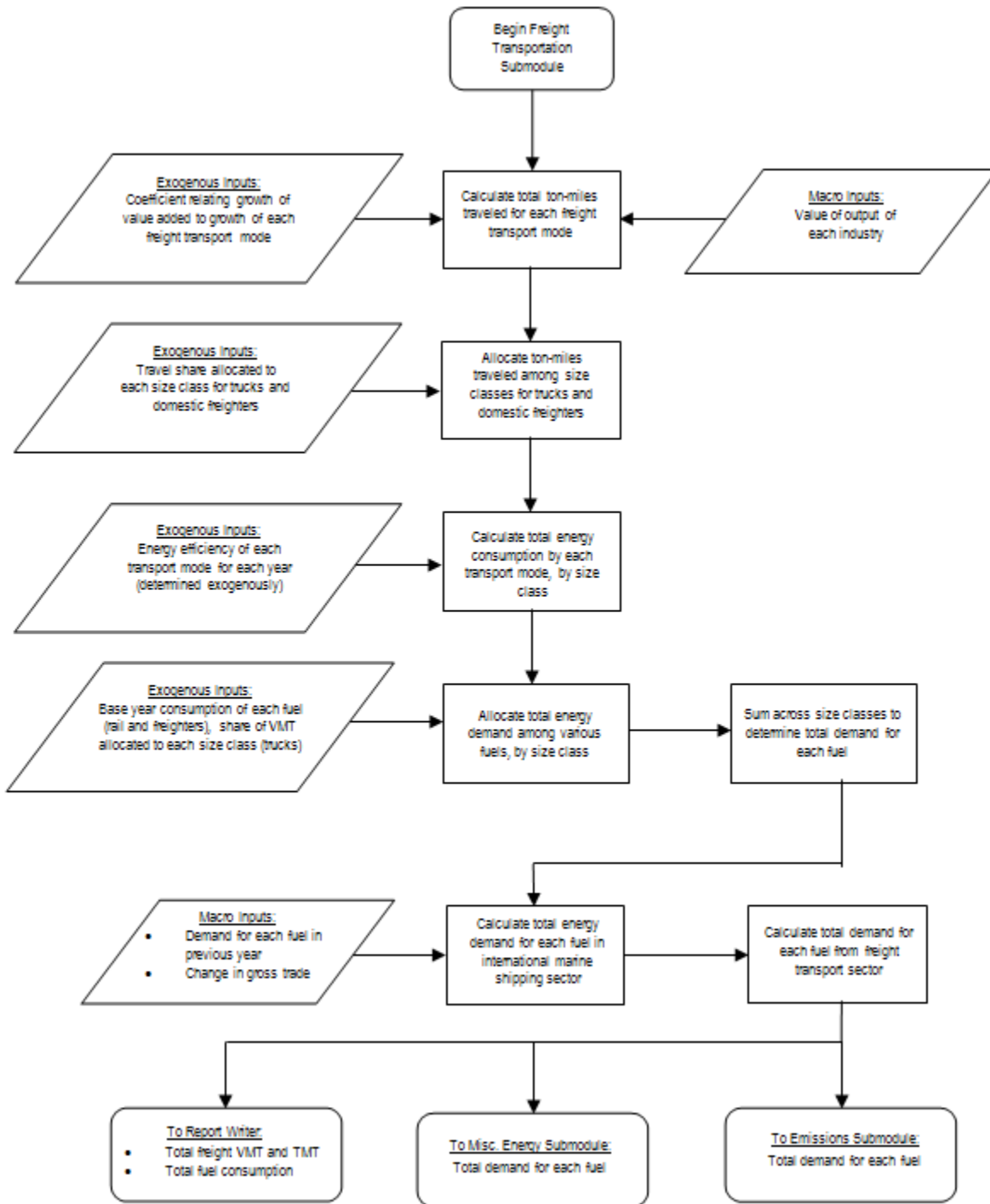
The truck sector of the Freight Transportation Submodule incorporates additional levels of detail. The trucking sector is divided according to market class with stock adjustments for each market class and fuel type.

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.

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 TDM.

Figure 13. Freight transportation submodule



Note: The Emissions Submodule is currently inactive.

The FTSAC projects the consumption of diesel fuel, motor gasoline, LPG, and CNG/LNG accounted for by freight trucks in each of 12 industrial sectors. Thirty-four truck vintages, three truck market classes, thirteen 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. The three truck market classes are defined as follows: 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.¹⁵ The thirteen fuel-efficiency market subclasses include two breakouts for medium-light size class, including pickup/van and vocational, one breakout for medium-heavy, including vocational, and ten breakouts for heavy. The ten subclasses for heavy include parceling the class by Class 7 or Class 8, day cab or sleeper cab, and low-, mid- or high-roof. These 13 fuel-efficiency market subclass categories are shown in Table 5. 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.

¹⁵ Class 3, 4 to 6, and 7 to 8 trucks are also referred to as medium-light, medium-heavy, and heavy trucks, respectively.

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

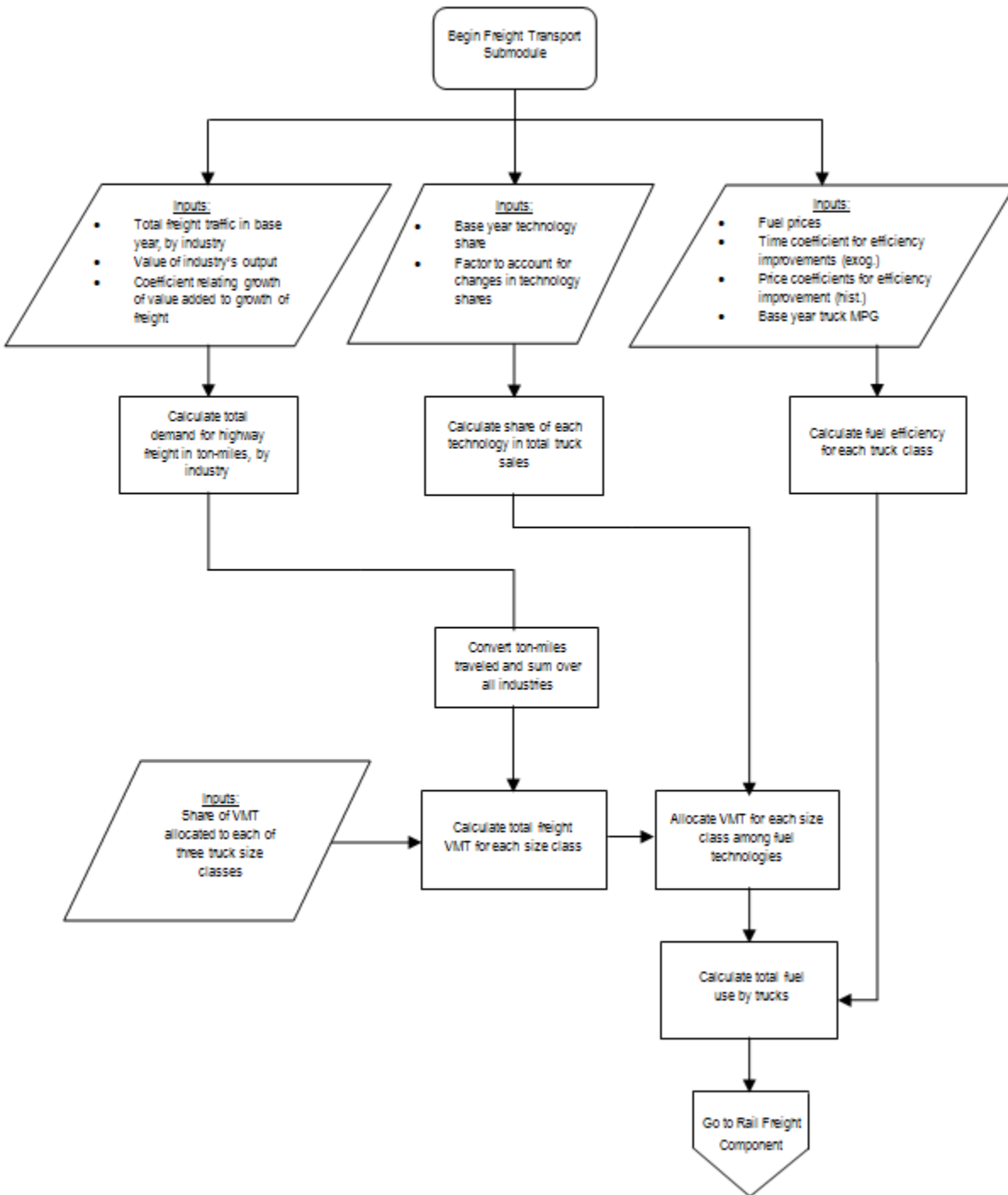
Vehicle Category	Market Class	Type	Roof ¹
1	3	Pickup and Van	-
2	3	Vocational	-
3	4-6	Vocational	-
4	7-8	Vocational	-
5	7	Tractor – day cab	Low
6	7	Tractor – day cab	Mid
7	7	Tractor – day cab	High
8	8	Tractor – day cab	Low
9	8	Tractor – day cab	Mid
10	8	Tractor – day cab	High
11	8	Tractor – sleeper cab	Low
12	8	Tractor – sleeper cab	Mid
13	8	Tractor – sleeper cab	High

¹Applies 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 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. Currently existing technologies gain market share via time-dependent exponential decay functions with exogenously determined maxima and minima, based on historical trends.

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,¹⁶ and include technologies such as advanced transmissions, lightweight materials, synthetic gear lube, advanced drag reduction, advanced tires, electronic engine controls, turbo-compounding, hybrid power trains, and port-injection. Future technologies can enter the market at various times 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 and CNG/LNG trucks.

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

$$TRIGGER_PRICE_{itech, icafe, ifuel} = \frac{TECHCOST_{icafe, itech}}{\sum_{IP=1}^{PAYBACK_{icafe, itech}} \frac{TEMP_BTU_{icafe, ifuel} * TECHEFF_{icafe, itech}}{(1 + *DISCRTXG)^{IP}}} \quad (196)$$

where

TRIGGER_PRICE = Fuel trigger price at which a technology, ITech, becomes economically viable.

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 = Average annual truck fuel usage.

TECHEFF = Incremental fuel economy improvement.

DISCRTXG = Discount rate.

IP = Index for payback periods.

itech = Freight truck technologies.

icafe = thirteen fuel-efficiency standard market classes.

ifuel = Index referring to fuel type, where *Frt_Fuel*=1 refers to diesel, *Frt_Fuel*=2 refers to gasoline, *Frt_Fuel*=3 refers to LPG and *Frt_Fuel*=4 refers to CNG/LNG.

¹⁶ 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.

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:

$$Avg_Fuel_ \$_{Year,ifuel} = \frac{PRICE_{Year,ifuel} + PRICE_{Year-1,ifuel} + PRICE_{Year-2,ifuel}}{3} \quad (197)$$

where

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

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

Technology market penetration depends on the level of fuel prices relative to the technology's cost-effective price. For each technology that has entered the market and for existing technologies, the effect of fuel prices on market penetration is determined for the current year by the equation:

$$PREFF_{Year,icafe,ifuel,itech} = 1 + TECHVAR_{SC,Frnt_Fuel,Frnt_Tech} * \left[\frac{Avg_Fuel_ \$_{Year,ifuel}}{TRIGGER_PRICE_{icafe,ifuel,itech}} - 1 \right] \quad (198)$$

where

PREFF = Effect of fuel price on market penetration rates for each freight technology.

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%.

SC = CAFE market/size class.

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:

$$P_{Year} = TECHBASESHR + (TECHMAX - TECHBASESHR) * \frac{1}{1 + e^{\frac{Year - TECHFYR - TECHMID}{TECHSHAPE}}} \quad (199)$$

where

P = Market penetration, by year.

TECHMAX = Maximum market penetration parameter; final market share of freight technology.

TECHBASESHR = Minimum market penetration parameter: market share of technology in 1992.

TECHMID = Parameter for existing technologies.

TECHSHAPE = Market penetration curve for existing technologies.

TECHFYR = First year technology is available.

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:

$$TECHSHR_{Year,icafe,ifuel,itech} = PREFF_{Year,icafe,ifuel,itech} * P_{Year} \quad (200)$$

where

TECHSHR = Market share of fuel-saving technology, Frt_Tech, for market class, SC, and fuel type, Frt_Fuel.

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:

$$TECHSHR_{Year,icafe,ifuel,itech} = TECHSHR_{Year-1,icafe,ifuel,itech} * PREFF_{Year,ifuel,itech} \quad (201)$$

Finally, if the technology is a fuel efficiency technology, the fuel price has not reached the trigger price, and the previous year's technology market share is zero, then the current year's market share is estimated assuming minimum penetration:

$$TECHSHR_{Year,icafe,ifuel,itech} = TECHBASESHR \quad (202)$$

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:

$$TECHSHR_{Year, icafe, ifuel, itech} = TECHSHR_{Year, icafe, ifuel, itech} * (1 - ADVSHR_{Year, icafe, ifuel, itech}) \quad (203)$$

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:

$$MPGEFF_{Year, icafe, ifuel} = \prod_{itech=1}^{37} (1 - TECHEFF_{icafe, ifuel, itech} * TECHSHR_{Year, icafe, ifuel, itech}) \quad (204)$$

where

MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in a given year and market class (SC).

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

$$NEW_MPG_{Year, icafe, AGE=1, ifuel} = \frac{BASEMPG_{icafe, ifuel}}{MPGEFF_{Year, icafe, ifuel}} \quad (205)$$

where

BASEMPG = 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 fuel type. Market share for freight trucks is divided among four fuel types: diesel, gasoline, LPG, and CNG/LNG.

