DOE/EIA-M070(2003)

The Transportation Sector Model of the National Energy Modeling System

Model Documentation Report

February 2003

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

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Model Abstract

Model Name

Transportation Sector Model

Model Acronym

TRAN

Description

The Transportation Sector Model is part of the National Energy Modeling system (NEMS) and incorporates an integrated modular design which is based upon economic, engineering, and demographic relationships that model transportation sector energy consumption at the nine Census Division level of detail. The Transportation Sector Model comprises the following components: Light Duty Vehicles, Light Duty Fleet Vehicles, Light Duty Stock (including Commercial Light Trucks), Air Travel, Freight Transport (truck, rail, and marine), and Miscellaneous Transport (military, mass transit, and recreational boats). The model provides sales estimates of 2 conventional and 14 alternative-fuel light duty vehicles, and consumption estimates of 12 main fuels.

Purpose of the Model

As a component of the National Energy Modeling System integrated forecasting tool, the transportation model generates mid-term forecasts of transportation sector energy consumption. The transportation model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact transportation sector energy consumption.

Most Recent Model Update

October, 2002.

Model Interfaces

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

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Documentation

Model Documentation Report: *Transportation Sector Model of the National Energy Modeling System*, DOE/EIA-M070(2002), April 2002.

Archive Media and Installation Manual(s)

NEMS-2002 (Part of the National Energy Modeling System archival package for the *Annual Energy Outlook 2002*, DOE/EIA-0383(2002)).

Energy System Described

Domestic transportation sector energy consumption.

Coverage

- Geographic: Nine Census Divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific.
- Time Unit/Frequency: Annual, 1995 through 2020.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants, pipeline fuel, and natural gas.
- Economic Sectors: Forecasts are produced for personal and commercial travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Model Interfaces

Model outputs are provided to the Integrating Module, which then sends them back to the supply modules.

Model Structure

Light-duty vehicles are classified according to the six EPA size classes for cars and light trucks. Freight trucks are divided into medium-duty and heavy-duty size classes. Buses are subdivided into commuter, intercity, and school buses. The air transport module contains both wide- and narrow-body aircraft. Rail transportation is composed of freight rail and three modes of personal rail travel: commuter, intercity and transit. Shipping is divided into domestic and international categories.

Special Features

The Transportation Sector Model has been created to allow the user to change various exogenous and endogenous input levels. The range of policy issues that the transportation model can evaluate are: fuel taxes and subsidies; fuel economy levels by size class; CAFE levels; vehicle pricing policies by size class; demand for vehicle performance within size classes; fleet vehicle sales by technology type; alternative-fuel vehicle sales shares; the Energy Policy Act; Low Emission Vehicle Program; VMT reduction; and greenhouse gas emissions levels.

Modeling Techniques

The modeling techniques employed in the Transportation Sector Model vary by module: econometrics for passenger travel, aviation, and new vehicle market shares; exogenous engineering and judgement for MPG, aircraft efficiency, and various freight characteristics; and structural for light-duty vehicle and aircraft capital stock estimations.

Independent Expert Reviews Conducted

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

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

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

Independent Evaluation of <u>EIA's Freight Transportation Model</u>, 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 System (SEDS), DOE/EIA-0214(99) May 2001.
- Short Term Energy Outlook, Oct. 2002, http://www.eia.doe.gov/pub/forecasting/steo/oldsteos/oct02.pdf

Non-DOE Input Sources:

- National Energy Accounts
- Federal Highway Administration, Highway Statistics, FHWA-PL-01-1011, Nov. 1, 2001
- Department of Transportation Air Travel Statistics
- U.S. Department of Transportation, Bureau of Transportation Statistics: Air Carrier Traffic Statistics Monthly, December 2001/2000
- National Highway Traffic and Safety Administration, Fuel Economy Report to Congress, Sep. 2001
- Oak Ridge National Laboratory, Transportation Energy Data Book Ed. 21, ORNL-6966, Sep. 2001
- Oak Ridge National Laboratory, Stacy C. Davis and Lorena F. Truett, Fleet Characteristics and Data Issues, Feb. 2003
- Federal Aviation Administration, FAA Aviation Forecasts: Fiscal Years 2002-2013, March 2002
- Department of Commerce, Bureau of the Census, Vehicle Inventory and Use Survey 1997, Oct 1999
- California Air Resources Board, Standards for Low-Emission and Clean Fuel Vehicles, Staff Report, July 1, 2001

1. INTRODUCTION

Statement of Purpose

This report documents the objectives, analytical approach and development of the National Energy Modeling System (NEMS) Transportation Model (TRAN). The report describes critical model assumptions, computational methodology, parameter estimation techniques, and model source code.

This document serves three purposes. First, it is a reference document providing a basic understanding of TRAN for model analysts, users, and the public. Second, this report meets the legal requirements of the Energy Information Administration (EIA) to provide adequate documentation in support of its statistical and forecast reports *(Public Law 93-275, § 57(b)(1))*. Third, it permits continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements.

1A. Model Summary

The NEMS Transportation Model comprises a series of semi-independent models which address different aspects of the transportation sector. The primary purpose of this model is to provide mid-term forecasts of transportation energy demand by fuel type including, but not limited to, motor gasoline, distillate, jet fuel, and alternative fuels (such as CNG) not commonly associated with transportation. The current NEMS forecast horizon extends to the year 2025 and uses 1990 as the base year. Forecasts are generated through the 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. This approach is useful in assessing the impacts of policy initiatives, legislative mandates which affect individual modes of travel, and technological developments.

The model also provides forecasts of selected intermediate values which 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 which are linked to forecasts of industrial output.

1B. Model Structure

The NEMS Transportation Model consists of six modules developed to represent a variety of travel modes which, in general, are very different in design and utilization, save for their intended purpose of conveying passengers and/or freight. The six modules are defined as the following: Light-Duty Vehicle, Light Duty Stock, Light Duty Fleet, Air Travel, Freight Transport, and Miscellaneous Transport. Each module, in turn, may comprise more than one submodel, consistent with the methodological requirements of the sector, and commensurate with the relative impact the sector has on overall transportation demand and energy use. A seventh inactive module exists in the Transportation Model which is designed to estimate criteria emissions from the transportation sector. The components of the six active modules are briefly described in turn below.

1B-1. Light-Duty Vehicle (LDV) Module

The LDV Module is the most extensive of the modules in TRAN, owing to the overwhelming choice of technology and make and models in automobile and light-truck markets. Forecasts of stocks and efficiencies of cars and light trucks are generated, disaggregated by vehicle size class, vintage, and engine technology, using the following submodels.

Fuel Economy Model (FEM)

The Fuel Economy Model uses estimates of future fuel prices, economic conditions, and the impact of legislative mandates to forecast the economic market share of numerous automotive technologies within twelve vehicle size classes, and the consequent impact on stock fuel efficiency of new vehicles. The results are subsequently used as inputs to other components of the Transportation Model.

Regional Sales Model (RSM)

The Regional Sales Model is a simple accounting mechanism which uses endogenous estimates of regional travel to produce estimates of regional sales which are then passed to the Light Duty Stock Model.

Alternative Fuel Vehicle (AFV) Model

The Alternative Fuel Vehicle Model uses estimates of new car fuel efficiency, obtained from the FEM, fuel cost, maintenance cost, battery replacement cost, range, multi-fuel capability, home refueling for electric vehicles, acceleration, luggage space, fuel availability, and make/model availability to generate market shares of each considered technology, as well as the overall market penetration of alternative fuel vehicles. This model is useful both to assess the penetration of AFV's and to allow analysis of policies that might impact this penetration.

LDV Stock Accounting Model

The LDV Stock Accounting Model takes sales and efficiency estimates for new cars and light trucks from the LDV and LDV Fleet Modules, determines the number of retirements of older vehicles and additions of fleet vehicles, and returns estimates of the number and characteristics of surviving vehicles.

Vehicle-Miles Traveled (VMT) Model

The VMT Model is the travel demand component of the LDV Stock Module which uses NEMS estimates of fuel price and personal income, along with population projections, to generate a forecast of the demand for personal travel. This is subsequently combined with forecasts of automotive stock efficiency to estimate fuel consumption by the existing stock of light duty vehicles.

Light-Duty Vehicle Fleet Module

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

1B-2. Air Travel Module

The air travel component of the NEMS Transportation Model comprises two separate submodels: the Air Travel Demand Model and the Aircraft Fleet Efficiency Model. These models use NEMS forecasts of fuel price, macroeconomic activity, and population growth, as well as assumptions about aircraft retirement rates and technological improvements to generate forecasts of passenger and freight travel demand and the consequent fuel consumption.

Air Travel Demand Model

The Air Travel Demand Model produces forecasts of passenger travel demand, expressed in revenue passenger-miles (RPM), and air freight demand, measured in revenue-ton miles (RTM). These are combined into a single demand for seat-miles (SMD), and passed to the Aircraft Fleet Efficiency Model, which adjusts aircraft stocks in order to meet that demand.

Aircraft Fleet Efficiency Model (AFEM)

The Aircraft Fleet Efficiency Model is a structured accounting mechanism which, subject to user-specified parameters, provides estimates of the number of narrow- and wide-body aircraft required to meet the demand generated in the preceding model. This model also estimates aircraft fleet efficiency using a weighted average of the characteristics of surviving aircraft and those acquired to meet demand.

1B-3. Freight Transport Module

The Freight Transport Module uses NEMS forecasts of real fuel prices, trade indices, coal production, and selected industries' output from the Macroeconomic Model to estimate travel demand and energy consumption in each of three primary freight modes: truck, rail, and marine. This component also provides estimates of modal efficiency growth, driven by assumptions about systemic improvements and modulated by fuel price forecasts.

1B-4. Miscellaneous Energy Use Module

The Miscellaneous Energy Use Module addresses transportation-related energy demands which can not readily be allocated to any of the preceding modules. These include: military fuel consumption, mass transit, recreational boating, and lubricants.

1C. Model Archival Citation

Archived as part of the NEMS production runs for the *Annual Energy Outlook 2003*.

1D. Report Organization

Chapter 2 of this report discusses the purpose of the Transportation Model, detailing its objectives, primary input and output quantities, and the relationship of TRAN to the other modules of the NEMS system. In Chapter 3, each of the constituent modules is addressed in detail, describing the rationale behind the module's design. A diagram of each module's structure is provided to illustrate model flows and key computations.

2. MODEL PURPOSE AND SCOPE

2A. Objectives

The NEMS Transportation Model achieves three objectives. First, it provides a policy-sensitive representation of the transportation sector within NEMS. Second, it generates mid-term forecasts, to 2025, of transportation energy demand at the census division level in support of the development of the *Annual Energy Outlook* (AEO). Third, it incorporates endogenous forecasts of the effects of technological innovation and vehicle choice.

2B. Model Overview

The Transportation Model is comprised of a group of submodules which are sequentially executed in a series of program calls. The flow of information between these modules is depicted in Figure 2-1. The model receives inputs from NEMS, principally in the form of fuel prices, vehicle sales, economic and demographic indicators, and estimates of defense spending. These inputs are described in greater detail in the following section.

The first module executed is the Light Duty Vehicle (LDV) Module, which addresses the characteristics of new cars and light trucks. This module comprises a series of submodels which provide estimates of new LDV fuel economy, the market shares of alternative fuel vehicles, and sales of vehicles to fleets. This information is passed to the LDV Fleet Module, a stock vintaging model which generates estimates of travel demand, fuel efficiency, and energy consumption by business, government, and utility fleets. The LDV Fleet Module subsequently passes estimates of vehicles transferred from fleet to private service to the LDV Stock Module, which also receives estimates of new LDV sales and fuel efficiency from the LDV Module. The LDV Stock Module generates driving, fuel economy, and fuel consumption estimates of the entire stock of those light duty vehicles which are not owned by fleets. Information from the LDV Stock Module is subsequently passed to the Miscellaneous Energy Use Module.

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

The Miscellaneous Energy Use Module receives estimates of military expenditures from NEMS to generate military fuel demand estimates; travel demand estimates from the LDV Stock Module and fuel efficiency estimates from the Freight Transport Module are used to calculate regional fuel consumption by mass transit vehicles; estimates of disposable personal income from NEMS are used to calculate the demand for fuel used in recreational boating; and the aggregate demand for highway travel, obtained from the preceding modules is used to estimate the demand for lubricants used in transportation.

The Transportation Model then sends information on regional fuel consumption, travel demand, and fuel economy back to NEMS, where it is integrated with the results of the economic, other demand, and supply models.

2C. Input and Output

In order to generate forecasts, the Transportation Model receives a variety of exogenous inputs from other NEMS modules. The primary source of these inputs is the Macroeconomic Model, which provides forecasts of economic and demographic indicators. Other inputs exogenous to TRAN but endogenous to NEMS include fuel prices forecasts from the various supply models. A complete listing of NEMS inputs to TRAN is provided in the Table 2-1.

A large number of data inputs exogenous to NEMS are supplied to the TRAN modules described above. These data sets remain constant throughout the forecast, and, to that extent, constitute a set of assumptions about current and future conditions.

Table 2-1. Inputs to TRAN from Other NEMS Models

NEMS Macro Model: Economic and Demographic Indicators	NEMS Supply Models: Prices		
	Natural Gas Transmission and Distribution	Petroleum Marketing	Electricity Market
• Merchandise Exports • Gross Domestic Product (GDP) • GDP Deflator • Disposable Income • U.S. Population • U.S. Population over 16 • U.S. Population over 60 • Industrial Output by SIC Code • Defense Spending	• CNG	• Motor Gasoline • Distillate • Residual Fuel Oil • Methanol • Ethanol • LPG • Jet Fuel • Aviation Gasoline	• Electricity

The Light Duty Vehicle Module, with its numerous submodels, requires the largest number of exogenous inputs. In the Fuel Economy Model, these inputs include the characteristics of the considered automotive technologies, such as their effects on vehicle horsepower, weight, fuel efficiency, and price. Vehicle characteristics in the AFV Model are similarly obtained, with vehicle price, range, emissions levels, and relative efficiency being read in from an external data file.

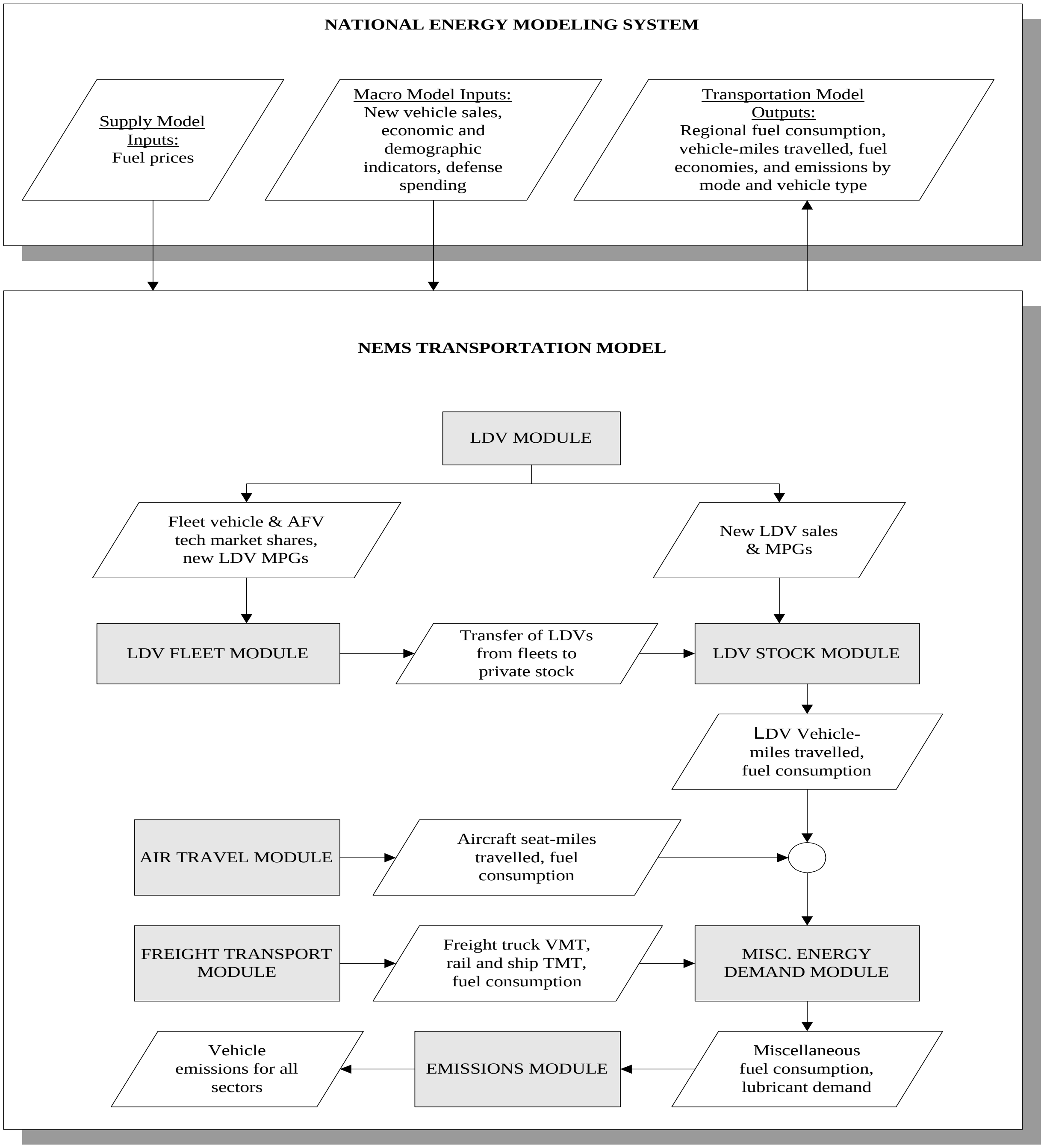
The LDV Stock Module uses vintage-dependent constants such as vehicle survival and relative driving rates, and fuel economy degradation factors to obtain estimates of stock efficiency.

The Air Travel Module receives exogenous estimates of aircraft load factors, new technology characteristics, and aircraft specifications which determine the average number of available seat-miles each plane will supply in a year. The Freight Module receives exogenous estimates of freight intensity, modal shares, and characteristics of the considered technologies.

Each submodel 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. For example, the FEM and the AFV Modules address twelve size classes (six for both car and light truck). The Transportation Model maps the output of each submodel into variables of the appropriate dimension for use in subsequent steps. Due to the lack of a uniform stratification scheme among the various transportation sectors, the primary dimensions across which key variables vary in TRAN are discussed in the individual module descriptions in the following section.

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

Figure 2-1. NEMS and the NEMS Transportation Sector Model



Note: the emissions module is currently inactive.

3. MODEL RATIONALE AND STRUCTURE

As described above, the NEMS Transportation Model is made up of an array of separate modules, each addressing different aspects of the transportation sector. In order to provide a consistent and lucid presentation of TRAN, these modules are discussed separately; where appropriate, individual module components are separately considered. Each section describes the general theoretical approach to the issue at hand, the assumptions which were incorporated in the development of the model, and the methodology employed.

The key computations and equations of each module are then presented, in order to provide a comprehensive overview of the Transportation Model. The equations follow the logic of the FORTRAN source code very closely to facilitate an understanding of the code and its structure. In several instances, a variable name will appear on both sides of an equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name.

Flowcharts are provided both within the text and at the end of each section. Those embedded within the "Model Structure" portion of the explanatory text give a general overview of each Module's structure, its interactions with other Modules within TRAN, and its input requirements from other NEMS Models. Flowcharts found at the end of each section are intended to be detailed, self-contained representations of Module calculations. Thus, for the sake of clarity, origins and destinations of external information flows are not specified.

3A. Light Duty Vehicle Module

This module tracks the purchases and retirements of cars and light trucks, forecasts their fuel efficiency, and estimates the consumption of a variety of fuels, based on projections of travel demand. The LDV Module is divided into three separate sections: the Fuel Economy Model, the Regional Sales Model, and the Alternative Fuel Vehicle Model. Due to the differing methodological approaches and data requirements, each section is presented individually.

3A-1. Fuel Economy Model[1]

The Fuel Economy Model (FEM) is a subcomponent of the Light Duty Vehicle segment of the NEMS Transportation Model. FEM produces estimates of new light duty vehicle fuel efficiency which are then used as inputs to other components of the Transportation Model.

The FEM module is a significant component of the Transportation Model because the demand for automotive fuel is directly affected by the efficiency with which that fuel is used. Due to the disparate characteristics of the various classes of light duty vehicles, this model addresses the commercial viability of up to sixty-three separate technologies within each of twelve vehicle market classes, four Corporate Average Fuel Economy (CAFE) groups, and fifteen fuel types. The six automobile market classes include five classes based on passenger plus cargo volume; these being Minicompact (volume < 85 ft^3), Subcompact (volume between 85 and 99 ft^3) , Compact (volume between 100 and 109 ft^3) , Midsize (volume between 110 and 119 ft^3) , Large (volume > 120 ft^3), and Two-seaters (all automobiles with two seats). Note that Station wagons fall into the same class as the sedan of the same make. For instance, the Ford Taurus station wagon is in the large automobile class, similar to the Ford Taurus sedan. The six classes of light truck are based mainly on utility and inertia weight and include compact and standard vans, pickups, and utility vehicles. The four groups for which CAFE standards are set are: Domestic Cars, Import Cars, Domestic Trucks, and Import Trucks.

The fuel economy of the fleet of new vehicles can change as a result of four factors:

1) A change in technological characteristics of each vehicle
2) A change in the level of acceleration performance of vehicles
3) A change in the mix of vehicle classes sold
4) A change in vehicle safety and emission standards.

To forecast technological change, the entire fleet of new cars and light duty trucks are disaggregated into twelve market classes that are relatively homogenous in terms of consumer perceived attributes such as size, price and utility. Technological improvements to each of these market classes are then forecast 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 forecast are as follows:

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[1]U.S. Department of Energy, Energy Information Administration, Updates to the Fuel Economy Model, provided by Energy and Environmental Analysis, 2001.

1) All manufacturers can obtain the same benefits from a given technology, provided they have adequate lead time (i.e., no technology is proprietary to a given manufacturer in the long term).

2) Manufacturers will generally adopt technological improvements that are perceived as cost-effective to the consumer, even without any regulatory pressure. However, the term cost-effectiveness needs to be interpreted in the manufacturer's context.

These forecasts also account for manufacturer lead time and tooling constraints that limit the rate of increase in the market penetration of new technologies. Users of the model are able to specify one of two scenarios under which these forecasts are made. The first, identified as the "Standard Technology Scenario", permits the consideration of sixty-three automotive technologies whose availability and cost-effectiveness are either well-documented or conservatively estimated. The second, identified as the "High Technology Scenario", modifies selected characteristics of the original matrix to render a more optimistic assessment of the cost and availability of technological improvements. Based on the technological improvements adopted, a fuel economy forecast assuming constant performance is developed for each of the market classes.

The fuel economy forecast must then be adjusted to account for changes in technology and changes in consumer preference for performance. The demand for increased acceleration performance for each size 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 forecast the change in horsepower, which is then used to forecast the change in fuel economy through an engineering relationship that links performance and fuel economy.

Finally, the change in the mix of market classes sold is forecast as a function of fuel price, vehicle price, and personal disposable income. The sales mix by class is used to calculate new fuel economy. The econometric model was derived from regression analysis of historical sales mix data over the 1978-1990 period augmented with vehicle price elasticities.[2] The model forecasts sales mix for the 6 car classes and the 6 light truck classes, while import market shares are held at fixed values by market class based on historical estimates.

The model also allows specification of CAFE standards by year, and of different standards for

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

domestic and import vehicles, as well as the penalty (in dollars) per car per mile per gallon below the standard. The standards are accounted for in the forecast by incorporating the penalty into the technology cost-effectiveness calculation. Hence, if the penalty is not large, the model assumes that manufacturers will adopt fuel-saving technology as long as it is cost-effective; that is, until the point where it becomes cheaper to pay the penalty for noncompliance. Thus, the model allows companies to choose non-compliance with CAFE standards as a cost-minimizing strategy, as may occur if penalties are set at unrealistic levels relative to the difficulty of achieving the CAFE standards.

Finally, the model also accounts for all known safety and emission standard changes during the forecast period. These are generally limited to the 1995-2005 time frame, however. Emission standards and safety standards increase vehicle weight, and in some cases decrease engine efficiency. The model accounts for the Tier II emission standards as well as the California "Low Emission Vehicle (LEV)" program, and the LEV program will be adopted in those states that have similar programs, namely Maine, Massachusetts, Vermont, New York, and California. Safety standards include fuel economy penalties for air bags, side intrusion and roof crush (rollover) strength requirements that are mandatory over the next ten years. Separately, anti-lock brakes are assumed to be incorporated in all vehicles, although they are not required by law.