Market penetration of alternative fuel freight trucks is more likely to be driven by legislative and/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) 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, and VMT group. 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:

$$ANN_ \$_ SAVINGS_ CNG_{ivmt,iflt,isc} = (VMT_ VEH_{ivmt,iflt,isc} * Avg_ Fuel_ \$_{fuel=1} / HDV_ MPG_{isc,fuel=1}) - (VMT_ VEH_{ivmt,iflt,isc} * Avg_ Fuel_ \$_{fuel=4} / HDV_ MPG_{isc,fuel=4}) \quad (206)$$

where

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

fuel = 1=diesel; 4=CNG/LNG.

isc = vehicle market size class.

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

$$NPV_ ADS_{Year} = NPV_ ADS_{Year-1} + \frac{ANN_ \$_ SAVINGS_ CNG_{ivmt,iflt,isc}}{(1 + DISCRTXG)^{Year}} \quad (207)$$

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:

$$BUY_ CNG_{Year,ivmt,iflt,isc} = VEH_ SHR_{ivmt,iflt,isc} * PBACK_ SHR_{Year} \quad (208)$$

where

PBACK_SHR = Distribution of payback periods by owner/operators.

Positive purchase decisions, BUY_CNG, by fleet, size class, and VMT group, occur if the incremental cost of CNG/LNG vehicles (\$17,000 for Class 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:

$$Fuel_Shr_{ift,isc,Year} = Fuel_Shr_{ift,isc,Year} + \sum_{ifuel=1}^4 BUY_CNG_{ivmt,ift,isc,Year} * MPATH_{ifuel,ift,isc,Year} \quad (209)$$

where

Fuel_Shr = Market share of CNG freight trucks.

BUY_CNG = Share of CNG vehicles bought by fleet and size class.

MPATH = Baseline market penetration for each fuel.

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

b) Final Market Share of LPG and CNG/LNG

The first step in this process is to calculate the fuel cost for new trucks of each market class and fuel type that is defined as:

$$FCOST_{Year,isc,ifuel} = \frac{Avg_Fuel_ \$_{Year,ifuel}}{HDV_MPG_{Year,isc,ifuel}} * HRATE \quad (210)$$

where

FCOST = Fuel cost of driving a truck of fuel type, Frt_Fuel, in \$ per mile.

HRATE = Heat rate of gasoline, in million Btu per gallon.

ifuel = 1 (diesel), 3 (LPG), 4 (CNG/LNG) = non-gasoline trucks.

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

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

$$DCOST_{Year,isc,ifuel} = 1 - PRAFDXG_{isc,ifuel} * \left[\frac{FCOST_{Year,isc,ifuel}}{FCOST_{Year,isc,ifuel=1}} - 1 \right] \quad (211)$$

where

DCOST = Fuel cost per mile of diesel relative to LPG and CNG/LNG.

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

ifuel = 3 (LPG), 4 (CNG/LNG).

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

$$SLOPE_{isc,ifuel,iflt} = \frac{\ln(0.01)}{0.5 * CYAFVXG_{isc,ifuel,iflt}} \quad \text{and} \quad (212)$$

$$MIDYR_{isc,ifuel,iflt} = TRGSHXG_{isc,ifuel,iflt} + (0.5 * CYAFVXG_{isc,ifuel,iflt})$$

where

iflt = Index referring to fleet type, where *FLT* = 1 refers to non-fleet trucks and *FLT* = 2 refers to fleet trucks.

SLOPE = Logistic market penetration curve parameter.

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

MIDYR = Logistic market penetration curve parameter representing “halfway point” to maximum market penetration.

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

ifuel = 3, 4.

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

$$MPATH_{Year,isc,ifuel,iflt} = X * Y \quad (213)$$

where

$$X = DCOST_{Year,isc,ifuel}$$

$$Y = \left[BFSHXG_{isc,ifuel,iflt} + \frac{EFSHXG_{isc,ifuel,iflt} - BFSHXG_{isc,ifuel,iflt}}{1 + e^{SLOPE_{isc,ifuel,iflt} * (Year - MIDYR_{isc,ifuel,iflt})}} \right]$$

BFSHXG = Base year (2010) market share of each fuel type.

EFSHXG = Maximum market share of each fuel type.

ifuel = 3, 4.

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:

$$Fuel_Shr_{Year,isc,ifuel,iflt} = \max \left[BFSHXG_{isc,ifuel,iflt}, MPATH_{Year,isc,ifuel,iflt} \right] \quad (214)$$

where

BFSHXG = Base year (2010) share of alternative fuels in truck purchases.

ifuel = 3, 4.

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

$$MPATH_{Year,isc,ifuel=1,iflt} = BFSHXG_{isc,ifuel=1,iflt} + \left[EFSHXG_{isc,ifuel=1,iflt} - BFSHXG_{isc,ifuel=1,iflt} \right] * \left[1 - e^{CSTDVG_{isc,iflt} + CSTDVG_{isc,iflt} * Year} \right] \quad (215)$$

where

CSTDVG, CSTDVG = 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, $ifuel=2$:

$$Fuel_Shr_{Year,isc,ifuel=1,iflt} = \min \left[1, \left(1 - \sum_{ifuel=3}^4 Fuel_Shr_{Year,isc,ifuel,iflt} \right) * MPATH_{Year,isc,ifuel=1,iflt} \right] \quad (216)$$

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

$$Fuel_Shr_{Year,isc,ifuel=2,iflt} = 1 - \sum_{ifuel=1,3,4} Fuel_Shr_{Year,isc,ifuel,iflt} \quad (217)$$

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:

$$TRKSTK_{Year,isc,AGE,ifuel,iflt} = TRKSTK_{Year-1,isc,AGE-1,ifuel,iflt} * (1 - SCRAP_{isc,AGE-1}) \quad (218)$$

where

TRKSTK = Existing stock of trucks.

SCRAP = Factor representing the proportion of trucks of each vintage that are scrapped each year.

AGE = 2, 3, 4; AGE = 1 refers to new truck sales.

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

$$TRF_{Year,isc,AGE,ifuel} = TFFXGRT_{isc,AGE} * TRKSTK_{Year,isc,AGE,ifuel,iflt=2} \quad (219)$$

where

TRF = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks.

TFFXGRT = 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:

$$TRKSTK_{Year,isc,AGE,ifuel,iflt=2} = TRKSTK_{Year,isc,AGE,ifuel,iflt=2} - TRF_{Year,isc,AGE,ifuel}$$

and (220)

$$TRKSTK_{Year,isc,AGE,ifuel,iflt=1} = TRKSTK_{Year,isc,AGE,ifuel,iflt=1} - TRF_{Year,isc,AGE,ifuel}$$

4. Calculate Purchases of New Trucks

New truck purchases are based on class 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:

$$NEWTRUCKS_{isc=1} = MC_VEHICLES_{5,Year} * 1000$$

$$NEWTRUCKS_{isc=2} = NEWCLS46_{Year} * MC_SUVTHAM_{Year} \quad (221)$$

$$NEWTRUCKS_{isc=3} = (1 - NEWCLS46_{Year}) * MCSUVTHAM_{Year}$$

where

MC_SUVTHAM = Total new truck sales for classes 4-8, from the Macroeconomic Activity Module.

NEWCLS46 = Truck classes 4 to 6 share of total truck sales.

MC_VEHICLES_{3,Year} = Sales of class 3 trucks from the Macroeconomic Activity Module (thousands).

isc = 1 refers to class 3; 2 refers to class 4 through 6; 3 refers to class 7 through 8.

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

$$TRKSTK_{Year,isc,AGE=1,ifuel} = NEWTRUCKS_{isc} * FLEETSHR_{Year,isc,ifuel,iflt} \quad (222)$$

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:

$$TVMT_{Year,SEC,REG} = TVMT_{Year-1,SEC,REG} * \frac{TTONMI_{Year,SEC,REG}}{TTONMI_{Year-1,SEC,REG}} \quad (223)$$

where

TVMT = Freight truck vehicle-miles traveled, by industrial sector and Census Division.

TTONMI = Freight truck ton-miles by industrial sector and Census Division.

The model then calculates the adjustment VMT per truck:

$$VMTADJR_{Year} = \frac{\sum_{SEC=1}^{10} VMTDMDR_{Year-1,SEC}}{\sum_{isc,AGE,ifuel,iflt} ANNVM T_{isc,AGE,ifuel} * TRKSTK_{Year,isc,AGE,ifuel,iflt}} \quad (224)$$

where

VMTDMDR = Annual sectoral VMT based on base year FHWA estimates of VMT.

ANNVMT = Base year VMT per truck by freight market classes.

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

$$VMTFLTR_{Year,isc,AGE,ifuel,iflt} = ANNVM T_{isc,AGE,ifuel} * VMTADJR_{Year} * TRKSTK_{Year,isc,AGE,ifuel,iflt} \quad (225)$$

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

$$FUELDMDR_{Year,isc,ifuel,iflt} = \sum_{AGE=1}^{34} \frac{VMTFLTR_{Year,isc,AGE,ifuel,iflt}}{HDV_MPG_{Year,isc,AGE,ifuel}} \quad (226)$$

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:

$$FUELBTUR_{Year,isc,ifuel,ift} = FUELDMDR_{Year,isc,ifuel,ift} * HRATE * 10^{-12} \quad (227)$$

where

FUELBTUR = Total fleet truck fuel consumption by market class and fuel type, 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, calculate ton-miles traveled (TMT) for coal across two coal regions, Coal_Reg, as follows:

$$COAL_TMT_{Year} = \sum_{Coal_Reg=1}^2 TRTMRRC_{Coal_Reg,Year} \quad (228)$$

where

COAL_TMT = Ton-miles traveled for coal in a given year.

TRTMRRC = Billion ton-miles by railroad for coal by coal region, from the Coal Market Module.

Coal_Reg = Region 1=east; Region 2=west.

Then, project the growth of coal rail freight ton-miles by Census Division:

$$RPROJ_CTONMI_{Year,REG} = RPROJ_CTONMI_{Year-1,REG} * \left(1 + \left[\frac{COALTMT_{Year} - COALTMT_{Year-1}}{COALTMT_{Year-1}}\right]\right) \quad (229)$$

Next, project the growth of non-coal rail freight ton-miles by Census Division and industrial sector:

$$RPROJ_NCTONMI_{Year,REG,ISIC} = TSIC_{REG,ISIC} * RTM_OUTPUT_{REG,ISIC} \quad (230)$$

where

$RPROJ_TONMI$ = Ton-miles traveled for non-coal in a given year.

RTM_OUTPUT = Ton-miles traveled per dollar of industrial output, $ISIC=1,10$.

$TSIC$ = Value of output of industry $ISIC$, in base year dollars.

Calculate aggregated rail ton-miles traveled, $RTMTT$, as follows:

$$RTMTT_{Year} = \sum_{REG=1}^9 \sum_{ISIC=1}^{10} RPROJ_NCTONMI_{Year,REG,ISIC} + \sum_{REG=1}^9 RPROJ_CTONMI_{Year,REG} \quad (231)$$

Energy consumption is then estimated using the projected rail energy efficiency as follows:

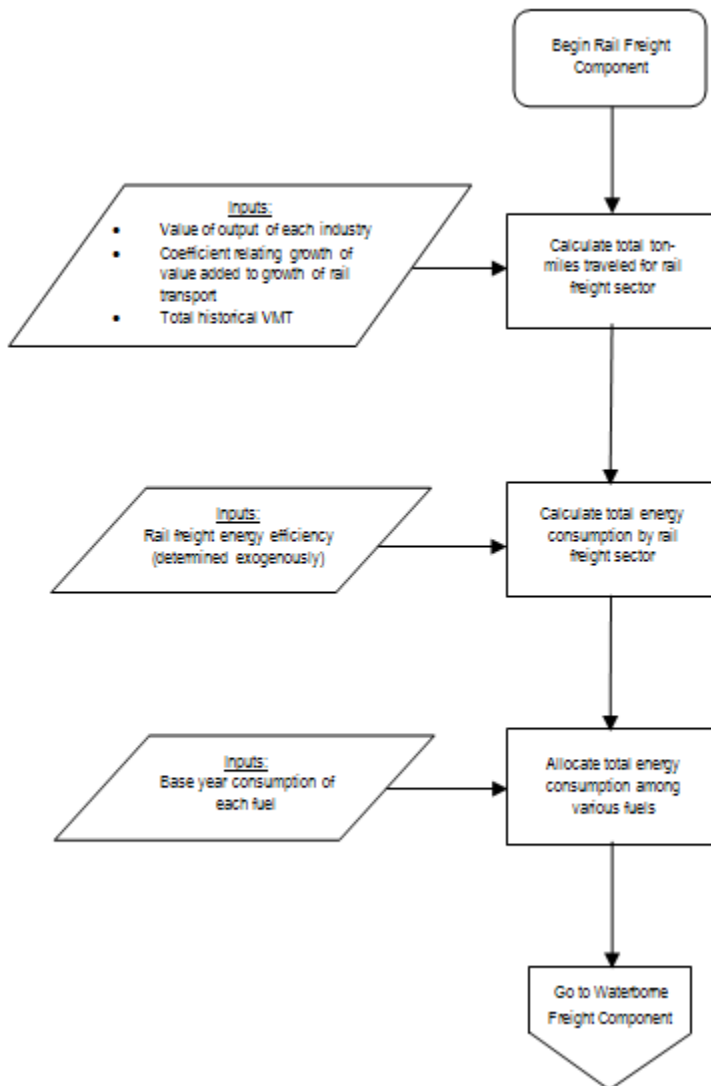
$$TQFRAILT_{Year,REG} = FREFF_{Year} * RTMTT_{Year,REG} \quad (232)$$

where

$TQFRAILT$ = Total energy consumption by freight trains.

$FREFF$ = 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:

$$NPV_LNG_{Year} = \frac{ANN_FUEL_SAVINGS_{PAYBK=1}}{1 + DISCRT} + \frac{ANN_FUEL_SAVINGS_{PAYBK}}{1 + DISCRT^{PAYBK}} \quad (233)$$

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:

$$TQRAILR_{Rail_Fuel,REG,Year} = TQFRAILT_{REG,Year} * RAIL_FUEL_SHR_{Rail_Fuel,Year} \quad (234)$$

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:

$$STMTT_{REG,Year} = \sum_{ISIC=1}^{10} \left[TSIC_{REG,ISIC,Year} * DSTM_OUTPUT_{REG,ISIC} * (1 + ANN_DECLINE_{Year}) \right] \quad (235)$$

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.

Energy use is subsequently estimated, using average energy efficiency:

$$TQDSHIPT_{REG,Year} = DSEFF_{Year} * STMTT_{REG,Year} \quad (236)$$

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:

$$TQDSHIPR_{Ship_Fuel,REG,Year} = TQDSHIPT_{REG,Year} * DOMSHIP_FUEL_SHR_{Ship_Fuel,Year} \quad (237)$$

where

SFD = Total regional domestic ship energy demand, by fuel and Census Division.

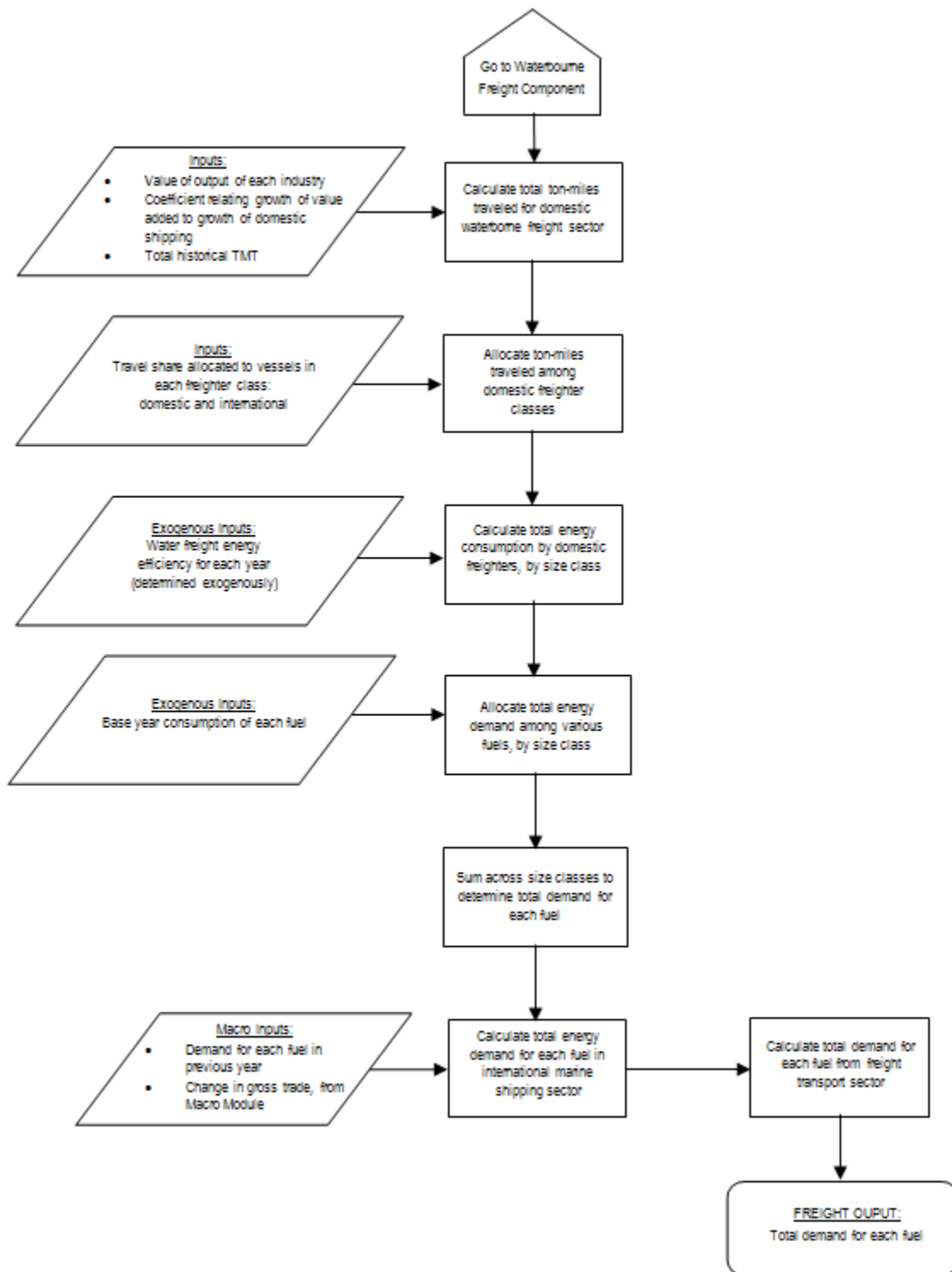
DOMSHIP_FUEL_SHR = Domestic shipping fuel share.

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 data¹⁷ 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.

¹⁷ Oak Ridge National Laboratory, *Transportation Energy Data Book Edition 28*, June 2009.

Figure 16. Waterborne freight component



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:

$$ISFDT_{Year} = ISFDT_{Year-1} + 0.5 * ISFDT_{Year-1} * INTS_B * \left[\frac{GROSST_{Year}}{GROSST_{Year-1}} - 1 \right] \quad (238)$$

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.

Total energy demand is then allocated among the four fuels by the following:

$$ISFD_{Ship_Fuel,Year} = ISFDT_{Year} * INTSHIP_FUEL_SHR_{Ship_Fuel,Year} \quad (239)$$

where

ISFD = International freighter energy demand, by fuel.

INTSHIP_FUEL_SHR = International shipping fuel share.

Regional fuel consumption is then calculated as:

$$TQISHIPR_{Ship_Fuel,REG,Year} = ISFD_{Ship_Fuel,Year} * SEDSHRXX_{Ship_Fuel,REG,Year} \quad (240)$$

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).

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:

$$MILTARGR_{Year} = \frac{MC_GFMLR_{Year}}{MC_GFMLR_{Year-1}} \quad (241)$$

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

$$MFD_{Mil_Fuel,Year} = MFD_{Mil_Fuel,Year-1} * MILTARGR_{Year} \quad (242)$$

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:

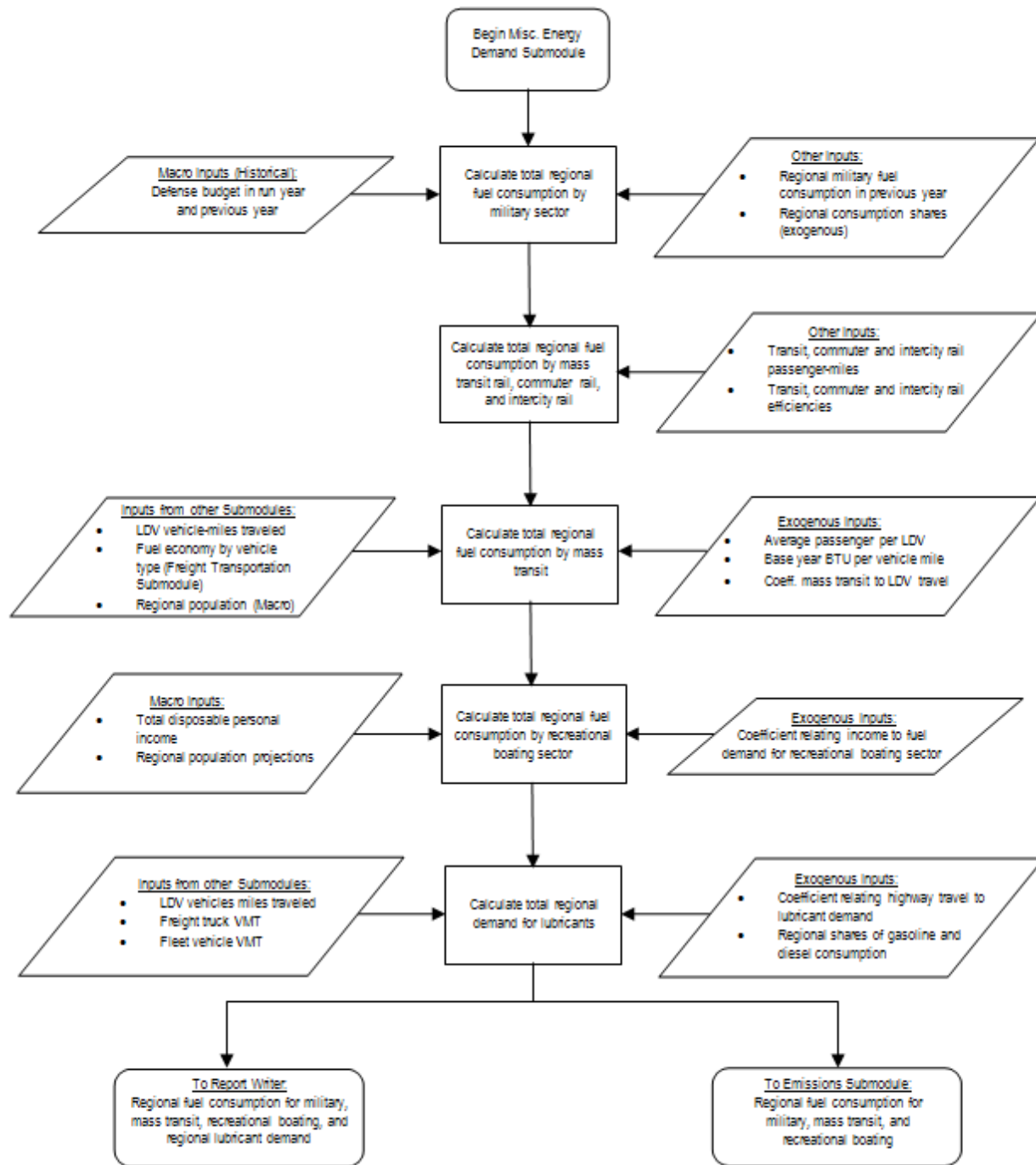
$$QMILTR_{Mil_Fuel,REG,Year} = MFD_{Mil_Fuel,Year} * MILTRSHR_{Mil_Fuel,REG,Year} \quad (243)$$

where

QMILTR = Regional fuel consumption, by fuel type, in Btu.

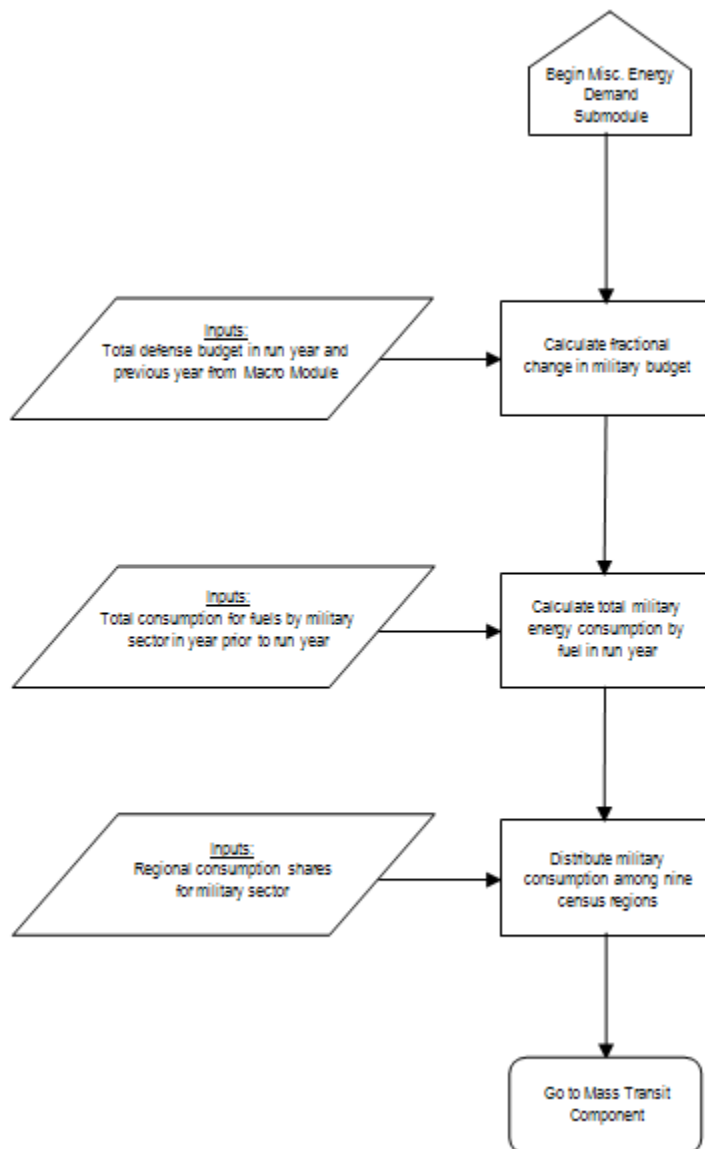
MILTRSHR = Regional consumption shares, from 1991 data, held constant.