The forecasts are calculated at the most disaggregate level of manufacturer type (domestic/ import), vehicle type (car/light truck) and market class. 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 EPA size classes, and are based on passenger and trunk volume. Truck classification is essentially identical to the EPA classification. This leads to a total of 24 possible classes (6 size classes x 2 vehicle types x 2 manufacturer types) but some have no vehicles, e.g., there are no domestic minicompact cars. These classes are individually forecast to 2025.

MODEL STRUCTURE

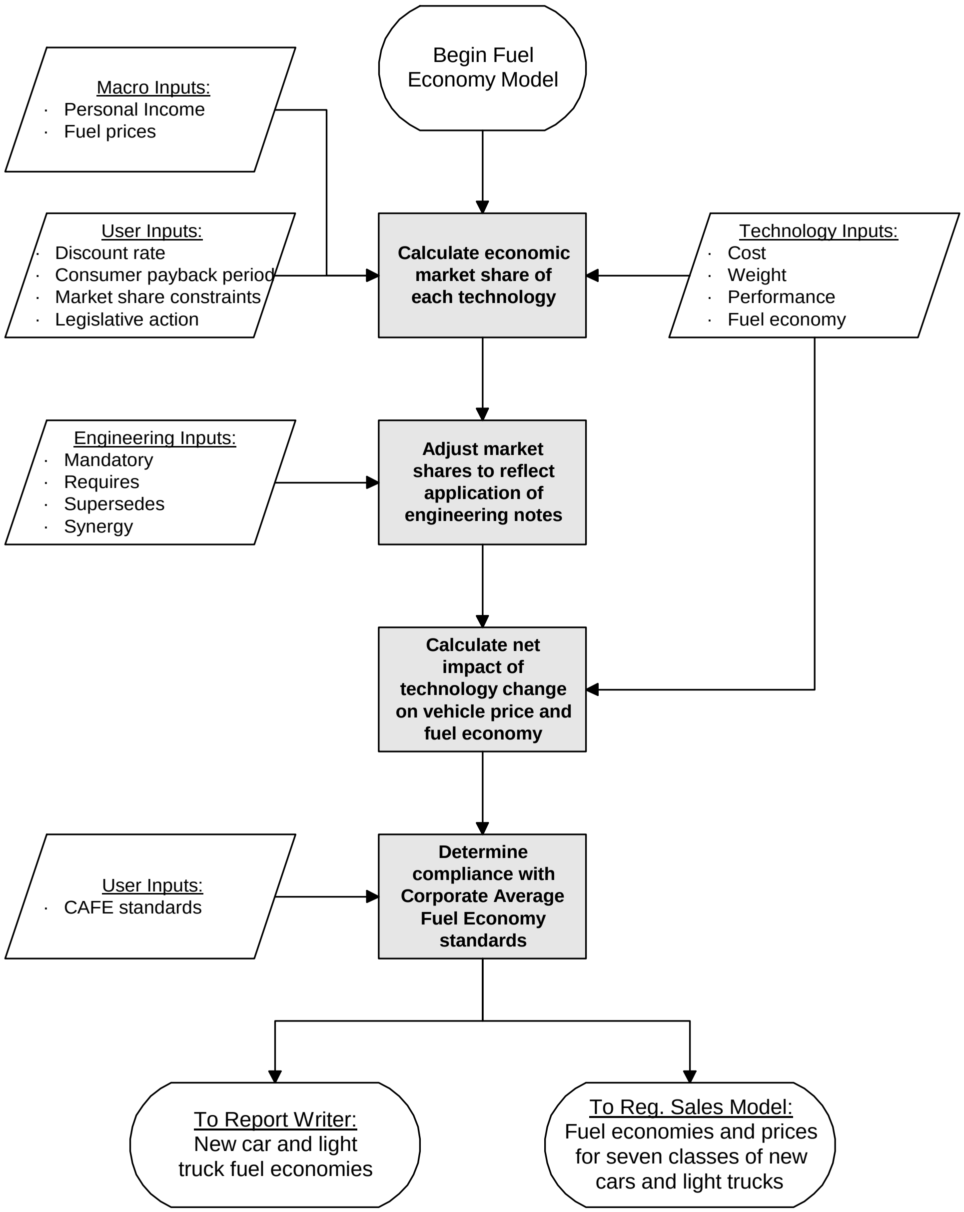
The Fuel Economy Model (FEM) forecasts fuel economy by vehicle class. FEM begins with a baseline, describing the fuel economy, weight, horsepower and price for each vehicle class in 2000. In each forecast period, the model identifies technologies which are available in the current year. Each available technology is subjected to a cost effectiveness test which balances the cost of the technology against the potential fuel savings and the value of any increase in performance provided by the technology. The cost effectiveness is used to generate an economic market share for the technology.

In certain cases there are adjustments which must be made to the calculated market shares. Some of these adjustments reflect engineering limitations to what may be adopted. Other adjustments reflect external forces that require certain types of technologies; safety and emissions technologies are both in this category. All of these adjustments are referred to collectively as "Engineering Notes." There are four types of engineering notes: *Mandatory*, *Requires*, *Synergistic*, and *Supersedes*. These are described in detail in the following sections.

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

Once these steps have been taken for all vehicle classes, the CAFE is calculated for each of the four groups: Domestic Cars, Import Cars, Domestic Trucks and Import Trucks. 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 CAFEs 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 FEM pass are equally applicable during the third pass and, therefore, are not recalculated. If CAFE is still not met after the second pass, then the horsepower increases will be deactivated and converted to equivalent fuel economy improvement, in effect, this assumes manufacturers will minimize their costs by reducing performance to comply with CAFE.

Figure 3A-1. Fuel Economy Model



ESTABLISH AFV CHARACTERISTICS RELATIVE TO CONVENTIONAL GASOLINE

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

1. Calculate AFV historic year values for automobile prices at different production levels.

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

$$PRICE_{Year,FuelType} = PRICE_{Year,Gasoline} + AFVADJPR_{FuelType,1,Year} \tag{1}$$

where:

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

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

$$PRICE_{Year,FuelType} = PRICE_{Year,Gasoline} + \frac{AFVADJPR_{FuelType,1,Year} + AFVADJPR_{FuelType,2,Year}}{2} \tag{2}$$

where:

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

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

$$PRICEHI_{Year,FuelType} = PRICE_{Year,Gasoline} + AFVADJPR_{FuelType,3,Year} \tag{3}$$

where:

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

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

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

where:

$AFVADJPR_{FuelType,4,Year}$ = Incremental price adjustment for a high production AFV truck.

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

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

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

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

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

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

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

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

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

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

Electric Hybrid vehicles have an additional price adjustment in addition to those made above. This adjustment applies to both cars and trucks. Note that these adjustments refer to the cost reduction learning curve for Nickel Metal Hydride (Ni-MH) batteries. This is because the EV/Hybrid cost reduction curve begins at the same time and proceeds at the same rate as that for Ni-MH batteries.

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

$$PRICE_{Year,ElectricHybrid} = PRICE_{Year,ElectricHybrid} + \left(NIMHY\$COST_{Year} * AFVADJPR_{ElectricHybrid,3,Year} * \frac{WEIGHT_{Year,Gasoline}}{WEIGHT_{Midsize,Domestic,Year,Gasoline}} \right) \quad \textbf{(9)}$$

where:

$AFVADJPR_{ElectricHybrid,3,Year}$ = Incremental price adjustment for a EV/Hybrid vehicles

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

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

$NIMHY\$COST_{Year}$ = Cost reduction learning curve for a Ni-MH battery

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

$$PRICEHI_{Year,ElectricHybrid} = PRICE_{Year,Gasoline} + \left(NIMHY\$COST_{Year} * AFVADJPR_{ElectricHybrid,3,Year} * \frac{WEIGHT_{Year,Gasoline}}{WEIGHT_{Midsize,Domestic,Year,Gasoline}} \right) \quad \textbf{(10)}$$

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

a) Fuel Economy Calculation:

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

where:

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

b) Weight Calculation:

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

where:

AFVADJWT = Input Weight adjustment, relative to gasoline vehicles, for an AFV.

c) Horsepower Calculation:

$$HP_{Year,FuelType} = HP_{Year,Gasoline} * (1 + AFVADJHP_{FuelType,Year}) \tag{13}$$

where:

AFVADJHP = Input Horsepower adjustment, relative to gasoline vehicles, for an AFV.

CALCULATE TECHNOLOGY MARKET SHARES

FEM first determines the cost effective market shares of technologies for each vehicle class and then calculates the resulting Fuel Economy, Weight, Horsepower and Price through the subroutine FEMCALC. In each forecast period this function is called three times. During the first pass, technology market shares are calculated for all vehicle classes. In the second pass, the technology market shares are recalculated for vehicles in groups failing to meet the CAFE standards. During this pass, the cost effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFE[3]. If a vehicle group continues to fail to meet CAFE standards after the second pass, no further adjustments to technology market shares are made. Rather, in the third pass, it is assumed that the manufacturers focus solely on CAFE compliance at the expense of increased performance.

For each vehicle class, FEMCALC follows these steps:

A. Calculate the economic market share for each technology
B. Apply the engineering notes to control market penetration
    - Adjust the economic market shares though application of the mandatory, supersedes and requires engineering 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 and Fuel Cell Characteristics
E. Adjust horsepower based on the new fuel economy and weight
F. Readjust fuel economy based on the new horsepower, and price based on the change in horsepower

Each step is described in more detail below. Readers should note that all of the calculations in this section take place within loops by Group (domestic and import cars and light trucks), Class, and Fuel

[3] See the variable REGCOST in Equation 22.

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 3A-2. These are addressed in turn below.

CALCULATE ECONOMIC MARKET SHARE

Fuel Savings Value

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

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

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

$$FIVEYR\$FUELCOST_1 = \frac{1}{5} * \sum_{i=Year-8}^{Year-4} FUELCOST_i$$

$$FIVEYR\$FUELCOST_2 = \frac{1}{5} * \sum_{i=Year-7}^{Year-3} FUELCOST_i \qquad \textbf{(14)}$$

$$PSLOPE = MAX\ (\ 0\ , FIVEYR\$FUELCOST_1 - FIVEYR\$FUELCOST_2\ )$$

where:

FUELCOST = The price of fuel in the specified prior years

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

$$PRICE\$EX_i = PSLOPE * (i+2) + FIVEYR\$FUELCOST_1 \tag{15}$$

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

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

where:

VMT = Annual vehicle-miles traveled
itc = The index representing the technology under consideration
FE = The fuel economy
DEL$FE = The fractional change in fuel economy associated with technology *itc*
PAYBACK = The user-specified payback period
DISCOUNT = The user-specified discount rate

Technology Cost

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

$$TECHCOST_{itc} = DEL\$COSTABS_{itc} + DEL\$COSTWGT_{itc} * [ABS(DEL\$WGTABS_{itc}) + ABS(DEL\$WGTWGT_{itc}) * WEIGHT_{Year-1,FuelType}] \tag{17}$$

where:

TECHCOST = The cost per vehicle of technology itc.
DEL$COSTABS = The absolute cost of technology *itc*.
DEL$COSTWGT = The weight-based change in cost ($/lb).
DEL$WGTABS = The fractional change in absolute weight-based cost associated with technology *itc.*

DEL\$WGTWGT = The fractional change in relative weight-based cost associated with technology *itc*.
WEIGHT = The original vehicle weight for different fuel type vehicles.

Learning Cost Adjustment

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

$$TECHCOST_{itc} = TECHCOST_{itc} * LEARN\$COST\$MULTIPLIER_1 * LEARN\$COST\$MULTIPLIER_2 * LEARN\$COST\$MULTIPLIER_3 * LEARN\$COST\$MULTIPLIER_4 \qquad \textbf{(18)}$$

where:

$LEARN\$COST\$MULTIPLIER_1$ = Cost adjustment due to scientific advances.
$LEARN\$COST\$MULTIPLIER_2$ = Cost adjustment due to manufacturing advances.
$LEARN\$COST\$MULTIPLIER_3$ = Cost adjustment due to design advances.
$LEARN\$COST\$MULTIPLIER_4$ = Cost adjustment due to production volume economies of scale.