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:

$$QMTRR_{\text{fuel,Region,Year}} = TRED_{\text{Region,Year}} + CREDE_{\text{Region,Year}} + IREDER_{\text{Region,Year}} \quad (244)$$

where

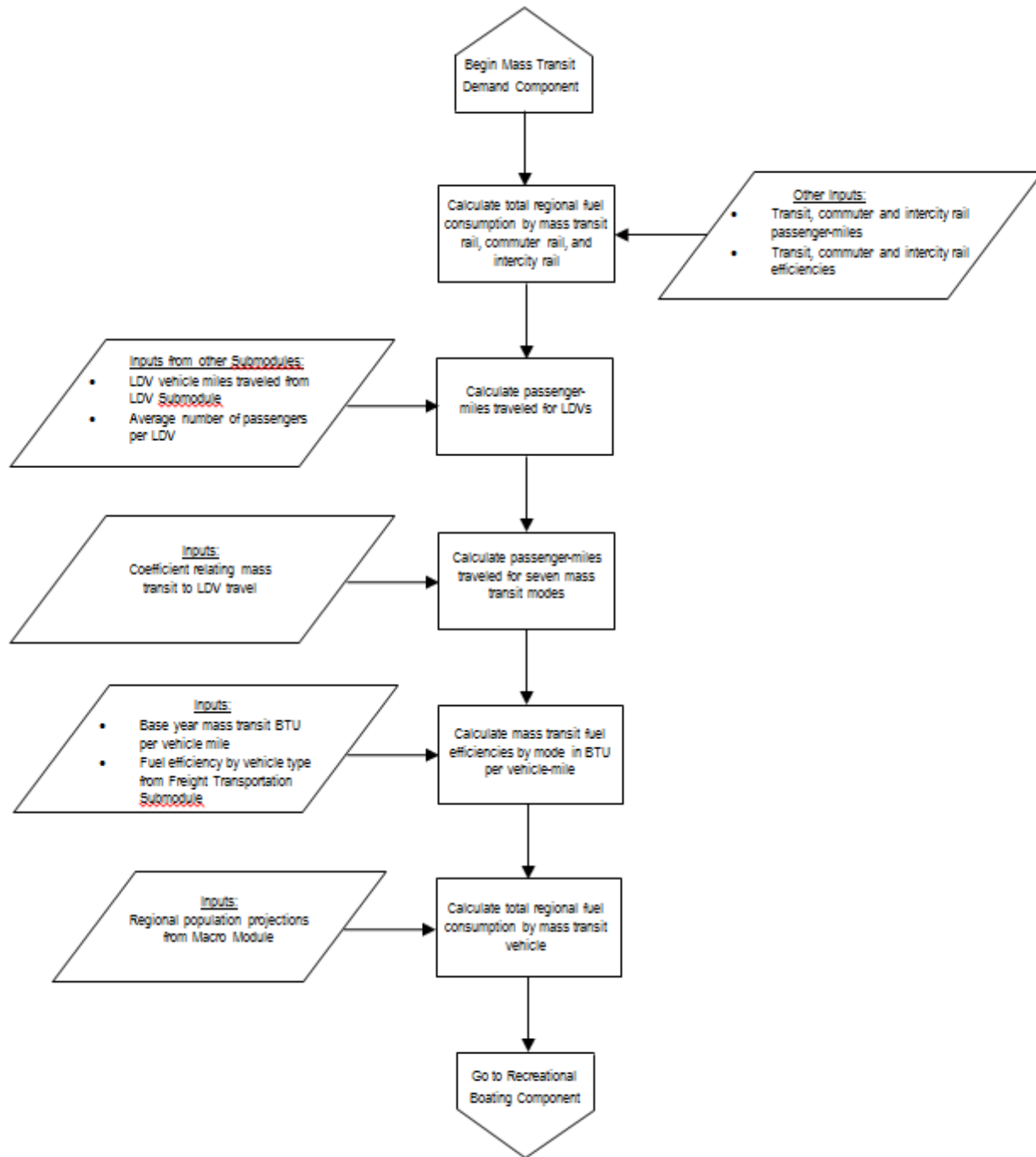
QMTRR = Passenger rail energy demand by fuel by region

TRED = Transit rail energy demand by Census Division

CREDE = Commuter rail energy demand by Census Division

IREDER = Intercity rail energy demand by Census Division

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:

$$TBPMT_{REG,Year} = TBPMTPC_{REG,Year} * MC_NP_{REG,Year} \quad (245)$$

where

TBPMT = Passenger-miles traveled for the transit bus mode.

TBPMTPC = Passenger-miles traveled per capita for the transit bus mode.

MC_NP = U.S. population from the Macroeconomic Activity Module.

IM = Index of transportation mode: 1 = Transit bus.

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:

$$\begin{aligned} TBBTUPM_{REG,Year} = & TBBTUPM_{REG,Year-1} * TBSYSEF_{REG} \\ & * 1 - \left(\left(1 - \left(\frac{TRFTMPG_{Year-1}}{TRFTMPG_{Year}} \right) * TBFSHR_{REG, Fuel=diesel, Year} \right) \right) \\ & * 1 + \left((TBFSHR_{REG, Fuel=CNG, Year} - TBFSHR_{REG, Fuel=CNG, Year-1}) * 0.25 \right) \end{aligned} \quad (246)$$

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:

$$QMTBR_{IM=1, Fuel, REG, Year} = TBPMT_{REG, Year} * TBBTUPM_{REG, Year} * TBFSHR_{REG, Fuel, Year} \quad (247)$$

where

QMTBR = Regional consumption of fuel, by mode.

The following equations describe the bus segment of the model for intercity and school buses:

$$TMOD_{IM,Year} = TMPASMIL_{IM} * MC_NP_{Year} \quad (248)$$

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.

IM = Index of transportation mode: 2 = Intercity Bus, 3 = 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:

$$\begin{aligned} TMEFF_{IM,Year} = & TMEFF_{IM,Year-1} * BUSSYSEF_{IM} \\ & * 1 - \left(\left(1 - \left(\frac{TRFTMPG_{Year-1}}{TRFTMPG_{Year}} \right) * QMODFSHR_{IM,2,Year} \right) \right) \\ & * 1 + \left(\left(QMODFSHR_{IM,3,Year} - QMODFSHR_{IM,3,Year-1} \right) * 0.25 \right) \end{aligned} \quad (249)$$

where

TMEFF = Btu per passenger-mile, by mass transit mode.

TRFTMPG = Freight MPG, by vehicle type, from the Freight Transportation Module.

BUSSYSEF = Bus system efficiency by mode, in Btu per passenger.

Total fuel consumption is calculated and distributed among regions according to their population shares:

$$\begin{aligned} QMTBR_{IM,Fuel,REG,Year} = & TMOD_{IM,Year} * TMEFF_{IM,Year} \\ & * \frac{MC_NP_{REG,Year}}{\sum_{REG=1}^9 MC_NP_{REG,Year}} * QMODFSHR_{IM,Fuel,Year} \end{aligned} \quad (250)$$

where

QMTBR = Regional consumption of fuel, by mode.

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:

$$RBEDPC_{Fuel,Year} = X1_{Fuel} + X2_{Fuel} * LOG(INC00\$NPT_{Year}) + X3_{Fuel} * PRICE04_{Fuel} \quad (251)$$

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:

$$RECFD_{Fuel,Year} = RBEDPC_{Fuel,Year-1} * \sum_{REG=1}^9 MC_{-} NP_{REG,Year} \quad (252)$$

where

RECFD = National recreational fuel consumption in year, Year, Fuel (where 1=Gasoline and 2 = Diesel).

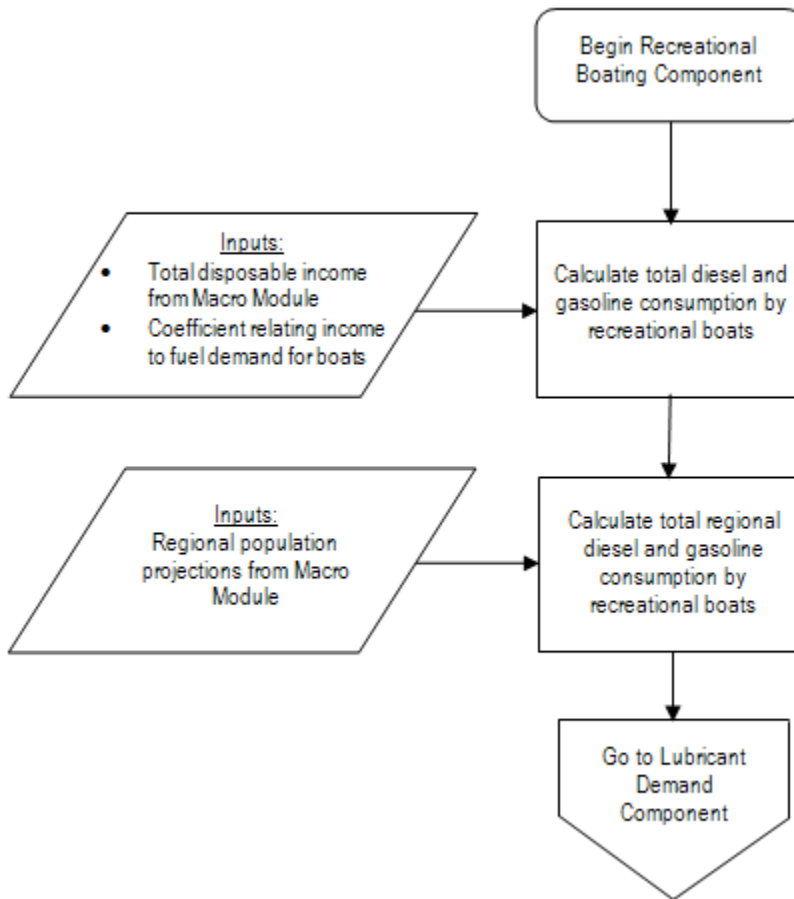
Following this, the regional consumption is calculated according to population, as for mass transit:

$$QRECR_{Fuel,REG,Year} = RECFD_{Fuel,Year} * \frac{MC_{-} NP_{REG,Year}}{\sum_{REG=1}^9 MC_{-} NP_{REG,Year}} \quad (253)$$

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:

$$HYWAY_{Year} = VMTEE_{Year} + FTVMT_{Year} + FLTVMT_{Year} \quad (254)$$

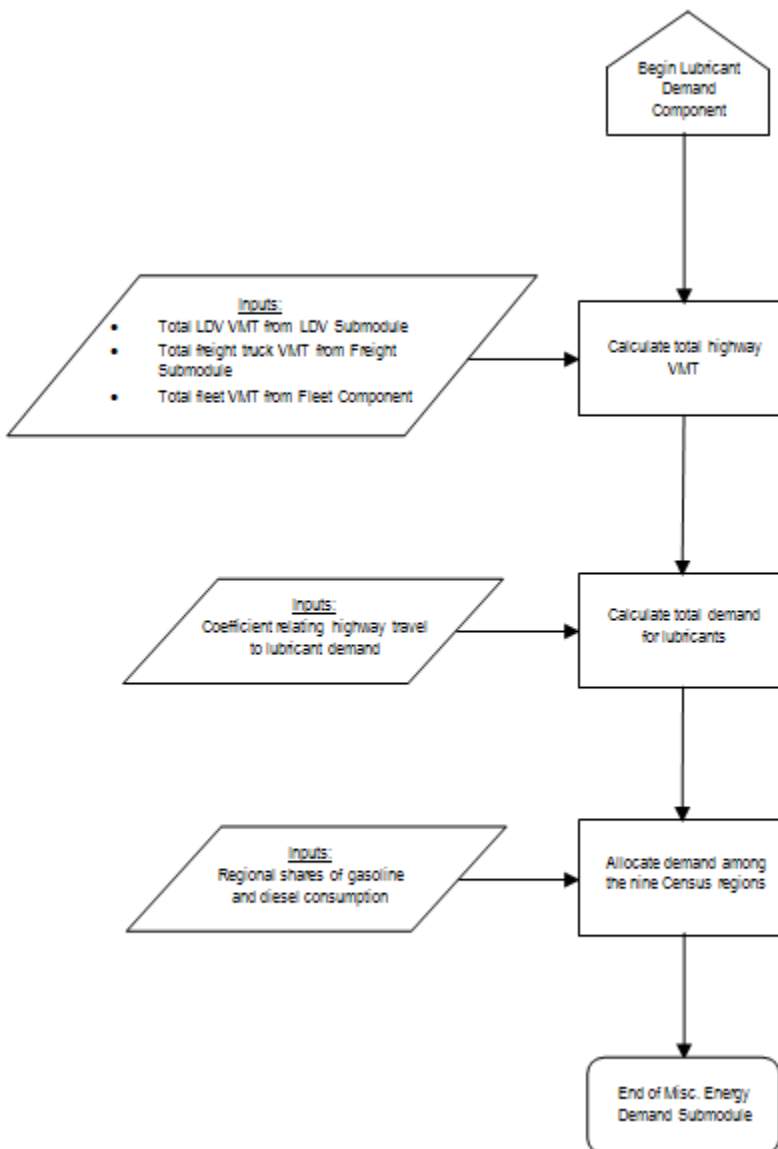
where

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:

$$LUBFD_{Year} = LUBFD_{Year-1} * \left[\frac{HYWAY_{Year}}{HYWAY_{Year-1}} \right]^{BETALUB} \quad (255)$$

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:

$$QLUBR_{REG,Year} = LUBFD_{Year} * \left[\frac{(VMTEE_{Year} + FLTVMT_{Year}) * SHRMG_{REG,Year} + FTVMT_{Year} * SHRDS_{Year}}{HYWAY_{Year}} \right] \quad (256)$$

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 Demand Module

Model Acronym

TDM

Description

The Transportation Demand Module (TDM) is part of the National Energy Modeling System (NEMS) and incorporates an integrated modular design that is based upon economic, engineering, and demographic relationships that model transportation sector energy consumption at the 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 TDM 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 NEMS, the TDM generates projections (through 2040) of transportation sector energy consumption. The TDM 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 2013 Model Interfaces

Receives inputs from the Electricity Market Module, Liquid Fuels Market Module, Natural Gas Transmission and Distribution Module, and the Macroeconomic Activity Module.