Performance Value

Although there are a number of technological factors which affect the perceived performance of a vehicle, in the interests of clarity and simplicity it was decided to use the vehicle's horsepower 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.

$$VAL\$PERF_{itc} = VALUEPERF * PERF\$COEFF * \frac{INCOME_{Year}}{INCOME_{Year-1}} * (1 + DEL\$FE_{itc}) * \frac{FUELCOST_{Year-1}}{FUELCOST_{Year}} * DEL\$HP_{itc} \qquad \textbf{(19)}$$

where:

VAL$PERF = The dollar value of performance of technology *itc*

VALUEPERF = The value associated with an incremental change in performance

PERF$COEFF = The parameter used to constrain vehicle performance

DEL$FE = The fractional change in fuel economy of technology *itc*

DEL$HP = The fractional change in horsepower of technology *itc*

FUELCOST = The actual price of fuel (in the given year)

<u>*Economic Market Share*</u>

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

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

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

$$MKT\$FUEL_{itc} = \frac{1}{1 + e^{MKT\$1COEFF \, * \, COSTEF\$FUEL_{itc}}} \quad \textbf{(22)}$$

$$MKT\$PERF_{itc} = \frac{1}{1 + e^{MKT\$2COEFF \, * \, COSTEF\$PERF_{itc}}} \quad \textbf{(23)}$$

where:

COSTEF$FUEL = A unitless measure of cost effectiveness based on fuel savings

COSTEF$PERF = A unitless measure of cost effectiveness based on performance

REGCOST[4] = A factor representing regulatory pressure to increase fuel economy, in $ per MPG

TECHCOST = The cost of the considered technology

VAL$PERF = The 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

[4]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.

MKT\$2COEFF = -4 if COSTEF\$PERF < 0, and -2 otherwise

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

$$ACTUAL\$MKT_{itc,Year} = PMAX_{itc} * MAX(MKT\$FUEL_{itc} \ , \ MKT\$PERF_{itc}) \qquad \textbf{(24)}$$

where:

ACTUAL\$MKT = The economic share, prior to consideration of engineering or regulatory constraints.

PMAX = The institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in a separate subroutine. This subroutine (FUNCMAX) sets the current year maximum market share based on the previous year's share (see Table 3-1).

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 which is below the market share in the previous period then the calculated value is overridden:

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

Finally, the economic market share is bounded above by the maximum market share, MKT\$MAX or 1.0, whichever is smaller:

$$ACTUAL\$MKT_{itc,Year} = MIN\ (\ 1 \ , \ MKT\$MAX_{itc} \ , \ ACTUAL\$MKT_{itc,Year}\ ) \qquad \textbf{(26)}$$

where:

MKT\$MAX = The maximum market share for technology *itc*

Figure 3A-2. Fuel Economy Model: Economic Market Share Calculation

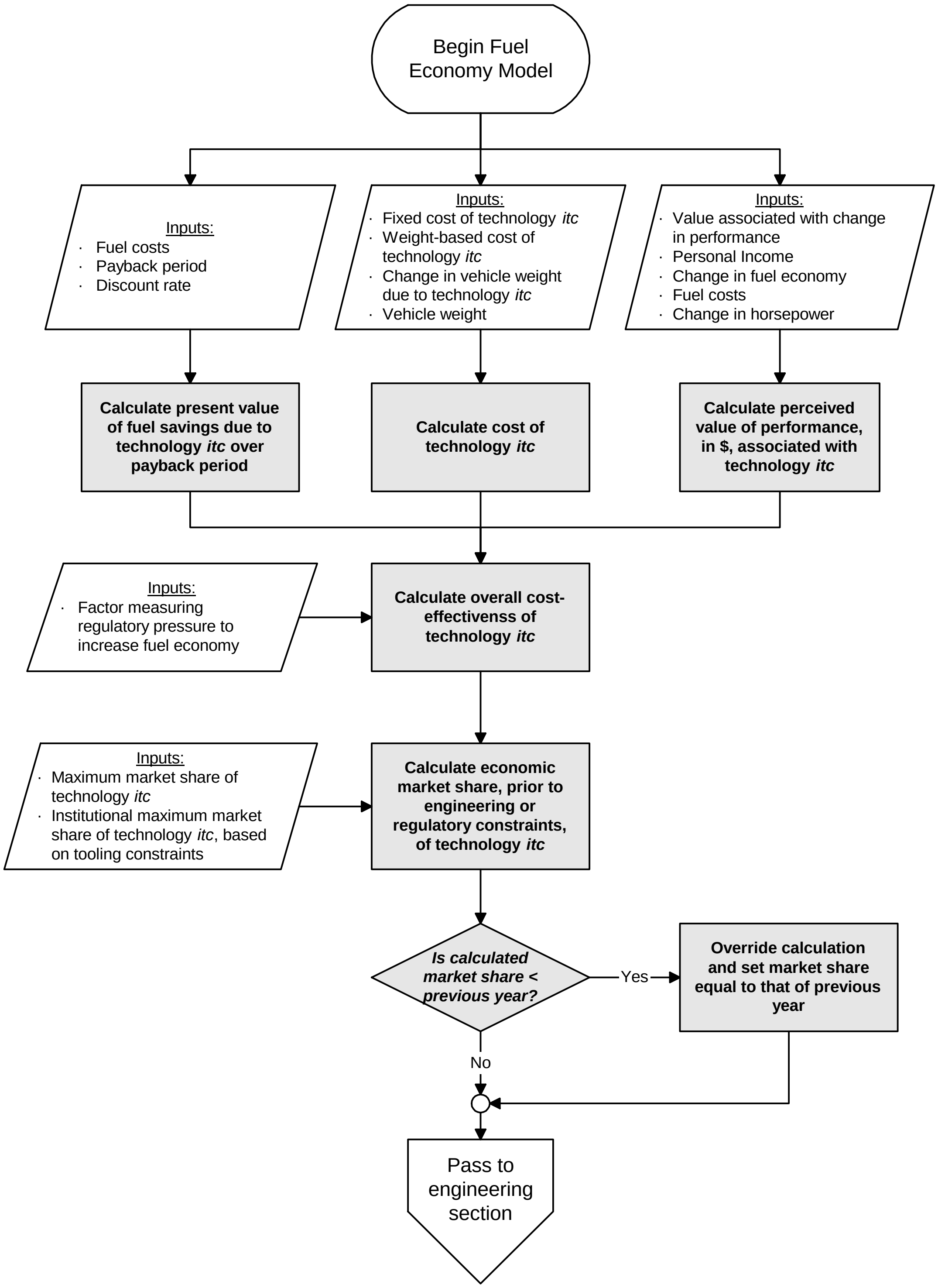


Table 3-1. Maximum Light Duty Vehicle Market Penetration Parameters

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

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 for every year thereafter.

APPLY THE ENGINEERING NOTES

The engineering notes consist of a number of overrides to the economic cost effectiveness calculations done in the previous step. The three types of notes (mandatory, supersedes and requires) directly affect the technology market share results obtained above. The other type of note, synergy, does not affect the market share and is applied after all other engineering notes have been applied, see Figure 3A-3.

Mandatory Notes

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

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

where:

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

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

$$\begin{aligned} ACTUAL\$MKT_{itc,Year} = MAX\ \Big[& ACTUAL\$MKT_{itc,Year}\ , \\ & MKT\$PEN_{itc,BaseYear,FuelType} + PHASESHR_{Year} * (MKT\$MAX_{itc} - MKT\$PEN_{itc,BaseYear,FuelType})\Big] \end{aligned} \qquad \textbf{(28)}$$

where:

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

Finally, the economic market share is bounded above by the maximum market share, or MKT$MAX:

$$ACTUAL\$MKT_{itc,Year} = MIN\ (\ ACTUAL\$MKT_{itc,Year}\ ,\ MKT\$MAX_{itc}\ ) \qquad \textbf{(29)}$$

<u>*Supersedes Notes*</u>

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.

Given a group of related technologies, first calculate the economic market share for each technology, and after applying the *mandatory* notes as described above, take the following steps.

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

$$TOT\$MKT_{itc,Year} = \sum_{ino=1}^{num\$sup} ACTUAL\$MKT_{ino,Year} \quad \textbf{(30)}$$

where:

TOT$MKT = The total market share of the considered group of technologies
ino = The index identifying the technologies in the superseding group related to technology *itc*.
num$sup = The number of technologies in the superseding group related to technology *itc*.

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

$$MAX\$SHARE = MAX\ (\ MKT\$MAX_{ino}\ ) \quad \textbf{(31)}$$

where:

MAX$SHARE = The maximum allowable market share of the group, *ino*.

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

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

$$DEL\$MKT_{itc} = TOT\$MKT_{itc,Year} - MAX\$SHARE \quad \textbf{(32)}$$

where:

DEL$MKT = The amount of the superseded technology's market share to be removed
itc = An index indicating superseded technology

b) adjust the market share of the superseded technology to reflect the decrement

$$ACTUAL\$MKT_{itc,Year} = ACTUAL\$MKT_{itc,Year} - DEL\$MKT_{itc} \quad \textbf{(33)}$$

c) adjust total market share to reflect this decrement

$$TOT\$MKT_{itc,Year} = MAX\$SHARE \quad \textbf{(34)}$$

<u>*Requires Notes*</u>

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

1) For a given technology *itc*, define a group of potential matching technologies, *req*, one of which must be present for *itc* to be present.
2) Sum the market shares of the matching technologies (*req*), ensuring total market share is no more than 1.0:

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

where:

REQ\$MKT = The total market share of those technologies which are required for the implementation of technology *itc*, indicating that technology's maximum share

3) Compare REQ\$MKT to the market share of technology *itc*:

$$ACTUAL\$MKT_{itc,Year} = MIN\left(ACTUAL\$MKT_{itc,Year}\ ,\ REQ\$MKT\right) \quad \textbf{(36)}$$

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

$$MKT\$PEN_{itc,Year} = ACTUAL\$MKT_{itc,Year} \quad \textbf{(37)}$$

Synergistic Notes

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

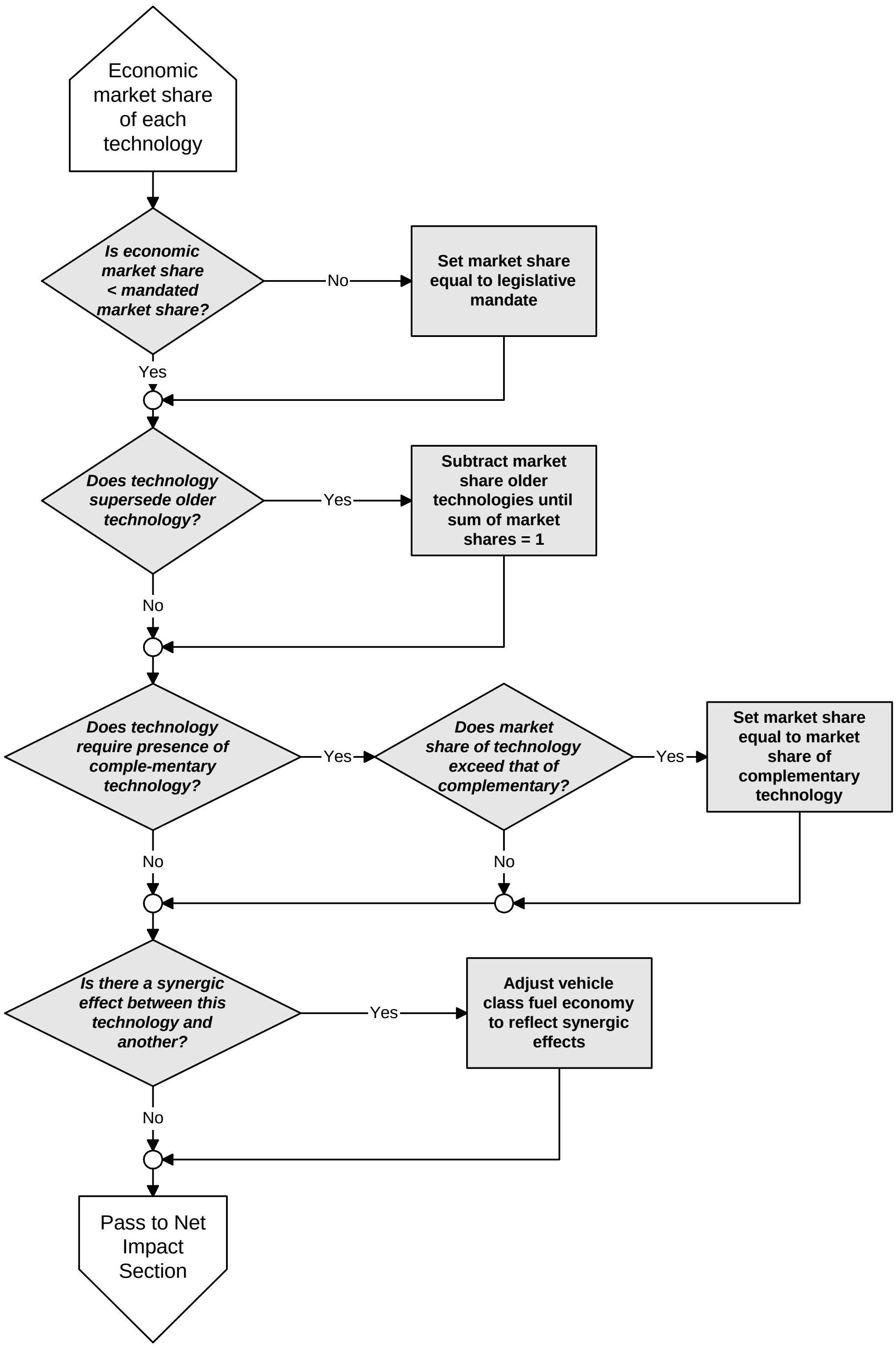
Synergy adjustments are made once all other engineering notes have been applied. Market share affected by synergy effects between two technologies is estimated as the probabilistic overlap between the market shares of the two technologies. Mathematically, this market share is expressed as the product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