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 2040.
- Products: motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG/LNG, methanol, ethanol, hydrogen, lubricants, pipeline fuel, and natural gas.
- Economic Sectors: projections are produced for personal and commercial travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Independent Expert Reviews Conducted

Independent Expert Review of Transportation Sector Component Design Report, June, 1992, conducted by David L. Greene, Oak Ridge National Laboratory.

Report of Findings on the NEMS Freight Transport Model, April 3, 2001, by David L. Greene, Oak Ridge National Laboratory.

Report of Findings, NEMS Freight Transport Model Review, April 4, 2001, by Mike Lawrence, Laurence O'Rourke, Jack Faucett Associates.

Independent Evaluation of EIA's Freight Transportation Model, Draft Report, April 11, 2001, by James S. Moore, Jr. P.E. TA Engineering, Inc.

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- State Energy Data 2011 (SEDS), Jun. 2013, www.eia.gov/states/seds .
- Short-Term Energy Outlook, Sep. 2013, 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 2009, May, 2010.
- Federal Highway Administration, <http://www.fhwa.dot.gov/policyinformation/statistics/2012>.
- National Highway Traffic Safety Administration, Final Model Year Fuel Economy Report, 2009.
- Oak Ridge National Laboratory, Transportation Energy Data Book Ed. 31, ORNL-6987, July 2012.
- Department of Commerce, Bureau of the Census, Vehicle Inventory and Use Survey 2002, December 2004.
- U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2011, <http://www.epa.gov/otaq/cert/mpg/fetrends/2012/420r12001.pdf>.
- 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>.

Appendix B. Acronyms

Acronym	Definition
ATV	Advanced Technology Vehicle
AFV	Alternative Fuel Vehicle
AFVADJ	Alternative Fuel Vehicle Adjustment Subroutine
ASM	Available Seat-Miles
AEO2012	Annual Energy Outlook 2012
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 TDM 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 and READHIST.

SUBROUTINE: TRAN

Description: The NEMS TDM 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 TDM 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: READWK1

Description: Reads the spreadsheet input file TRNLDV.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. 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 ZEVs and ULEVs. The vehicle group-average technology penetration rate (%) and cost are calculated and summed across domestic and imports to produce market penetration rate (%) and average cost tables, but only for gasoline vehicles. It then calculates regional vehicle sales, by technology, within six market classes. This subroutine then calculates mandated sales of ZEVs by participating states including Massachusetts, Maine, Vermont, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Arizona, New Mexico, Oregon, California, and Washington. It then calculates ZEV legislative alternative sales by region. Additional ATV shares based on maximum allowable ZEV hybrid credits are also calculated including hybrid vehicles, fuel cell gasoline, and fuel cell methanol vehicles. After estimating the total adjusted vehicle sales, calculations are made for new absolute market shares for each vehicle technology.

Called by: TLDV

Calls: None

Equations: 1-163

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 AFV 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 3-8. 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 afstock.wk1, including variables such as fleet stocks by fuel and vintage, 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: 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. This subroutine calculates fuel consumption by Class 2b vehicles (8,500 to 10,000 lbs GVWR). It distributes historical stock values across vintages and updates stocks to reflect scrappage and new sales and calculate total Class 2b stocks, vehicle-miles traveled, and growth in travel (which is estimated as the weighted average growth of industry sector output for 1) agriculture, 2) mining, 3) construction, 4) manufacturing, 5) utilities, and 6) personal travel). It then calculates aggregate sales-weighted new commercial light truck MPG and VMT-weighted commercial light truck stock average MPG.

Called by: 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: 228-233

SUBROUTINE: TSHIP

Description: This subroutine calculates energy use for shipping. It calculates the international shipping fuel use split by the two fuel types: distillate and residual. It calculates ton-miles traveled for domestic shipping and the fractional change in fuel efficiency.

Called by: TRAN

Calls: None

Equations: 234-240

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

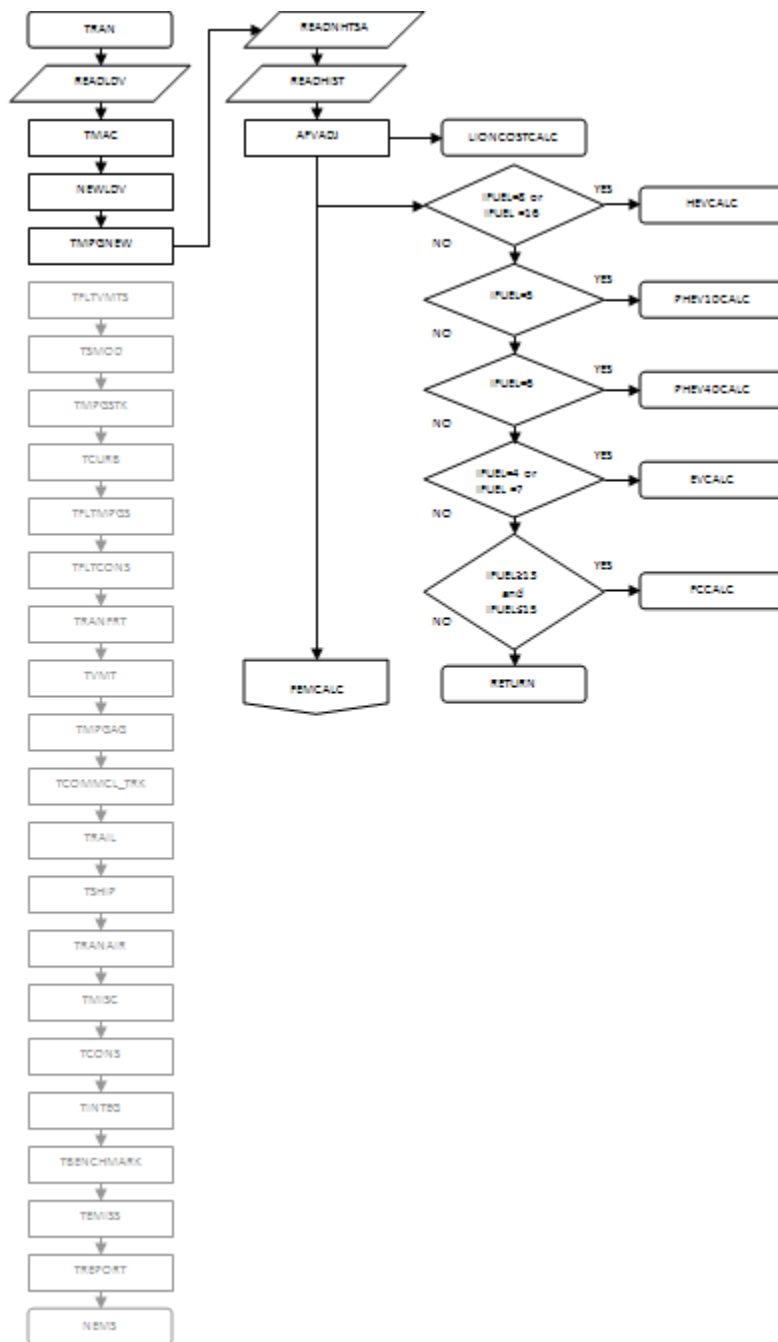
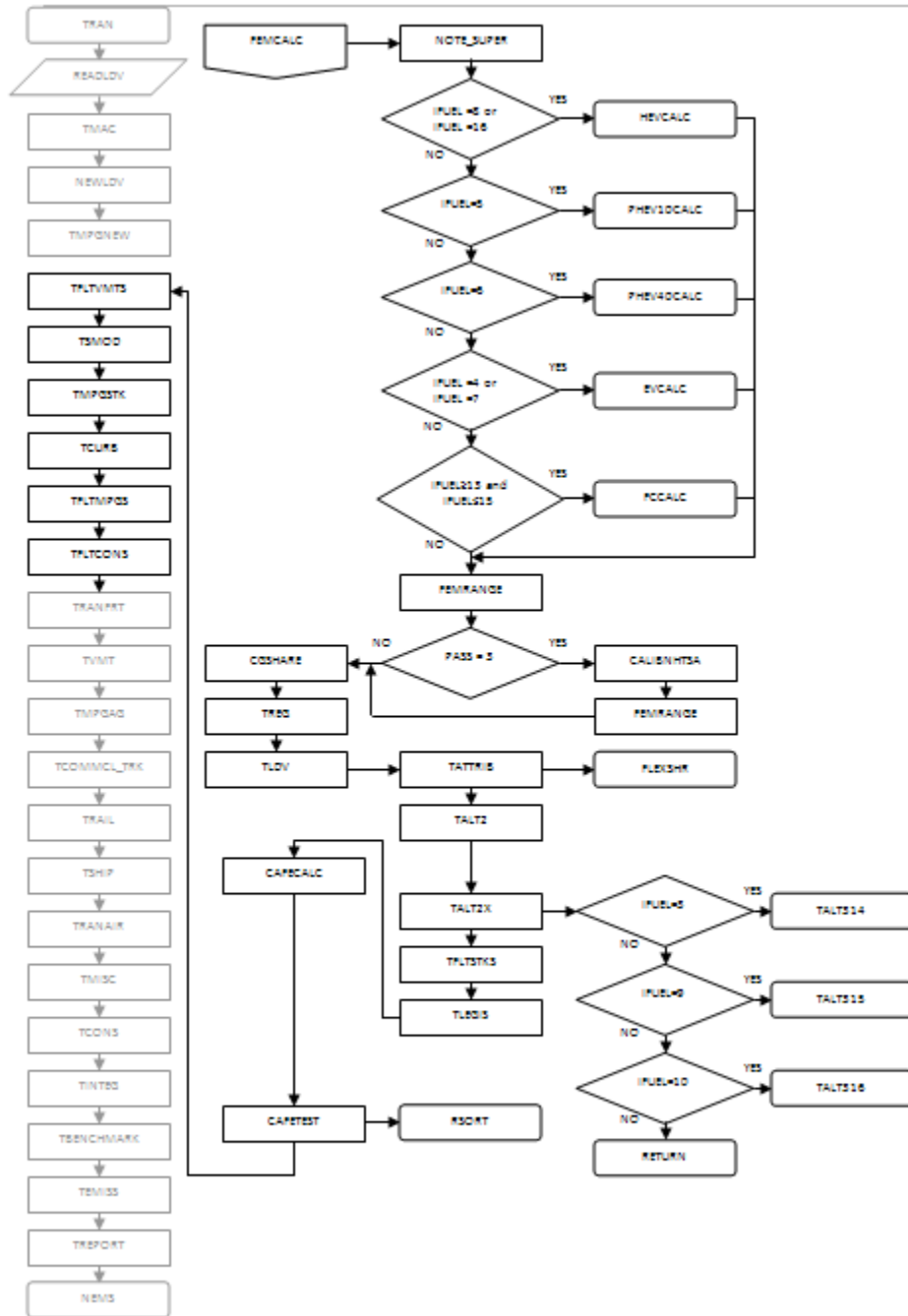


Figure 22. Flowchart of calls made by TRAN subroutine (cont.)