$$SYNERGY\$LOSS_{itc} = \sum_{syn} \left(MKT\$PEN_{itc,Year} * MKT\$PEN_{syn,Year} - MKT\$PEN_{itc,Year-1} * MKT\$PEN_{syn,Year-1} \right) * SYNR\$DEL_{itc,syn} \quad \textbf{(38)}$$

where:

SYNERGY$LOSS = The estimated synergy loss for all technologies synergistic with technology, *itc*.
syn = The set of technologies synergistic with technology itc.
SNR$DEL = The synergistic effect of related technologies on fuel economy.

Figure 3A-3. Fuel Economy Model 2: Engineering Notes



CALCULATE NET IMPACT OF TECHNOLOGY CHANGE

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

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,Year} - MKT\$PEN_{itc,Year-1} \qquad \textbf{(39)}$$

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

<u>*Fuel Economy*</u>

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

$$FE_{Year} = FE_{Year-1} + FE_{Year-1} * \left(\sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * DEL\$FE_{itc} * SYNERGY\$LOSS_{itc}\right) \qquad \textbf{(40)}$$

where:

NUMTECH = Number of newly adopted technologies

<u>*Vehicle Weight*</u>

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

$$WEIGHT_{Year,FuelType} = WEIGHT_{Year,FuelType} + DELTA\$MKT_{itc} * \left[DEL\$WGTABS_{itc} + WEIGHT_{Year,FuelType} * DEL\$WGTWGT_{itc}\right] \qquad \textbf{(41)}$$

where:

DEL$WGTABS = The change in weight (lbs) associated with technology *itc*
DEL$WGTWGT = The fractional change in vehicle weight due to technology itc
WEIGHT = Vehicle weight, by size class, group, and fuel type initialized to the previous year's value and subsequently modified with each iteration of the model.

Vehicle Price

Current price for a vehicle class is calculated as the previous price plus the sum of incremental changes in the technology cost due to newly adopted technologies. This calculation is used to equally scale up both low volume prices, at 2,500 units/year, and high volume prices, at 25,000 units/year, as described in equations 1 through 12:

$$PRICE_{Year} = PRICE_{Year-1} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * TECHCOST_{itc} \tag{42}$$

where:

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

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

ESTIMATE EV AND FUEL CELL CHARACTERISTICS

Electric Vehicles

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

The first step in EVCALC is determination of the battery weight and cost for both lead acid and Nickel Metal Hydride (Ni-MH) batteries. The numerical constants in the equations represent the result of exogenous analysis and professional judgment on the part of the model developers.

1) Weight and cost of a lead acid battery

$$BATTERY1\$WT = 0.60 * WEIGHT_{Year,Gasoline}$$

$$and \tag{43}$$

$$BATTERY1\$COST = BATTERY1\$WT * 2.30 * 1.75 + 1500$$

where:

BATTERY1\$WT = Weight of a lead acid battery large enough to provide adequate range and performance
BATTERY1\$COST = Cost of a lead acid battery
0.60 = Fraction of vehicle weight accounted for by the battery system

$2.30 = Cost/pound of a lead acid battery
1.75 = Cost multiplier to determine retail price
$1,500 = Fixed cost amortization per unit EV
WEIGHT = weight of a gasoline vehicle

2) Weight and cost of a nickel metal hydride battery

$$BATTERY2\$WT = 0.203 * WEIGHT_{Year,Gasoline}$$

$$and \tag{44}$$

$$BATTERY2\$COST = BATTERY2\$WT * 8.20 * 1.75 + 1500$$

where:

0.203 = Fraction of vehicle weight accounted for by the battery system
BATTERY2$WT = Weight of a Ni-MH battery large enough to provide adequate range and performance
BATTERY2$COST = Cost of a Ni-MH battery
$8.20 = Cost/pound of a Ni-MH battery
1.75 = Cost multiplier to determine retail price
$1,500 = Fixed cost amortization per unit EV
WEIGHT = weight of a gasoline vehicle

The next step is to apply a learning curve adjustment to the cost of the battery. It is assumed that there is a twenty-five (25) percent cost reduction/decade for both lead acid and Nickel Metal Hydride batteries. The learning curves have been pre-calculated and are initialized in data input file, trninput.wk1. The lead acid curve begins immediately, while the Nickel Metal Hydride battery costs do not begin to go down until after 2003.

3) Learning curve adjustment for battery costs

$$BATTERY1\$COST = BATTERY1\$COST * LEADACID\$COST_{Year}$$

$$and \tag{45}$$

$$BATTERY2\$COST = BATTERY2\$COST * NIMHY\$COST_{Year}$$

where:

LEADACID$COST = Cost reduction learning curve for a lead acid battery
NIMHY$COST = Cost reduction learning curve for a Ni-MH battery

Next, the average price of an electric vehicle battery is determined based on the expected market shares of lead acid and Nickel Metal Hydride batteries:

4) Average price of an electric vehicle battery

$$\begin{aligned} BATTERY_{Year,\,Electric\,Vehicle} &= BATTERY1\$COST \ * \ (1 \ - \ NIMHY\$MKTSH_{Year}) \\ &+ \ BATTERY2\$COST \ * \ NIMHY\$MKTSH_{Year} \end{aligned} \tag{46}$$

where:

BATTERY = Average price of an electric vehicle battery
NIMHY$MKYSH = Expected market share of Ni-MH batteries.

Finally, Price, Weight and Fuel Economy are calculated:

5) Electric Vehicle Price

$$PRICE_{Year,ElectricVehicle} = PRICE_{Year,ElectricVehicle} + BATTERY_{Year,ElectricVehicle} \tag{47}$$

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

6) Electric Vehicle Weight

$$\begin{aligned} WEIGHT_{Year,ElectricVehicle} &= \frac{BATTERY1\$WT}{0.375} \ * \ (1 - NIMHY\$MKTSH_{Year}) \\ &+ \ \frac{BATTERY2\$WT}{0.22} \ * \ NIMHY\$MKTSH_{Year} \end{aligned} \tag{48}$$

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

$$FE_{Year,\,Electric\,Vehicle} = \left[\frac{0.8 \ \cdot \ (2{,}200)}{0.16 \ \cdot \ WEIGHT_{Year,ElectricVehicle}} \right] \tag{49}$$

Hybrid Electric Vehicles (HEV)

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

$$PRICE_{Year,HEV} = PRICE_{Year,Gasoline} + NIMHY\$COST_{Year} * AFVADJPR_{Year,HEV} * \frac{WEIGHT_{Year,\ class,Gasoline}}{WEIGHT_{Year,\ mid-size,Gasoline}} \quad \textbf{(50)}$$

Fuel Cell Vehicles

The subroutine FCCALC calculates fuel cell cost, vehicle price for low volume sales, at 2,500 units/year, and high volume sales, at 25,000 units/year, and fuel economy for methanol , hydrogen, and gasoline fuel cell vehicles, respectively. Note that although values for fuel cell vehicles are calculated for the early years, it is not likely that there will actually be any on the road until at least 2005. Hydrogen supply is expected to be a major problem for the corresponding vehicles. In the following equations the *FC* subscript refers to Methanol, Hydrogen and Gasoline Fuel Cells.

1) Fuel Cell Cost

$$FUELCELL_{Year,FC} = 30 * \frac{WEIGHT_{Year,Gasoline}}{2200} * FUELCELL\$COST_{Year,FC} \quad \textbf{(51)}$$

where:

FUELCELL = Cost of the fuel cell
FUELCELL$COST = Exogenous input for the cost of the fuel cell in $/kw
WEIGHT = weight of a gasoline vehicle

2) Battery Power Required to initially power the vehicle

$$BATTERY\$POWER = 20 * \frac{WEIGHT_{Year,Gasoline}}{2200} \quad \textbf{(52)}$$

where:

BATTERY$POWER = Required battery power in Kw

3) Weight of Battery

$$BATTERY\$WT = 2.2 * \frac{BATTERY\$POWER}{0.5} \quad \textbf{(53)}$$

where:

2.2 = Base battery weight in lbs.
BATTERY$WT = Weight of the battery

4) Cost of Battery

$$BATTERY_{Year,FC} = 2.30 * BATTERY\$WT * LEADACID\$COST_{Year} \quad \textbf{(54)}$$

where:

BATTERY = Cost of the lead acid battery
$2.30 = Initial cost per pound for the battery
$LEADACID\$COST_{Year}$ = Cost reduction learning curve for a lead acid battery

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

$$FUELCELL_{Year,FC} = (FUELCELL_{Year,FC} + BATTERY_{Year,FC} + HTANK_{FC}) * 1.75 + 1500 \quad \textbf{(55)}$$

where:

HTANK = Cost of the hydrogen storage tank: $0 for methanol and gasoline FC, $3,000 for hydrogen FC
1.75 = Cost multiplier to determine retail price
$1,500 = Fixed cost amortization per unit fuel cell vehicle

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

$$PRICE_{Year,FC} = PRICE_{Year,FC} + FUELCELL_{Year,FC} \quad \textbf{(56)}$$

7) Fuel Cell Fuel Economy (gasoline equivalent mpg)

$$FE_{Year,FC} = \frac{1}{GALPERMILE_{FC} * \frac{WEIGHT_{Year,Gasoline}}{1000}} \quad \textbf{(57)}$$

where:

GALPERMILE = 0.00625 for Methanol FC, 0.0057 for Hydrogen FC, and 0.00667 for Gasoline FC

ADJUST HORSEPOWER

Calculating the net impact of changes in technology share on vehicle horsepower is a three step process. See Figure 3A-4.

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:

$$HP_{Year,FuelType} = WEIGHT_{Year,FuelType} * \frac{HP_{Year-1,FuelType}}{WEIGHT_{Year-1,FuelType}} \tag{58}$$

where:

HP = Vehicle horsepower
WEIGHT = Vehicle weight

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

$$HP_{Year,FuelType} = 0.8 * WEIGHT_{Year,FuelType} * \frac{HP_{Year,Gasoline}}{WEIGHT_{Year,Gasoline}} \tag{59}$$

where:

FuelType = Dedicated Electric and Fuel Cell vehicles

Adjust Horsepower

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

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:

$$TECH\$ADJHP_{Year} = \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * DEL\$HP_{itc} \quad \textbf{(60)}$$

where:

DEL$HP = the fractional change in horsepower by technology type

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.

$$PERF\$ADJHP_{Year} = \left(\frac{INCOME_{Year}}{INCOME_{Year-1}}\right)^{0.9} * \left(\frac{PRICE_{Year-1}}{PRICE_{Year}}\right)^{0.9} * \left(\frac{FE_{Year}}{FE_{Year-1}}\right)^{0.2} * \left(\frac{FUELCOST_{Year-1}}{FUELCOST_{Year}}\right)^{0.2} - 1 \quad \textbf{(61)}$$

where:

PERF$ADJHP = Performance Vehicle horsepower adjustment factor

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

$$DEMAND\$USED = [PERFCAP - HP\$WGT_{BaseYear}] * \left[\frac{USEDCAP}{1 - USEDCAP} \right] \quad \textbf{(62)}$$

where:

DEMAND$USED = Demand accrued between 1990 and 2000
PERFCAP = Performance cap
HP$WGT = Horsepower to weight ratio in the given year, in this case BaseYear
USEDCAP = Input parameter

$$PERF\$COEFF_{Year} = 1 - \left[\frac{HP\$WGT_{Year} - HP\$WGT_{BaseYear} + DEMAND\$USED}{PERFCAP - HP\$WGT_{BaseYear} + DEMAND\$USED} \right] \quad \textbf{(63)}$$

where:

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

$$PERF\$ADJHP_{Year} = PERF\$ADJHP_{Year} * PERFFACT * PERF\$COEFF_{Year} \quad \textbf{(64)}$$

where:

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

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

The total horsepower adjustment is now calculated:

$$TTL\$ADJHP_{Year} = TECH\$ADJHP_{Year} + PERF\$ADJHP_{Year} \quad \textbf{(65)}$$

Maximum Limit on Total Horsepower Adjustment

The total horsepower adjustment for a given forecast year is constrained in several ways. First, the total adjustment in any one year is limited to 10 percent. If an adjustment greater than 10 percent is calculated by the econometric algorithms described above, the additional consumer demand portion is adjusted downward first since the fuel economy impacts of this demand are not yet considered in the fuel economy forecasts. 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$GIVEBACK, is tracked and converted into equivalent fuel economy since the basic fuel economy forecast already incorporates the full impact of technology-based horsepower adjustments. Hence, if total horsepower adjustment, TTL$ADJHP, is greater than 10 percent:

$$\begin{aligned} HP\$GIVEBACK_{Year} &= TTL\$ADJHP_{Year} - 0.1 \\ PERF\$ADJHP_{Year} &= PERF\$ADJHP_{Year} - HP\$GIVEBACK_{Year} \end{aligned} \tag{66}$$

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

$$TECH\$ADJHP_{Year} = TECH\$ADJHP_{Year} + PERF\$ADJHP_{Year} \tag{67}$$

Now, calculate the modified total horsepower adjustment:

$$TTL\$ADJHP_{Year} = TECH\$ADJHP_{Year} + PERF\$ADJHP_{Year} \tag{68}$$

Maximum Limit on Horsepower to Weight Ratio

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

Horsepower to Weight Ratio Must Ensure Driveability

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

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

$$\begin{aligned}
MIN\$ADJHP_{Year} &= \left[\frac{HP\$WGT\$MIN_{BaseYear}}{HP\$WGT_{Year}} - 1 \right] \\
PERF\$ADJHP_{Year} &= PERF\$ADJHP_{Year} + MIN\$ADJHP_{Year} - TTL\$ADJHP_{Year} \\
TTL\$ADJHP_{Year} &= TECH\$ADJHP_{Year} + PERF\$ADJHP_{Year}
\end{aligned} \tag{69}$$

Final Horsepower Adjustment for CAFE Compliance

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

$$\begin{aligned}
EXCESS\$ADJHP_{Year} &= MIN[TECH\$ADJHP_{Year}, TTL\$ADJHP_{Year} - MIN\$ADJHP_{Year}] \\
TECH\$ADJHP_{Year} &= TECH\$ADJHP_{Year} - EXCESS\$ADJHP_{Year} \\
TTL\$ADJHP_{Year} &= TECH\$ADJHP_{Year} + PERF\$ADJHP_{Year}
\end{aligned} \tag{70}$$

Compute the horsepower give back;

$$HP\$GIVEBACK_{Year} = HP\$GIVEBACK_{Year} + EXCESS\$ADJHP_{Year} \tag{71}$$

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

$$HP_{Year,FuelType} = HP_{Year,FuelType} * (1 + TTL\$ADJHP_{Year}) \tag{72}$$

READJUST FUEL ECONOMY AND PRICE

Once the horsepower adjustment has been determined, the final fuel economy for the vehicle is calculated.

Fuel Economy Adjustment Factor

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

$$PERF\$ADJHP_{Year} = PERF\$ADJHP_{Year} - HP\$GIVEBACK_{Year} \tag{73}$$

$$ADJFE_{Year} = -0.22 * PERF\$ADJHP_{Year} - 0.560 * SIGN * PERF\$ADJHP^2_{Year} \tag{74}$$

where:

SIGN = -1, if PERF$ADJHP < 0, and +1 otherwise.

Adjusted Fuel Economy

The final vehicle fuel economy is then determined as follows:

$$FE_{Year} = FE_{Year} * (1 + ADJFE_{Year}) \tag{75}$$

Adjusted Vehicle Price

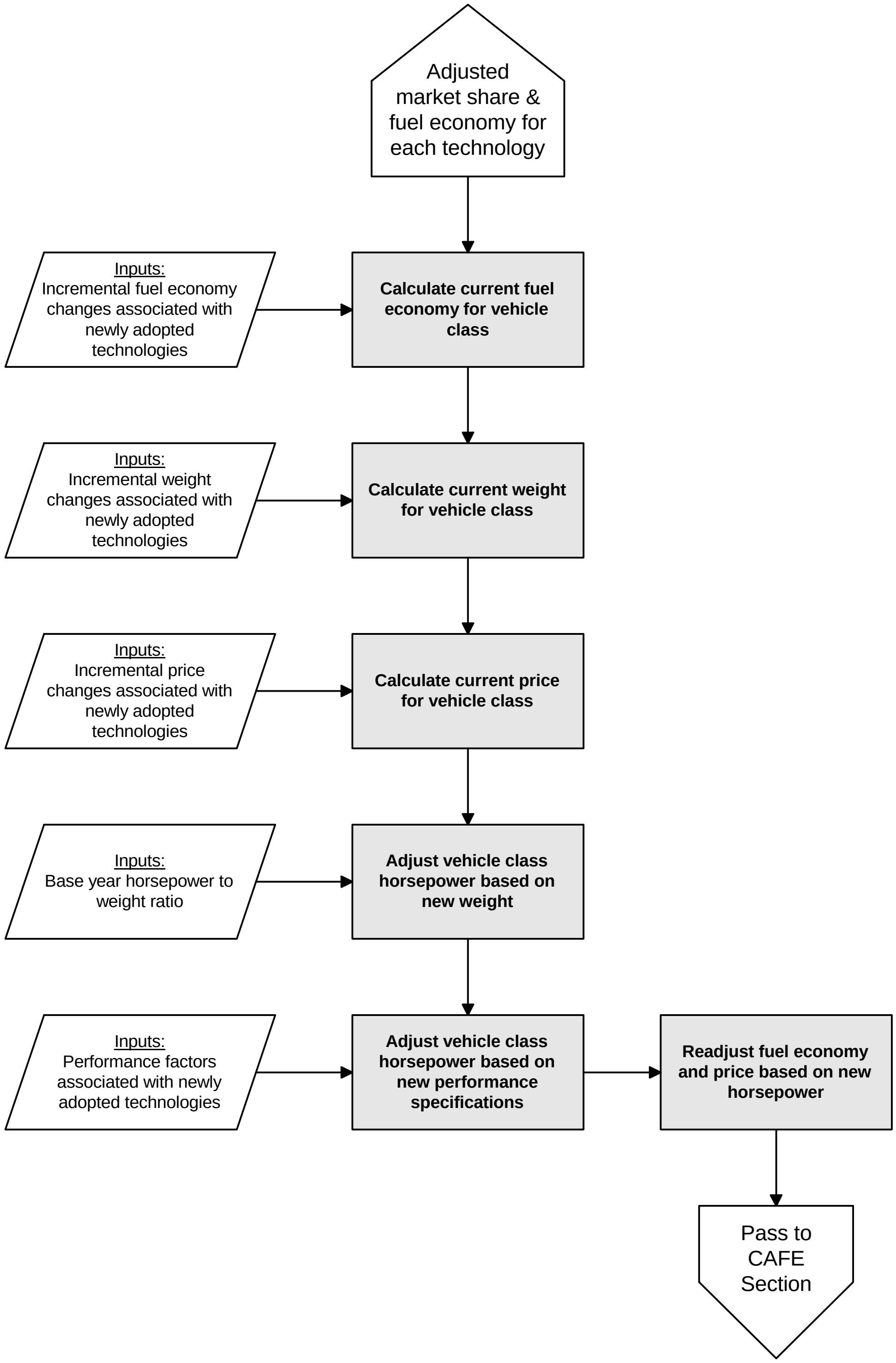
Vehicle price is finally estimated:

$$PRICE_{Year} = PRICE_{Year} + PERF\$ADJHP_{Year} * VALUEPERF_{Year} \tag{76}$$

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

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

Figure 3A-4. Fuel Economy Model: Weight and Horsepower Calculations



Estimate Vehicle Range

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

$$RANGE_{Year,FuelType} = TANKSIZE * FE_{Year,Gasoline} * (1 + AFVADJRN_{FuelType}) \qquad \textbf{(77)}$$

where:

RANGE = Vehicle range
TANKSIZE = Tank size for a gasoline vehicle of the same size class
AFVADJRN = Range adjustment, relative to gasoline, for an AFV (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 alternative fuel vehicles.

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

CALCULATE CLASS MARKET SHARES

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

$$\begin{aligned} DIFFLN_{Year} = A * \ln\left(\frac{Year}{Year-1}\right) &+ B * \ln\left(\frac{FUELCOST_{Year}}{FUELCOST_{Year-1}}\right) \\ &+ C * \ln\left(\frac{INCOME_{Year} - \$13{,}000}{INCOME_{Year-1} - \$13{,}000}\right) \\ &+ D * \ln\left(\frac{PRICE_{Year,Gasoline}}{PRICE_{Year-1,Gasoline}}\right) \end{aligned} \qquad \textbf{(78)}$$

where:

DIFFLN = the log market share increment from the year, Year.
A,B,C,D = coefficients, elasticities, exogenously introduced from trninput.wk1.

Class Market Shares

Solve for the log-share ratio:

$$RATIO\$LN = DIFFLN_{Year} + \ln\left(\frac{CLASS\$SHARE_{class,group,CLYear}}{1 - CLASS\$SHARE_{class,group,CLYear}} \right) \quad \textbf{(79)}$$

where:

RATIO$LN = Log of the market share ratio of the considered vehicle class
CLASS$SHARE = Class market share, assigned to the appropriate vehicle class and group.
class = 6 Vehicle Classes
group = 4 CAFE Groups

Solve for the class market share:

$$CLASS\$SHARE_{class,group,Year} = \frac{e^{(RATIO\$LN)}}{1 + e^{(RATIO\$LN)}} \quad \textbf{(80)}$$

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

$$CLASS\$SHARE_{class,groupYear} = \frac{CLASS\$SHARE_{class,group,Year}}{\sum_{class=1}^{6} CLASS\$SHARE_{class,group,Year}} \quad \textbf{(81)}$$

CALCULATE CORPORATE AVERAGE FUEL ECONOMY (CAFE)