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
NEWCARS	New car sales
NEWCLS12A	New light truck sales, class 1-2a
NEWCLS2B	New Class 2b vehicles
TMC_CPI	Consumer price index-
TMC_EX	Real exports
TMC_IM	Real imports
TMC_PGDP	GDP deflator
Global definitions	
ACCL	Vehicle acceleration - 0 to 60 mph
ACTUAL_MKT	Technology market share = MKT_PEN
ADJFE	Fuel economy adjustment associated with performance adjustment
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
AFVFE	
AFVFETOT	
AHPCAR	Average car horsepower
AHPTRUCK	Average light truck horsepower
AltCafe	Logic switch for CAFE used for light trucks
ALTRUEMPG	
APPLYPHEV	Enables PHEV learning EIEA08 and stimulus
APSHR11	
APSHR22	
APSHR44	
APSHR55	
ATPZEV	Total (%) mandated gas hybrid and methanol/gas fuel cell vehicles
AVCOST	Technology cost aggregated over class
AVSALES	
AVSALEST	
AWTCAR	Average car weight
AWTTRUCK	Average light truck weight
BASE	FEM attribute index value for the base year

VARIABLE NAME	VARIABLE DESCRIPTION
BASMDEMD	
Batt_Credit	Total battery credit
BATTERY	Weighted average battery cost
BETAFA2	ATV NMLM level 2, fuel availability 1
BETAFA22	ATV NMLM level 2, fuel availability 2
BRCOST25	Battery replacement cost - currently set to zero
BYR	Base year for TRAN
CAFE_STAND	CAFE standards
Cafe_Used	
CafeBank	
CafeBankA	
CafeNeed	
CAFEPASS	Indicates manufacturer has passed CAFE standard
CafeWork	
CARFLG	Alternate Technology Vehicles introduction year for car classes
CarSales	
CarSales2	
CCMPGLDV	
CDFRFG	
CFCoefA, CFCoefB, CFCoefC, CFCoefD	Car coefs
CFE	MPG used to calculate effectiveness = FE(ICL,IGP,PREV,IFUEL)
CLASS_SHARE	Vehicle class market shares (within vehicle groups)
CLASSBASEYR	Vehicle class first year of sales
CLASSFLAG	Vehicle class applicability flag
CLASSLABEL	Vehicle class labels
CMPG_IT	Car MPG by technology type
CMPGSTK	
COEF_A	ATV Y-intercept or alpha coefficient
COEF_B	ATV fuel price elasticities
COEF_C	ATV income elasticities
COEF_P	ATV vehicle price elasticities
COEFF_DES	Coefficient for design learning curve
COEFF_MAN	Coefficient for manufacturing learning curve
COEFF_SCI	Coefficient for science learning curve
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
DE	
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)

VARIABLE NAME	VARIABLE DESCRIPTION
DELTA_MKT	Incremental increase in subsystem technology market share
DISCOUNT	Discount rate
DOMCAR	Vehicle group index value for a domestic car
EG_MPG	
EISAE85	Implement EISA07 ethanol requirements
EISAMPG	Implement EISA07 CAFE standards
Elec_Stor\$	Cost of on-board electricity systems and storage
EPACTOT	Total EPACT92 fleet vehicle sales
EV_Batt_Wt	EV battery weight (lbs) per kWh
EV_Credit	EV tax credit
EV_DOD	EV battery depth of discharge (percentage)
EV_kWhr	EV battery size (kWh)
EVBat\$_KWhr	EV battery cost per kWh
EV_Sys_Cost	EV non-battery system cost
EXPENDVEH	
FAVAIL	Fuel availability by technology, region, year
FAVL	
FCHI	Vehicle fueling configuration maximum fuel cell index value
FCLDV	
FCLO	Vehicle fueling configuration minimum fuel cell index value
FCV_kWhr	Fuel cell vehicle battery size
FE	Vehicle class base fuel economy
FEMHP	FEM horsepower data for report writer
FEMMPG	FEM fuel economy data for report writer
FEMPEN	FEM technology penetration data for report writer
FEMPRI	FEM low volume price data for report writer
FEMPRIH	FEM high volume price data for report writer
FEMRNG	FEM range data for report writer
FEMTSZ	FEM fuel tank size data for report writer
FEMVOL	FEM volume data for report writer
FEMWGT	FEM weight data for report writer
FF	For subroutine PRNTRSLT - MTCM diagnostic
FLCOST	Fuel cost per mile
FLTAFSHR	Percent of fleet AFVs by size class
FLTAR05	2005 fleet car stock by fleet type, fuel type, and vintage
FLTCRAT	Fraction of total car sales attributed to fleets
FLTCSHR	Fraction of fleet cars purchased by a given fleet type
FLTECH	Fleet
FLTECHSAL	Fleet
FLTFLDVBUR	Fleet
FLTFUELBTU	Fleet
FLTLDVSHR	Percent of fleet vehicles by fleet type and size
FLTMPG	Fleet mpg
FLTMPGTOT2	Total fleet mpg
FLTSALSC	Fleet sales
FLTSSHR	% of fleet vehicle by fleet type, size, vehicle type
FLTSTKC	1990-2009 car fleet stock
FLTSTKT	1990-2009 light truck fleet stock

VARIABLE NAME	VARIABLE DESCRIPTION
FLTSTKVN	Fleet
FLTTECCSHR	2005 car AFV shares by fleet type
FLTTECTSHR	2005 light truck AFV shares by fleet type
FLTTLLDVBTU	Fleet LDV fuel consumption by fleet type
FLTTOTMPG	Total fleet mpg
FLTTRAT	Fraction of total truck sales attributed to fleets
FLTTRK05	2005 fleet truck stock by fleet type, fuel type, and vintage
FLTTSHR	Fraction of fleet trucks purchased by a given fleet type
FLTVMT	Fleet
FLTVMTECH	Fleet
FLTVMTYR	Annual miles of travel per vehicle
FPMpg	
FPMpgGrp	
FPRICE	Fuel price by region
FPrint	
FRSTYEAR	First year of technology introduction
FTYPELABEL	Fueling type labels based on index scheme one
FUELCELL	Incremental fuel cell cost
FuelCell\$kW	Fuel cell cost (\$/kW)
FUELSAVE	Expected fuel savings of advanced subsystem technology
FUELYRS	Number of years of fueling station data
GAS	Vehicle fueling configuration index value for gasoline
GASMPG_ACTUAL	Diagnostic check of forecast vs. actual fuel economy
GBInc	The increment of the HP giveback that is to be used
GROUPLABEL	Vehicle group labels
GROUPSUM	Sum of class shares by manufacturer
GrpDIMap	Map for how groups are defined back to domestic (=1) and import (=2)
GrpMap	Map for how groups are defined back to vehicle types: cars and light trucks
HAPShr44	ATV technology shares by market share
HEV_Batt_Wt	HEV battery weight (lbs) per kWh
HEV_kWhr	HEV battery size (kWh)
HEV_Sys_\$	HEV non-battery system cost
HEVBat\$kWhr	HEV battery cost per kWh
HFCost	Hydrogen fuel cost, from price and mpg
HFUEL	Home refueling
HP	Vehicle class base horsepower
HPrice	Hydrogen price in cents per gallon
HEVBat\$kWhr	HEV battery cost per kWh
HFCost	Hydrogen fuel cost, from price and mpg
HFUEL	Home refueling
HP	Vehicle class base horsepower
HPrice	Hydrogen price in cents per gallon
HVSales	Hydrogen vehicle sales

VARIABLE NAME	VARIABLE DESCRIPTION
HVStkS	Hydrogen vehicle stock shares by region and year
HVStkT	Hydrogen vehicle total stock by region and year
HVStkV	Hydrogen vehicle vintaged stocks
I,J,K	Miscellaneous indices
ICL	Vehicle market class
IE	VMT income elasticity
IFTYP,IFTYP2	Fleet and aircraft type indices
IFUEL	Fuel engine technology: 1- Gasoline, 2-TDI Diesel, 3-Ethanol flex, 4-Ethanol, 5-Plug-in gasoline hybrid, 6-Methanol flex, 7-Electric, 8-Diesel hybrid, 9-CNG/LNG bi-fuel, 10-LPG bi-fuel, 11-CNG/LNG, 12-LPG, 13-Fuel cell methanol, 14-Fuel cell hydrogen, 15-Fuel cell gasoline, 16-Gasoline hybrid
IFUEL,IFUELX	Fuel type indices
IGP	Vehicle group
INITSTA	Initial refueling stations by fuel, year, region
INOTE,IATV,IYR	Engineering note, ATV type, and year indices
IREGN,IRAILREGN,IAGE	Region and age indices
ITECH	Technology type
IVTYP	Vehicle type
kWh_Credit	EIEA08 PHEV credit per kWh
LASTID	Parameter for index describing number of technologies
LDVSTK	
Li_ion_Cost	Lithium-ion battery cost (\$/kWh)
LION_MKTSH	Lithium-ion battery market share for Electric Vehicles
LTAfstk	
LTDFRFG	
LTSTK	
LUBFD	Transportation lubricant demand
LUBFDH	Historic transportation lubricant demand
LUGG	Vehicle luggage space
LUGGCAR	Luggage space by technology, market class
LUGGTRK	Luggage space by technology, market class
LYR	Last forecast year
MAINT	Vehicle maintenance cost
MAINTCAR	Car maintenance cost by technology, market class
MAINTTRK	Truck maintenance cost by technology, market class
MAND_ORIDE	Mandatory engineering note parameters
MANDMKSH	Mandatory engineering note parameters
MANDYEAR	Mandatory engineering note parameters
Max_Credit	EIEA08 PHEV max credit
MAX_SHARE	Maximum technology market share = MMAX
MAXACTECH = 9	Maximum number of aircraft technologies
MAXAGE = 20	Number of light-duty vehicle (LDV) vintages
MAXATV = 15	Number of LDV non-gasoline fueling configurations
MAXATYP = 3	Number of aircraft types (narrow-body/wide-body)
MAXCLASS = 6	Number of vehicle classes in each light-duty group
MAXFLEET = 3	Number of LDV fleet types (private/government/utility)
MAXFUEL = 8	Number of distinct fueling station types
MAXGROUP = 4	Number of LDV size groups (domestic/import, car/truck)

VARIABLE NAME	VARIABLE DESCRIPTION
MAXLDV = 16	Number of LDV fueling configurations
MAXLTAGE = 20	Number of commercial light truck vintages
MAXNMLM = 13	Number of coefficients for the nested multinomial logit model
MAXNOTE = 200	Number of light-duty vehicle engineering notes
MAXRAILREGN = 2	Number of rail regions (east/west)
MAXTECH = 100	Number of light-duty vehicle technologies
MAXVGROUP = 9	Number of light-duty vehicle groups (4-car and 5-light truck)
MAXVTYP = 2	Number of light-duty vehicle types (car/truck)
MFD	Total military use by fuel type
MFDH	Historic military use by fuel type
MIDSIZE	Vehicle class index value for a midsize car
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
MMSWITCH	ATV make/model availability switch
MPG_ACTUAL	
MPGC	
MPGFLT	
MPGFLTSTK	mpg Fleet
MPGT	
MPGTECH	
MSSplit	Split of vehicle sales between large city, small city, and rural
MSStkS	Share of vehicle stocks by 3 types
MUCHE85	Consumer preference for E-85
N	Trans variable for curiyr
NCS	
NCSTECH	
NCSTSC	Car sales by class
NHTSAFE	NHTSA fuel economy
NHTSAHP	NHTSA horsepower
NHTSALYR	Last year of NHTSA data
NHTSASAL	NHTSA sales
NHTSAWGT	NHTSA weight
NiMH_Cost	Nickel metal hydride battery cost (\$/kWh)
NLTECH	
NLTS	
NLTSTSC	Light truck sales by class
NUM_REQ,NUM_SUP,NUM_MAN,	Engineering note counters
NUM_SYN	
NUMTECH	Actual number of input technologies
NVS7SC	

VARIABLE NAME	VARIABLE DESCRIPTION
O_UNIT	For subroutine PRNTRSLT - MTCM diagnostic
OCLASS_SHARE	Vehicle class market shares (across all vehicle groups)
OLD_PMAX	Used to determine incremental increase in subsystem market penetration
OLDFSTK	Fleet
OLDFSTKT	
PASAFSTK	
PASS,pass2	
PassNo	Controls two passes for high and low volume sales
PASSTK	
PAYBACK	Payback period
PCTFAVAIL	Exogenous fuel availability by fuel, region, year
PctPHEV10	Percent of PHEV10 energy use that is electric
PctPHEV40	Percent of PHEV40 energy use that is electric
PE	VMT price elasticity
PERFCAP	Vehicle class performance cap
PERFFACT	Vehicle class base performance factor
PERGRP	Manufacture share of sales by size class
PerMPG	
PerSal	
PHASESHR	Fraction of total mandatory share by year
PHEV_Credit	EIEA08 PHEV vehicle credit
PHEV_DOD	PHEV battery depth of discharge
PHEVEIEA	Implement PHEV tax credits in EIEA08
PHEV_Peak	Indicates sales maximum has been reached
PHEVPlug	Share of consumers who can plug in a PHEV
PHEV_Stock	Total sales of PHEVs
PHEV10_Batt_Wt	PHEV10 battery weight (lbs) per kWh
PHEV10_kWh	PHEV10 battery size (kWh)
PHEV10_Sys_	PHEV10 non-battery system cost
PHEV10Bat\$kWh	PHEV10 battery cost per kWh
PHEV10ElecVMT	Percent of PHEV10 VMT in all-electric mode
PHEV40_Batt_Wt	PHEV40 battery weight (lbs) per kWh
PHEV40_kWh	PHEV40 battery size (kWh)
PHEV40_Sys_	PHEV40 non-battery system cost
PHEV40Bat\$kWh	PHEV40 battery cost per kWh
PHEV40ElecVMT	Percent of PHEV40 VMT in all-electric mode
PMGTR90\$	National gasoline price in 1990 dollars
PREV	FEM attribute index value for the previous year
PRICE	Vehicle class base price (low volume)
PRICE_EX	Expected fuel price used in cost-effectiveness calculation
PRICE_HY	Regional hydrogen price from EE/RE ,ANL
PRICEHI	Vehicle class base price (high volume)
PRINT_FE,PRINT_TECH, PRINT_DIAG	Print flags
PSLOPE	Expected rate of change in future fuel price
PSPR	Average vehicle price

VARIABLE NAME	VARIABLE DESCRIPTION
RANGE	Vehicle driving range
RATIO	Used to determine size class shares
RATIO_BYR	Used to determine size class shares
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
REQUIRED	Indicates required subsystem technology
REQUIRES	Required engineering note parameters
RETURN_STAT	Technology supersedes check
ROUNDOFF_ERROR	Rounding error buffer
RSHR	
SIGN	Positive or negative indicator
SSURVLT	
SSURVP	
STA_RAT	Refuel stations per vehicle stock
STKCAR	
STKCT	
STKTOT	
STKTR	
SUM_MKS	Diagnostic used to check forecasted vs. actual mpg
SUM_MKS_FE	Diagnostic used to check forecasted vs. actual mpg
SUPERSEDES	Supersedes engineering note parameters
SURVFLT	Survival rate of given vintage
SURVFLTB	
SYNERGY	Synergy engineering note parameters
SYNR_DEL	Synergy engineering note parameters
SYS_AFFECT	Vehicle system affected
TANKSIZE	Vehicle class base fuel tank size
TE_MPG10, TE_MPG40, TG_MPG10, TE_MPG40, PHEVPlug	
TEC_ORNL	Technology cost
TECH_APPLIC	Fueling type applicability indicator
TECH_CNT	
TECHCOST	First cost of subsystem technology - cost adjustments (economies of scale, etc) made to this value
TEHCOSTAHT	Absolute incremental change in cost (\$) - high technology case
TEHCOSTALT	Absolute incremental change in cost (\$) - low tech case
TEHCOSTRHT	Relative incremental change in cost (\$/lb) - high technology case
TEHCOSTRLT	Relative incremental change in cost (\$/lb) - low tech case
TECHFHT	Incremental change in fuel economy (percent) - high technology case
TECHFELT	Incremental change in fuel economy (percent) - low tech case
TECHID	Technology identification number
TECHLABEL	Technology label
TECHMKTSHARELT	Technology base and maximum market shares - low technology case
TECHNCS	
TECHNLT	
TFCoefA	Light truck coefficients
TFCoefB	

VARIABLE NAME	VARIABLE DESCRIPTION
TFCoefC	
TFCoefD	
TFLTECHSTK	
TMPASMIL	Passenger miles per capita by bus type
TMPG_IT	Truck mpg by technology type
TOPACAGE	Maximum aircraft age (47 years)
TOT_MKT	Total market share of subsystem technology
TOTALSALSC	
TOTFLTCAR	Total fleet car
TOTLEV	
TOTMIC	
TOTMIT	
TQLDV	
TRKFLG	Alternate Technology Vehicles introduction year for truck classes
TrkSales	
TrkSales2	
Ttl_Credit	Total PHEV credit
TTLZEV	Total (%) mandated ZEV sales
TTMPGLDV	
TTMPGSTK	
USED CAP	Fraction of vehicle class performance cap used
VAL_PERF	Value of performance improvement to consumer
VALUEPERF	Vehicle class base performance value
VFSTKPF	
vhp_adj	Weight based hp adjustment
VINTSHR	Vintage shares
VMT	Annual VMT by vintage
VOLUME	Vehicle class base interior volume
VRNG	Vehicle range
VSPLDV	
VSTK	
WEIGHT	Vehicle class base curb weight
WGT	Light-duty vehicle weight
X11	ATV NMLM level 1, technology set general cost
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
XYR	Base year for MTCS
YRS	Actual model year (1989+curiyr)

VARIABLE NAME	VARIABLE DESCRIPTION
ZEV	Total (%) mandated electric vehicles
ZEVCARCD1	% CD1 cars covered under ZEV mandate
ZEVCARCD2	% CD2 cars covered under ZEV mandate
ZEVCARCD9	% CD9 cars covered under ZEV mandate
ZEVLTKCD1	% CD1 light trucks covered under ZEV mandate
ZEVLTKCD2	% CD2 light trucks covered under ZEV mandate
ZEVLTKCD9	% CD9 light trucks covered under ZEV mandate
ZFCV	Total (%) mandated hydrogen fuel cell vehicles
LDV Submodule	
LDV Stock Accounting Component	
CARSTKHIST	Historic (1995-2004) car stock by tech/fuel type
CDF	Degradation factor for car
CMPGSTKGAS95	On road mpg 1990 gasoline
HHCARSTK05	2005 household car stock by vintage
HHRKSTK05	2005 household light truck stock by vintage
HIST_SHARE	Vehicle class market shares (within vehicle groups)
LTDF	Degradation factor for light truck
LTSTKHIST	Historic (1995-2004) light truck stock by tech/fuel type
LVMT	Light truck VMT per vintage
MPGFLTH	Historic LDV on-road mpg
PASSTK90DES	Vehicle stock diesel 1990-2000
PASSTK90GAS	Vehicle stock gas 1990-2000
PVMT	Car VMT per vintage
SCMPGH	Historic car stock on-road mpg
STKAVGWGT	Stock average weight by vintage
STMPGH	Historic light truck on-road mpg
SURVLT	Survival rates for light trucks
SURVP	Survival rates for cars
TRWTCAR_HIST	Historic average vehicle weight of car stock
TRWTTRK_HIST	Historic average vehicle weight of light truck stock
LDV VMT Stock Component	
AGGLICDRIVER	Licensed drivers by VMT age groups
AGGLICDRIVER_REG	Regional licensed drivers by age groups
ALPHA	Beta constant for LDV VMT equation
BETACOST	Beta coefficient price effect
BETAEMP	Beta coefficient employment
BETAINC	Beta coefficient income effect
BETAVMT	Beta coefficient VMT effect
BETAVPLD	Beta coefficient vehicles per licensed driver
COSTMI	Fuel cost of driving one mile (2004 cents per gallon)
EMP_RATE	Employment rate
F_CD_AGE_DIST	Regional female population distribution by age
LICDRIVER	Licensed drivers by region, gender and age cohorts
LICRATE_M	Licensing rate of male population 16+

VARIABLE NAME	VARIABLE DESCRIPTION
LICRATE_F	Licensing rate of female population 16+
M_CD_AGE_DIST	Regional male population distribution by age
POP_DIST	Population distribution by age and gender
RHO	Rho constant
TMC_NP16A	Population of age 16+
VMTECH	Total VMT by vehicle type (16)
VMTEE	Total household LDV VMT
VMTEER1	Regional VMT by gender and age cohorts
VMTEER	Sum of regional VMT
VMTLD	VMT per licensed driver
VMTLDV	Total LDV (<8,500 lbs GVWR) VMT
New LDV	
CARSHRT	Non-normalized projected car share
TRKSHARE	Historic/normalized light truck share of LDV sales
TRKSHRT	Non-normalized projected truck share
TTLSHR	Total non-normalized share
Commercial Light Truck Component	
BCLBTU	Regional CLT fuel consumption Btu
CLS2BPER	Class 2B gasoline and diesel sales percentages
CLTBTUT	Total CLT consumption by Btu
CLTGAL	CLT consumption in gals
CLTMPG	CLT stock mpg by vintage, cur/lag year
CLTMPGV	Class 2b fuel economy by vintage
CLTSIC	SIC output averaged across 6 categories
CLTSTK	CLT stocks by vintage, cur/lag year
CLTSTKIN	Initial CLT stock by year, 1990:2000
CLTSURV	Survival fraction from prior year by vintage
CLTVINTSHR	Base year (2000) stocks by vintage as shares
CLTVMT	VMT by vintage, cur/lag year
CLTVMTDIST	Distribution of VMT by Industry
CLTVMTT	Total CLT VMT
CLTVMTV	Class 2b vehicle travel by vintage
CLTVMTVA	VMT by vintage, cur/lag year
Air Demand Submodule	
airregs	World air regions; us, non_us, and total world
AIRUNIT	Air output file unit
GDPNUS	Non-US GDP
maxreg = 2	US, non-US regs
Air Energy Use	
AGDBTU	General aviation gasoline demand
JFBTU	Jet fuel demand (Btu)
QJETR_NUS	Total Non-US jet fuel demand (quads)
Aircraft Efficiency	
ASMAC	ASM per aircraft by type

VARIABLE NAME	VARIABLE DESCRIPTION
ASMPGT	Aircraft efficiency after technology addition (1=new, 2=Stock)
NEW_SMPG	New aircraft efficiency by type
SMPG	Average efficiency by aircraft type and vintage
SMPG_AVG	Average efficiency by aircraft type
SMPGD	2002 domestic aircraft efficiency by type and vintage
SMPGI	2002 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
Revenue Passenger Miles (RPM)	
DUMMYD	Dummy array - independent variable for domestic RPM
DUMMYI	Dummy array - independent variable for int RPM
DUMMYN	Dummy array - independent var for non-US rpm
MC_COMMFLSP_REF	Common floor space, miscellaneous includes airports
RPM_MAXCAP	Infrastructure constraint
RPMD_PC	Per capita domestic revenue passenger miles
RPMI_PC	Per capita international revenue passenger miles
RPMD	Domestic revenue passenger miles by aircraft type
RPMI	International revenue passenger miles by aircraft type
RPMN	Non-US revenue passenger miles by aircraft type
RPMTD	Total domestic revenue passenger miles
RPMTI	Total international revenue passenger miles
RPMTN	Total non-US revenue passenger miles
RPMTOT_US	Total revenue passenger miles (dom + intl)
SRPMD	Domestic share-RPM
SRPMI	International share-RPM
SRPMN	Non-US share-RPM
Load Factors	
LFDOM	Load factor for domestic travel by aircraft type
LFDOMAVG	Average load factor for domestic travel
LFINTAVG	Average load factor for international travel
LFINTER	Load factor for international travel 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
PCTAC_SALES_NUS	Non-US aircraft sales growth factor (0.75)
PCTAC_SALES_US	US aircraft sales growth factor (0.8)

VARIABLE NAME	VARIABLE DESCRIPTION
Aircraft Stocks	
PCT_PARKED	Percent of aircraft parked by type vintage
STK_SUP	Aircraft stock (passenger +cargo) by aircraft type and vintage
STK_SUP_TOT	Aircraft stock (passenger +cargo) total by aircraft type
STKACHIST	Last hist yr passenger aircraft stk by type and vintage
STKACPHIST	Last hist yr parked aircraft stock by type and vintage
STKCACHIST	Last hist yr cargo aircraft stock by type and vintage
STKCACPHIST	Last hist yr parked cargo act stock by type and vintage
STKCARGO_ACTIVE_TOT	Cargo aircraft total active stock by aircraft type
STKCARGO_PARKED_TOT	Cargo aircraft total parked stock by aircraft type
STKCARGO_TOT	Total aircraft cargo stock by aircraft type
STKPASS	Passenger aircraft stock by aircraft type and vintage
STKPASS_ACTIVE_TOT	Passenger aircraft total active stock by aircraft type
STKPASS_PARKED_TOT	Passenger aircraft total parked stock by aircraft type
STKPASS_TOT	Passenger aircraft stock total by aircraft type
SURVAC	Aircraft survival curves by aircraft type
Air Freight	
RTM_FAC	Revenue ton miles growth factor
RTMAC	RTM per aircraft by type
SRTMD	Demand share - RTM
Yield	
LCPMD	Domestic yield lower bound
LCPMI	International yield lower bound
YIELD	Revenue per passenger mile
Coefficients for air model	
Domestic yield	
ALPHAYD	Beta constant
BETAFUELD	Beta fuel price
BETATIMED	Beta time
RHOYD	Rho coefficient
International yield	
ALPHAYI	Beta constant
BETAFUELI	Beta fuel price
BETATIMEI	Beta time
RHOYI	Rho coefficient
Domestic RPM demand	
ALPHARD	Beta constant
BETADMYD	Beta dummy
BETAINCD	Beta income
BETARPM	Beta RPM
BETAYLDD	Beta yield
RHORD	Rho coefficient

VARIABLE NAME	VARIABLE DESCRIPTION
International RPM demand	
ALPHARI	Beta constant
BETADMYI	Beta dummy
BETAINCI	Beta income
BETARPMI	Beta RPM
BETAYLDI	Beta yield
RHORI	Rho coefficient
Non-US RPM demand	
ALPHARN	Beta constant – non-US rpm
BETADMYN	Beta dummy – non-US rpm
BETAINCN	Beta income – non-US rpm
BETARPMN	Beta rpm – non-US rpm
BETAYLDN	Beta yield – non-US rpm
RHORN	Rho coefficient – non-US rpm
US Aircraft Sales	
ALPHASALUS	Beta constant - US sales
BETARPMSUS	Beta rpm - US sales
BETAGDPSUS	Beta GDP - US sales
BETATIMSUS	Beta time - US sales
Non-US Aircraft Sales	
ALPHASALN	Beta constant – non-US sales
BETARPMSN	Beta rpm – non-US sales
BETAGDPSN	Beta GDP – non-US sales
BETATIMSN	Beta time – non-US sales
Revenue ton miles (RTM) demanded	
ALPHARTM	Beta constant
BETAPJFR	Beta fuel price
BETAXIMR	Beta export/import
RHORTM	Rho coefficient
SRTMN	Non-US demand share – RTM
Freight Transportation Submodule	
Rail Freight Model	
BRTMTT	Benchmarked travel demand
DISCRT	Discount rate applied by freight railroads
FREFF	Freight rail efficiency (1000 Btu/ton-mile)
LNG_MAXPEN	Maximum penetration for LNG locomotives
LOCOM_BTU	Average annual Btu by Class I railroad
LOCOM_LIFE	Locomotive lifecycle utilization rate
PAYBK	Payback period demanded by freight railroads
RAIL_FUEL	Historic rail fuel shares
REG_SHR	Regional fuel share
RAIL_TONMI	Freight rail ton-miles traveled (billion)
RHIST_NCTONMI	Historic total freight rail non-coal ton-miles
RHIST_CTONMI	Historic total freight rail coal ton-miles
RLNG_INCCOST	Incremental cost for LNG locomotive