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

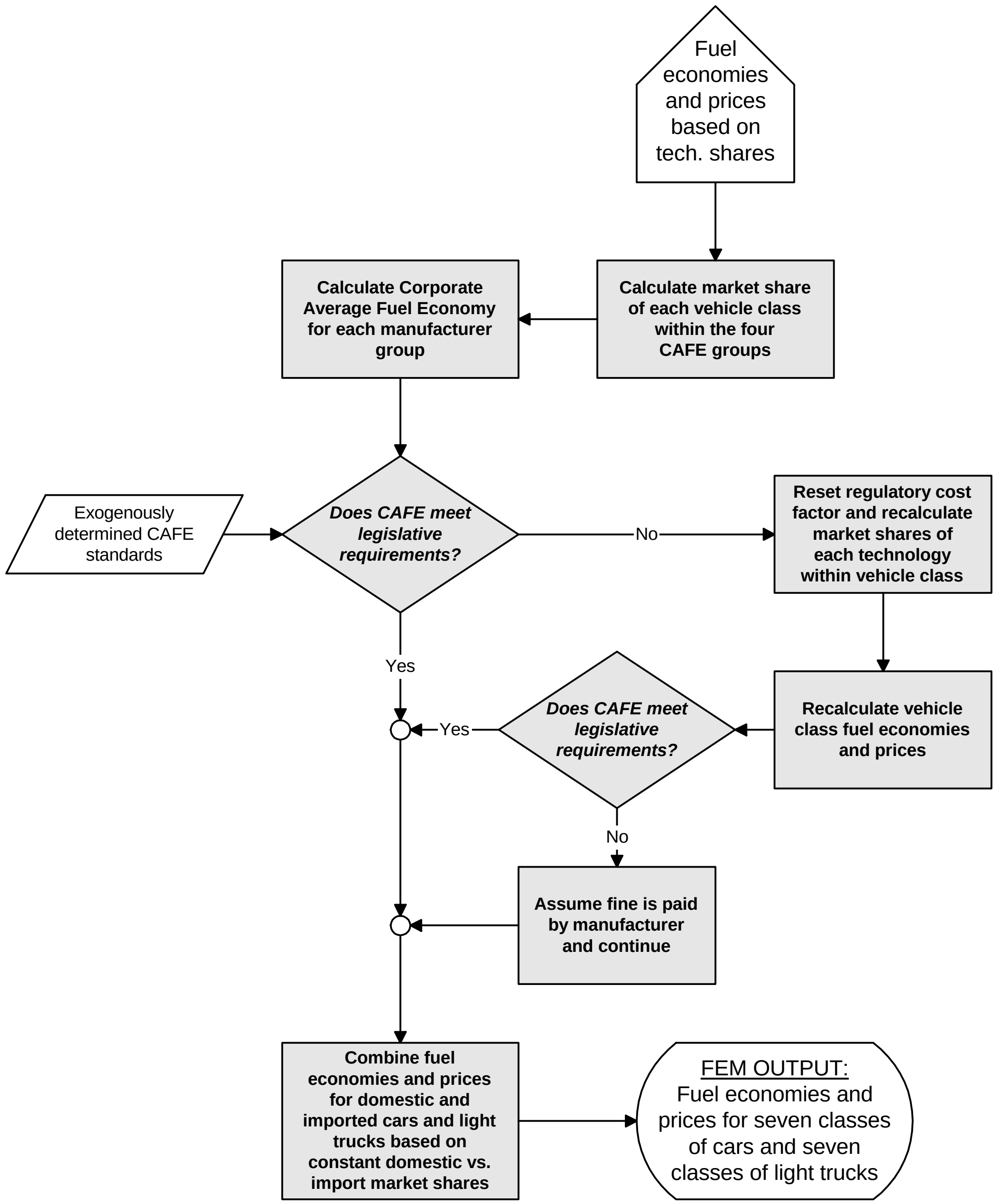
1) Domestic Cars
2) Import Cars
3) Domestic Trucks
4) Import Trucks

For each vehicle group the CAFE calculation proceeds as follows:

$$CAFE_{group,Year} = \frac{\sum_{class=1}^{6} CLASS\$SHARE_{class,group,Year}}{\sum_{class=1}^{6} \frac{CLASS\$SHARE_{class,group,Year}}{FE_{class,group,Year}}} \qquad \textbf{(82)}$$

This CAFE estimate is then compared with the legislative standard for the manufacturer group and year. If the forecast CAFE is less than the standard, a second iteration of the model is performed after resetting the regulatory cost (REGCOST). If the recalculated CAFE is still below the standard, a third iteration occurs, and the manufacturer is then assumed to pay the fine, see Figure 3A-5.

Figure 3A-5. Fuel Economy Model 4: CAFE Calculations



COMBINE RESULTS OF DOMESTIC AND IMPORTED VEHICLES

In subsequent components of the transportation model, domestic and imported vehicles are not treated separately. It is therefore necessary to construct an aggregate estimate of each vehicle characteristic for each class of car and light truck. Aggregate vehicle characteristics are determined by weighting each vehicle class, *class*, by their relative share of the market (PERGRP). These figures are assumed to be constant across classes and time, and have been obtained from Oak Ridge National Laboratory estimates of the domestic, *dom*, and imported, *imp*, market shares:[5]

$$MPG_{vt,class} = \frac{1}{\dfrac{PERGRP_{dom,class}}{FE_{dom,class}} + \dfrac{PERGRP_{imp,class}}{FE_{imp,class}}} \tag{83}$$

$$\begin{aligned} HPW_{vt,class} = & \ (HP_{dom,class} * PERGRP_{dom,class}) \\ & + (HP_{imp,class} * PERGRP_{imp,class}) \end{aligned} \tag{84}$$

$$\begin{aligned} PRI_{vt,class} = & \ (PRICE_{dom,class} * PERGRP_{dom,class}) \\ & + (PRICE_{imp,class} * PERGRP_{imp,class}) \end{aligned} \tag{85}$$

$$\begin{aligned} VRNG_{vt,class} = RNG_{i,class} = & \ (RANGE_{dom,class} * PERGRP_{dom,class}) \\ & + (RANGE_{imp,class} * PERGRP_{imp,class}) \end{aligned} \tag{86}$$

$$\begin{aligned} WGT_{vt,class} = & \ (WEIGHT_{dom,class} * PERGRP_{dom,class}) \\ & + (WEIGHT_{imp,class} * PERGRP_{imp,class}) \end{aligned} \tag{87}$$

[5] Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 20*, ORNL-6959, October 2000. For Cars: Table 7.3, 1998 data. For Light Trucks: Table 7.4, 1998 data.

where:

MPG = Vehicle fuel economy
HPW = Vehicle horsepower
PRI = Vehicle price
RNG = Vehicle range
WGT = Vehicle weight
PERGRP = Percent of vehicles import or domestic by size class
vt = 1 (cars, except minicompacts); 2 (light trucks, except standard pickups, standard vans, and standard utilities

All mini-compact cars are imported and all standard vans are produced domestically.

These numbers are then passed to the Alternative Fuel Vehicle (AFV) Model, and the overall fleet stock model to produce estimates of fleet efficiencies.

3A-2. Regional Sales Model

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

Nationwide estimates of new car sales come from the NEMS Macro Module. In order to comply with the NEMS requirement for regional fuel consumption estimates, the Regional Sales Model allocates new car and light truck sales among the nine Census divisions and permits regional variations in vehicle attributes. This also gives the Transportation Model the capability to analyze regional differences in alternative vehicle legislation. For example, California has implemented legislation requiring that 10 percent of all vehicles sold by the year 2005 be zero emissions vehicles. Massachusetts, Maine, Vermont, and New York have taken steps to adopt the California standards, and the Transportation Model assumes that they will be successful.

This is not a separate model in itself, but rather a series of intermediate calculations used to generate several regional variables which are used in subsequent steps in the Transportation Model. It comprises two subroutines, TSIZE and TREG; the first calculates light vehicle size 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 size class.

Redistribute FEM Sale Shares Among Six Size Classes

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

It is first necessary to reallocate the estimates of car and light truck sales supplied by the Macroeconomic Module. This is required due to the fact that definitions used in the Transportation Module differ from those used in the Macroeconomic Module. The trucks enumerated by the Macroeconomic Module's definition of light trucks includes all trucks less than 14,000 pounds gross vehicle weight. In the Transportation Module these trucks are addressed in three separate sections: trucks under 8,500 pounds are included in the LDV Model; trucks between 8,500 and 10,000 pounds are modeled separately in the Class 2b Vehicle Model; and trucks over 10,000 pounds are included in the Highway Freight Model. Additionally, the LDV Module estimates the allocation of LDV sales between cars and light trucks, reflecting the changing purchase patterns of consumers who have been shifting their purchases toward minivans and sport utility vehicles in recent years.

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

$$NEWCARS_{Year} = \left(MC\_SQTRCARS_{Year} + MC\_SQDTRUCKSL_{Year}\right) * LTCLS12A_{Year} * \left(1 - CARLTSHR_{Year}\right)$$

$$\textit{and} \tag{88}$$

$$NEWCLS12A_{Year} = \left(MC\_SQTRCARS_{Year} + MC\_SQDTRUCKSL_{Year}\right) * LTCLS12A_{Year} * CARLTSHR_{Year}$$

where:

NEWCARS = Total new car sales
NEWCLS12A = Total new light truck sales
MC_SQTRCARS = Total car sales, from the macroeconomic module
MC_SQDTRUCKS = Total light truck sales (under 14,000 pounds), from the macroeconomic module
LTCLS12A = Fraction of light trucks in class 12A
CARLTSHR = Allocation factor representing light duty truck fraction of heavy duty vehicle sales

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

$$NVS7SC_{group=1-2,class,Year} = CLASS\$SHARE_{class,group=1-2,Year} * NEWCARS_{Year} * \left(1 - FLTCRAT_{Year}\right) * SALESHR_{group=1-2,Year}$$

$$and \tag{89}$$

$$NVS7SC_{group=3-4,class,Year} = CLASS\$SHARE_{class,group=3-4,Year} * NEWCLS12A_{Year} * \left(1 - FLTTRAT_{Year}\right) * SALESHR_{group=3-4,Year}$$

where:

NVS7SC = Non-fleet, non-commercial sales
CLASS$SHARE = The market share for each automobile class, from FEM
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 which are domestic/imported by year

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

$$NCSTSCF_{class,Year} = \sum_{group=1}^{2} \left(NVS7SC_{group,class,Year}\right)$$

$$and \tag{90}$$

$$NLTSTSCF_{class,Year} = \sum_{group=3}^{4} \left(NVS7SC_{group,class,Year}\right)$$

where:

NCSTSCF = Sales of cars by 6 EPA size classes
NLTSTSCF = Sales of light trucks by 6 EPA size classes

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

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

and **(91)**

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

where:

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

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

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

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

and **(92)**

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

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

Determine Regional Values of Fuel Demand and Vehicle Sales

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

$$SEDSHR_{FUEL,REG,Year} = \frac{SEDSHR_{FUEL,REG,Year-1} * \left(\dfrac{TMC\_YD_{REG,Year}}{TMC\_YD_{REG,Year-1}} \right)}{\sum_{REG=1}^{9} SEDSHR_{FUEL,REG,Year-1} * \left(\dfrac{TMC\_YD_{REG,Year}}{TMC\_YD_{REG,Year-1}} \right)} \tag{93}$$

where:

SEDSHR = Regional share of the consumption of a given fuel in period, *Year*.
TMC_YD = Estimated disposable personal income by region REG
REG = Index referring to Census region

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

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

Determine the regional cost of driving per mile:

$$COSTMIR_{REG,Year} = 0.1251 * \left(\frac{PMGTR_{REG,Year}}{MPGFLT_{Year}} \right) \tag{94}$$

where:

COSTMIR = The cost per mile of driving in region *REG*, in $/mile
PMGTR = The regional price of motor gasoline, in $/MMBTU
MPGFLT = The previous year's stock MPG for non-fleet vehicles
0.1251 = A conversion factor for gasoline, in MMBTU/gal, 5.253/42.0.

Calculate regional income:

$$INCOMER_{REG,Year} = \left(\frac{TMC\_YD_{REG,Year}}{MC\_N_{REG,Year}} \right) \tag{95}$$

where:

INCOMER = Regional per capita disposable income
TMC_YD = Total disposable income in region *REG*
MC_N = Total population in region *REG*

Estimate regional driving demand:[6]

$$\begin{aligned} VMT16R_{REG,Year} &= \rho\, VMT16R_{REG,Year-1} + \beta_0 (1 - \rho) + \beta_1 \left(COSTMIR_{REG,Year} - \rho\, COSTMIR_{REG,Year-1} \right) \\ &+ \beta_2 \left(INCOMER_{REG,Year} - \rho\, INCOMER_{REG,Year-1} \right) + \beta_3 \left(PRFEM_{Year} - \rho\, PRFEM_{Year-1} \right) \end{aligned} \tag{96}$$

and:

$$VMTEER_{REG,Year} = VMT16R_{REG,Year} * MC\_N16N_{REG,Year} \tag{97}$$

where:

VMT16R = Vehicle-miles traveled per population over 16 years of age
PRFEM = Ratio of female to male driving rates
ρ = Lag factor for the difference equation
VMTEER = Total VMT in region *REG*
MC_N16N = Total regional population over the age of 16

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,Year} = \frac{VMTEER_{REG,Year}}{\sum_{REG=1}^{9} VMTEER_{REG,Year}} \tag{98}$$

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

[6] The development and estimation of the VMT equation is described in detail later, in the VMT Model (Section 3B-2).

$$NCS_{REG,class,Year} = NCSTSC_{class,Year} * RSHR_{REG,Year} \tag{99}$$

and:

$$NLTS_{REG,class,Year} = NLTSTSC_{class,Year} * RSHR_{REG,Year} \tag{100}$$

where:

NCS = New car sales, by size class and region
NLTS = New light truck sales, by size class and region

3A-3. AFV Model

The Alternative Fuel Vehicle (AFV) Model is a forecasting tool designed to support the Light Duty Vehicle (LDV) Module of the NEMS Transportation Sector Model. This model uses estimates of new car fuel efficiency obtained from the Fuel Economy Model (FEM) subcomponent of the LDV Module, and fuel price estimates generated by NEMS to generate market shares of each considered technology. The model is useful both to assess the penetration of alternative-fuel vehicles and to allow analysis of policies that might impact this penetration.