VARIABLE NAME	VARIABLE DESCRIPTION
RLNG_LEARN	Learning rate applied to LNG incremental cost
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
BSTMTT	Benchmarked travel demand
DOMSHIP_FUEL_SHR	Domestic shipping fuel share
DSEFF	Domestic marine vessel efficiency
DSHIP_TONMILE	Domestic marine ton-miles traveled (billion)
DSHIST_TONMI	Historic total domestic marine ton-miles
DSTM_OUTPUT	Domestic marine ton-miles per dollar industrial output
STMTT	Domestic marine Ttravel (billion ton-miles)
TQSHIP	Domestic marine energy demand by fuel type
TQDSHIPR	Regional energy demand by fuel type
TQSHIPT	Total domestic marine energy demand
International Waterborne	
BTQSHIPR	Benchmarked energy demand
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)
TQSHIPR	Regional energy demand by fuel type
Miscellaneous Energy Demand Submodule	
MILTRSHR90	Military regional consumption shares by fuel, region
PDSTR04\$	Regional diesel price 2004\$
PMGTR04\$	Regional gasoline price 2004\$
Transit Rail Submodule	
TRCON	Travel demand constant term
TRDUM	Travel demand dummy
TRED	Transit rail energy demand by CD
TREDHIST	Historic transit rail energy use
TREFF	Transit rail efficiency (Btu/passenger mile)
TREFFHIST	Historic transit rail efficiency
TRFC	Travel demand fuel cost 2004\$
TRINC	Travel demand log of income
TRRPM	Transit rail passenger miles traveled
TRRPMHIST	Historic transit rail passenger miles traveled
Commuter Rail Submodule	
CRCON	Travel demand constant term
CRDUM	Travel demand dummy
CRED	Commuter rail energy demand by CD
CREDD	Commuter rail diesel demand by CD

VARIABLE NAME	VARIABLE DESCRIPTION
CREDDHIST	Historic commuter rail diesel demand
CREDDSHR	Share of commuter rail energy demand that is diesel
CREDE	Commuter rail electricity demand by CD
CREDEHIST	Historic commuter rail electricity demand
CREFF	Commuter rail efficiency (Btu/passenger mile)
CREFFHIST	Historic commuter rail efficiency
CRFC	Travel demand fuel cost 2004\$
CRINC	Travel demand log of income
CRRPM	Commuter rail passenger miles traveled
CRRPMHIST	Historic commuter rail passenger miles traveled
Intercity Rail Submodule	
IRCON	Travel demand constant term
IREDD	Intercity rail energy demand
IREDDHIST	Historic intercity rail diesel demand
IREDDR	Intercity rail diesel demand by CD
IREDDSHR	Diesel share of total demand
IREDE	Intercity rail electricity demand
IREDEHIST	Historic intercity rail electricity demand
IREDER	Intercity rail electricity demand by CD
IREFF	Intercity rail efficiency (Btu/passenger mile)
IREFFHIST	Historic intercity rail efficiency
IRFC	Travel demand fuel cost 2004\$
IRINC	Travel demand log of income
IRPMCL	Lag of travel demand per capita
IRPMPC	Passenger miles per capita (16+)
IRPMPCHIST	Historic passenger miles per capita (16+)
IRREGSHR	Fuel shares by region
IRRPM	Intercity rail passenger miles traveled
IRRPMHIST	Historic intercity rail passenger miles traveled
Bus Mass Transit	
BUSSYSEF	Bus system efficiency by mode, in Btu per passenger
QMODFSHR	Bus fuel shares
QMODFSHRH	Historic bus fuel shares
TMEFF	Bus efficiency (Btu/passenger mile)
TMEFFINIT	Historic bus efficiency (Btu/passenger mile)
TMFD	National bus energy demand
TMOD	Bus passenger miles
TMODINIT	Historic bus passenger miles
Recreational Boating Demand Component	
RBCON	Energy demand constant term
RBEDPC	Energy demand per capita by fuel type
RBFC	Energy demand fuel cost 2004\$

VARIABLE NAME	VARIABLE DESCRIPTION
RBINC	Energy demand log of income
RECFD	Energy demand by fuel type (gasoline, diesel)
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	
CARLTSHR	Historical car share of LDV sales
CARSHARE	Projected car share of LDV sales
DUMM	Car share dummy
STEO Benchmarking	
BEN_DS	Benchmarks
BEN_JF	
BEN_MG	
BEN_RS	
BFLTCLDVBTUR	
BFLTMTECH	
BFVMTECHSC	
BQAGR	
BQJETR	
BQLUBR	
BQMILTR	
BQMODR	
BQRECR	
BTQDSHIPR	Benchmark domestic waterborne energy demand
BTQFREIRSC	
BTQISHIPR	Benchmark international waterborne energy demand
BTQLDV	
BVMTECH	
CUM_PEN	
FTYPELABEL	Fueling type labels based on index scheme one
FUELTX	Incremental petroleum fuel tax - nominal \$/million Btu
FUELTX87	Incremental petroleum fuel tax - in 1987\$
GEN_LENGTH,RED_CYCLES, DESIGN_RED, CURR_CYCLE	Technology learning curve parameters
LEARN_COST_MULTIPLIER	Technology learning curve parameters
LTSHRR	Light truck market shares by class
MANADJBASE,MANADJMIN, MANUF_ELAST,MANUF_BASE	Technology learning curve parameters
PASSHRR	Car market shares by class
PassNo	Controls two passes for high and low volume sales.
PCTAF	Percent alt. fuel for flex and bi vehicles
SALESHR	Car and light truck sales shares by group
SCI_TIME,SCI_SUCCESS,YEARS_MKTD	Cost
SCMPG	On-road stock mpg household cars

VARIABLE NAME	VARIABLE DESCRIPTION
STDSTR	STEO History + forecast for distillate, shared to regions
STJFTR	STEO History + forecast for jet fuel, shared to regions
STMGTR	STEO History + forecast for motor gasoline, shared to regions
STMPG	On-road stock mpg household light trucks
STRSTR	STEO History + forecast for residual, shared to regions
TLDVMPG	On-road stock fuel economy for all cars, light trucks, total
VOLADJBASE,VOLADJMIN, VOL_ELAST,VOL_BASE	Technology learning curve parameters
Variables in TRANFRT Submodule	
AGE	Number of vintages for truck stocks
EMISTECH	Emission Technologies are for technologies -24(to 40)
FLT	Truck: fleet
FNEW	NEW VEHICLE for reporting variables
FSTK	FREIGHT STOCK for reporting variables
FUEL	Number of fuel types: 1 - Diesel, 2 - Gasoline, 3 - LPG, 4 - CNG/LNG
HRATE	Btu/Gallon ratio to Gasoline
HV	Market class of vehicle: heavy, Classes 7-8
MDH	Market class of vehicle: medium-heavy, Classes 4-6
MDL	Market class of vehicle: medium-light, Class 3
NFT	Truck: Non-fleet
SC	Number of Truck Market classes: 1 - Medium-Light, Class 3, 2 - Medium-Heavy, Classes 4-6, 3 - Heavy, Classes 7-8
SEC	Number of Industrial sectors: 1 - Chemicals, Rubber, and Plastic, 2 - Primary Metals, 3 - Processed Food, 4 - Paper Products, 5 - Petroleum Products, 6 - Stone, Clay, Glass, Concrete, 7 - Metal Durables, 8 - Other Manufacturing, 9 - Agriculture, 10 - Mining, 11 - Utility, 12 - Government
TECH	New technologies available: 1 - Aero Dynamics I, 2 - Aero Dynamics II, 3 - Aero Dynamics III, 4 - Aero Dynamics IV: pneumatic blowing, 5 - Tires I: radials, 6 - Tires II, 7 - Tires III, 8 - Tires IV, 9 - Transmission: lock-up, 10 - Diesel Engine I, 11 - Diesel Engine II, 12 - Diesel Engine III, 13 - Diesel Engine IV, 14 - Diesel Engine V, 15 - Diesel Engine VI, 16 - Diesel Engine VII, 17 - Diesel Engine VIII, 18 - Gasoline Engine I, 19 - Gasoline Engine II, 20 - Gasoline Engine III, 21 - Gasoline Engine IV, 22 - Weight Reduction I, 23 - Blank, 24 - Diesel Emission - NOx I, 25 - Diesel Emission - NOx II, 26 - Diesel Emission - NOx III, 27 - Diesel Emission - NOx IV, 28 - Diesel Emission - PM I, 29 - Diesel Emission - PM II, 30 - Diesel Emission - HC/CO I, 31 - Diesel Emission - HC/CO II, 32 - Blank, 33 - Gasoline Emission -PM I, 34 - Gasoline Emission - NOx I, 35 - Gasoline Emission - NOx II: oxygen sensors, 36 - Gasoline Emission - NOx III: , 37 - Gasoline Emission - HC/CO I: oxygen sensors, 38 - Gasoline Emission - HC/CO II, 39 - Gasoline Emission - HC/CO III, 40 – Blank
TK	Truck
Subscripts	
IAGE	Index for vintage
IFUEL	Index for fuel type
ITECH	Index for Technology
IYR	Index for year

VARIABLE NAME	VARIABLE DESCRIPTION
EV100	Electric vehicle with 100 mile range
EV200	Electric vehicle with 200 mile range
Variables	
ANNVMT	Average annual VMT per vehicle
BAFSHXG	
BAVSHXG	Market penetration curve parameter: Market share of technology in 1992
BFSHXG	Base year (92) Market share of each fuel
BSMPGXG	Fuel economy for medium/heavy trucks w/ no fuel-saving technologies
BUY_CNG	Purchase CNG vehicle=1, Not buy CNG vehicle=0
CAPCXG	Exogenous capital cost of a technology
CAPCXG_T	
CFAVPC	Average price of fuel over 3 years
CFMPG	Fuel economy in mpg miles/cubic CNG
CFPRCXG	Price of fuel, in \$ per MMBtu
COEFTXG	Market penetration curve for existing technologies
CSTCXG	Market penetration curve for existing technologies
CSTDVXG	Market penetration curve parameter for diesel
CSTDXG	Market penetration curve parameter for diesel
CYLXG	Exogenous parameter: num of years to maximum penetration
DISCRTXG	Discount rate
CNGMKTPEN	Historic CNG market penetration
DSLKMKTPEN	Historic diesel market penetration
GASMKTPEN	Historic gasoline market penetration
LPGMKTPEN	Historic LPG market penetration
EAVSHXG	
EAVSHXG	Market penetration curve parameter: Final Market share of technology
EAVSHXG_T	
EFSHXG	Final market share of each fuel
ENDSHXG	Market penetration parameter: final market share technology
FSHFLT	Fuel shares for New trucks by market class, fleet/non-fleet
FSHFLT_STK	Fuel shares for the entire stock of trucks
FSHR_CNG	Share of CNG freight trucks purchased
FTMPG	MPG by size, and fuel
FTMPG_S	MPG by market class
FUELBTUR	Total truck fuel consumption in trillion Btu by region
FUELDMDR	Freight truck energy demand by region
HARMONIC_MEAN	Function to calculate average mpg weighted by VMT
HTRTXG	Heat rate: Btu per gallon (conversion factor)
MBTUTKXG	Average truck fuel usage
MPGEFF	Total effect of all fuel-saving technology on new truck fuel efficiency

VARIABLE NAME	VARIABLE DESCRIPTION
MPGIPXG	Percent improvement fuel economy by technology
MPGIPXG_T	
NEW_CLASS_3	Temporary new Class 3 sales
NEWCLS46	Share of truck sales in class 4-8 that are class 4-6, by year
NEWTRUCKS	Sales of new trucks by market class and fleet/non-fleet + total
NEWTRUCKS_TOT	Temporary for new truck sales from macro
OUTPUT	Economic output of each sector
PAYBKXG	Payback period
PRAFDFXG	Parameter: variation AFV Market share due to different fuel prices
preff	Market Penetration Price sensitivity multiplier
prefflag	Market Penetration Price sensitivity multiplier, lagged
PRVRXG	Fuel price sensitivity parameter for each technology
SCRAP	Truck scrappage rate
SPRSDEFF	Market shares of superseding technology
SPRSDMTXG	The 2nd technology supercedes the 1st technology
STKCLS3FL	Truck stock 2000 from ORNL-processed Polk data, class 3, fleet
STKCLS3NFL	Truck stock 2000 from ORNL-processed Polk data, class 3, non-fleet
STKCLS46FL	Truck stock 2000 from ORNL-processed Polk data, class 4-6, fleet
STKCLS46NFL	Truck stock 2000 from ORNL-processed Polk data, class 4-6, non-fleet
STKCLS78FL	Truck stock 2000 from ORNL-processed Polk data, class 7-8, fleet
STKCLS78NFL	Truck stock 2000 from ORNL-processed Polk data, class 7-8, non-fleet
T_FUELBTU	
TFFXGRT	Exogenous % of trucks/vintage transferred from fleet to non-fleet
TGPRCXG	Exogenous fuel price where a technology becomes economical
THIST_VMT	Historical truck vehicle-miles traveled
TRF	Trucks trans fleet to non-fleet w/ no restrictions
TRGSHXG	Logistics parameter: 1/2 way to maximum Market penetration
TRKSTK	Truck population (current/lag year, market class, vintage, fuel, fleet/non-fleet)
TRKTMP	
TR_VMT	Total truck vehicle-miles traveled (billion)
TTM_OUTPUT	Truck ton-miles per dollar of industrial output
TTONMI_ORIG	Truck ton-miles for base year
TVMT_ORIG	Truck vehicle-miles traveled for base year
USFUEL	Temporary summing variable for fuel
VMT_BY_SEC	Shares of VMT by Sector
VMTCLS3V	VMT per truck by fuel and vintage, class 3
VMTCLS46V	VMT per truck by fuel and vintage, class 4-6
VMTCLS78V	VMT per truck by fuel and vintage, class 7-8
VMTDMDR	Aggregate VMT by sector and Census Division
VMTFLT	VMT at its most detailed
VMTFLTR	VMT at its most detailed by region
VMTFLT_SAFF_T	

Appendix E. Bibliography

The Transportation 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 *AEO2014*.

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