The objective of the AFV model is to estimate the market penetration (market shares) of alternative-fuel vehicles during the period 1990-2025. The methodology used in the AFV module is based on attribute-based discrete choice techniques and logit-type choice functions. The methodology consists of the estimation of a demand function for vehicle sales in the U.S. market and the derivation of coefficients for the vehicle and fuel attributes which portrays consumer demand. Once the demand function has been determined, projections of the changes in vehicle and fuel attributes for the considered technologies are multiplied by the corresponding attribute coefficients to produce the market share penetration for the various technologies.

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

$$\log \frac{P_i}{1 - P_i} = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_i X_i + \varepsilon_i$$

where P_i is the probability of a consumer choosing vehicle i, $ß_1$ is the constant, $ß_i$ are the coefficients of vehicle and fuel attributes and X_i are vehicle and fuel attributes.

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

The calculation of the market share penetration of alternative fuel vehicle sales is expressed in the following equation:

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

where:

S_{it} = market share sales of vehicle type i in year t,
P_{it} = aggregate probability over population N of choosing type i in year t,
n = individual n from population N,
P_{itn} = probability of individual n choosing type i in year t,
V_{itn} = a function of the K elements of the vector of attributes (A) and coefficients (B), generally linear in parameters, i.e.:

$$V = ß_1X_1 + ß_2X_2 + . . . + ß_kX_k$$

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

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

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

MODEL STRUCTURE

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

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

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

Calculate vehicle purchase price in nominal dollars:

$$PSPR_{vt,FuelType,class} = PRI_{vt,FuelType,class} * TMC\_PGDP \qquad \textbf{(103)}$$

where:

vt = Index referring to vehicle type (car or light truck)
FuelType= Index referring to fuel type (1-16)
class= Index referring to vehicle size class (1-6)
PRI = Aggregate vehicle price, obtained from FEM, and constrained not to drop below gasoline vehicle price plus the high volume differential between gasoline and ATV
TMC_PGDP = Implicit GDP price deflator from Macro Module, used to convert $90 to nominal $

Calculate fuel costs:

$$FLCOST_{vt,FuelType,class,REG} = \frac{FPRICE_{FuelType,REG} * TMC\_PGDP}{MPG_{vt,FuelType,class}} \qquad \textbf{(104)}$$

where:

FLCOST = Fuel operating costs for each technology, in nominal $ per mile
FPRICE = Vehicle fuel price in nominal $ / gallon
REG = Index referring to 9 census regions
MPG = Aggregate vehicle fuel economy

Calculate acceleration (0-60 mph) in seconds:

$$ACCL_{vt,FuelType,class} = e^{(-0.00275)} * \left(\frac{HPW_{vt,FuelType,class}}{WGT_{vt,FuelType,class}} \right)^{-0.776} \quad \textbf{(105)}$$

Calculate maintenance and battery costs in nominal dollars:

$$\begin{gathered} MAINT_{1,FuelType,class,REG} = MAINTCAR_{FuelType,REG} * TMC\_PGDP * V \\ and \\ MAINT_{2,FuelType,class,REG} = MAINTTRK_{FuelType,REG} * TMC\_PGDP * V \end{gathered} \quad \textbf{(106)}$$

where:

MAINTCAR = Car maintenance and battery costs in $ 96, from OTT Quality Metrics 99
MAINTTRK = Light truck maintenance and battery costs in $ 96, from OTT Quality Metrics 99
TMC_PGDP * V = conversion from $96 to nominal $

Calculate Fuel Availability (TALT2) Subroutine Methodology

The fuel availability variable attempts to capture the dynamic associated with increasing numbers 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 AFV Logit Model as an input into determining the proportion of the travel associated with use of the alternative-fuel in a flex or bi-fuel vehicle. Fuel availability is also used more directly in the utility function within the AFV Logit Model to proportion the sales among various vehicle types or technology groups. The final fuel availability variable is configured as an index relative to the number of gasoline refueling stations.

Calculate the vehicle stocks by the highway fuel type to determine refueling stations that might be using the fuel. The mapping from engine technology fuel type to highway fuel type is as follows;

engine technology fuel type	highway fuel type
gasoline	–> gasoline
diesel and diesel hybrid	–> diesel
flex-fuel and dedicated ethanol	–> ethanol / gasoline [7]
flex-fuel, dedicated and fuel cell methanol	–> methanol / gasoline[7]
bi-fuel and dedicated cng	–> cng
bi-fuel and dedicated lpg	–> lpg
dedicated electricity	–> electricity
hydrogen fuel cell	–> hydrogen

$$PREDSTK_{hwy\_fuel,\ Year} = LDVSTK_{FuelType,\ Year-1} + W * LDVSTK_{FuelType=\ flex\ :\ bi-fuel,\ Year-1} \quad \textbf{(107)}$$

where:

PREDSTK = Predicted vehicle stock used to calculate needed refueling stations
LDVSTK = Vehicle stock, by engine technology fuel type, 1 ... 16, using above mapping
W = weight given to assumed proportion of flex or bi-fuel vehicle stock that refuel with alternative fuel
hwy_fuel= highway fuel type, 1...8

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

$$ALTSTAT_{hwy\_fuel,\ Year} = ALTSTAT_{hwy\_fuel,\ Year-1} + \frac{PREDSTK_{hwy\_fuel,\ Year} - PREDSTK_{hwy\_fuel,\ Year-1}}{STARAT_{hwy\_fuel}} \quad \textbf{(108)}$$

where:

ALTSTAT = Total national level alternative-fuel refueling stations
STARAT = Ratio of refueling stations to vehicle stock based on history

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

[7] For flex-fuel vehicles.

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

$$AFVSHREG_{REG,hwy\_fuel,Year} = \frac{FUELVSAL_{REG,\ hwy\_fuel,Year}}{\sum FUELVSAL_{REG,hwy\_fuel,Year}} \quad \textbf{(109)}$$

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

where:

NCSTECH = Regional car sales by engine technology fuel type
NLTECH = Regional light truck sales by engine technology fuel type
FUELVSAL = Regional vehicle sales within a highway fuel type
AFVSHREG = Regional vehicle sales shares within a highway fuel type
ALTSTA = Regional alternative-fuel refueling stations by highway fuel type

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

$$FAVAIL_{hwy\_fuel,Year,REG} = \frac{ALTSTA_{REG,hwy\_fuel,Year}}{ALTSTA_{REG,gasoline,Year}} \quad \textbf{(110)}$$

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

$$FAVL_{FuelType,REG,Year} = FAVAIL_{hwy\_fuel,Year,ir} \quad \textbf{(111)}$$

where the fuel type mapping is described above.

Operation of the model begins at the third level and progresses to the first level, because the valuations at the lower levels are used as a part of the evaluation at the upper levels of the logit model.

Level Three

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

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

(112)

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

where:

X3132 = Coefficient for vehicle range; (X3132 = Flex methanol, X3142 = Flex ethanol, X3152 = CNG Bi-fuel, and X3162 = LPG Bi-fuel)
X31 = Coefficient for level 3 multi-fuel generalized cost by vehicle type, *vt*, and size class, *class*
X23 = Coefficient for logit level 2 vehicle range
X22 = Coefficient for logit level 2 fuel cost
BETAFA = Coefficient for fuel availability linear component
BETAFA2 = Coefficient for fuel availability non-linear component

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

$$UISUM_{FuelType} = X31_{vt,class} * FLCOST_{vt,FuelType,class,REG} + X3132 * (1/VRNG_{vt,FuelType,class}) + BETAFA * e^{(BETAFA2_{vt,class} * FAVL_{FuelType,REG})} \quad \textbf{(113)}$$

where:

UISUM = Utility Value function for vehicle attributes at multi-fuel level for fuel type and region
FLCOST = Fuel cost of driving per mile for AFV fuel technology, *FuelType*, in cents per mile
VRNG = Vehicle range in miles
FAVL = Fuel availability indexed relative to gasoline
FuelType = AFV fuel technologies, gasoline, flex-fuels ethanol and methanol, and bi-fuels cng and lpg

3) Utility values are exponentiated and summed.

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

(114)

$$ETOT = \sum ESUM$$

where:

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

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

$$GENCOST = \frac{1}{X31_{vt,class}} * \log(ETOT) \tag{115}$$

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

Level Two

The second level of the AFV logit model calculates the market shares among the AFV technologies within each of the five first level groups. As stated previously, the five groups consist of : 1) conventional vehicles (gasoline, diesel, flex-fuel methanol and ethanol, and bi-fuels cng and lpg), 2) hybrid electric vehicles (gasoline and diesel fueled), 3) dedicated alternative fuel vehicles (ethanol, methanol, compressed natural gas (CNG), and LPG fueled), 4) fuel cell vehicles (gasoline, methanol, and hydrogen fueled), and 5) electric vehicles (using lead-acid or nickel-metal hydride batteries). Second level market shares are estimated separately for flex and bi-fueled vehicles versus shares estimated for dedicated fuel vehicles.

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

$$\begin{aligned} UISUM_{jt} = {} & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * GENCOST \\ & + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\ & + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\ & + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log(MMAVAIL_{vt,class,FuelType,Year}) \\ & + X210_{vt,FuelType} \end{aligned} \tag{116}$$

where:

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

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

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

X24 = Coefficient for battery replacement cost at the second level

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

X26 = Coefficient for electric vehicle home refueling capability
X27 = Coefficient for maintenance cost in dollars
X28 = Coefficient for luggage space indexed to gasoline vehicle
X29 = Coefficient for vehicle make and model diversity availability relative to gasoline
X210 = Coefficient for calibration coefficient determined in trninput.wk1 input file
PSPR = Vehicle price at the second level in dollars
BRCOST25 = Battery replacement cost at the second level
ACCL = Vehicle acceleration time from 0 to 60 miles per hour in seconds
HFUEL = Electric vehicle home refueling capability dummy variable (0,1 value)
MAINT = Maintenance cost in dollars
LUGG = Luggage space indexed to gasoline vehicle
MMAVAIL = Vehicle make and model diversity availability relative to gasoline exogenously determined in trninput.wk1 input file

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

$$\begin{aligned} UISUM_{jt} = {} & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * FLCOST \\ & + X23_{vt,class} * \left(\frac{1}{VRNG_{vt,FuelType,class,Year}}\right) \\ & + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\ & + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\ & + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log(MMAVAIL_{vt,class,FuelType,Year}) \\ & + X210_{vt,FuelType} + BETAFA2_{vt,class} * e^{(BETAFA22_{vt,class} * FAVL_{FuelType,REG,Year})} \end{aligned} \quad \textbf{(117)}$$

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

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

$$ETOT_{jg} = \sum_{jt\ c\ jg} ESUM_{jt} \quad \textbf{(118)}$$

$$XSHARE_{jg,jt} = \frac{ESUM_{jt}}{ETOT_{jg}}$$

Level One

Calculate the generalized cost function as a function of the sum of the exponentiated utility values for each jg group

$$GCOST_{jg} = \frac{1}{X21_{vt,class}} * \log(ETOT_{jg}) \tag{119}$$

where:

GCOST = Generalized cost function of the jg group

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

$$UISUM_{jg} = X11_{vt,class} * GCOST_{jg} \tag{120}$$

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

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

$$YSHARE_{jg} = \frac{ESUM_{jg}}{\sum_{jg=1}^{5} ESUM_{jg}} \tag{121}$$

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

where:

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

APSHR44 is used in equation (140), the vehicle sales equation in the LDV Fleet module.

3B. LDV Fleet Module

The Light Duty Vehicle Fleet Module 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 Module includes a characterization of Class 2b vehicles, which are used in business and trade, and are not classifiable under either the LDV model or the Highway Freight Model.

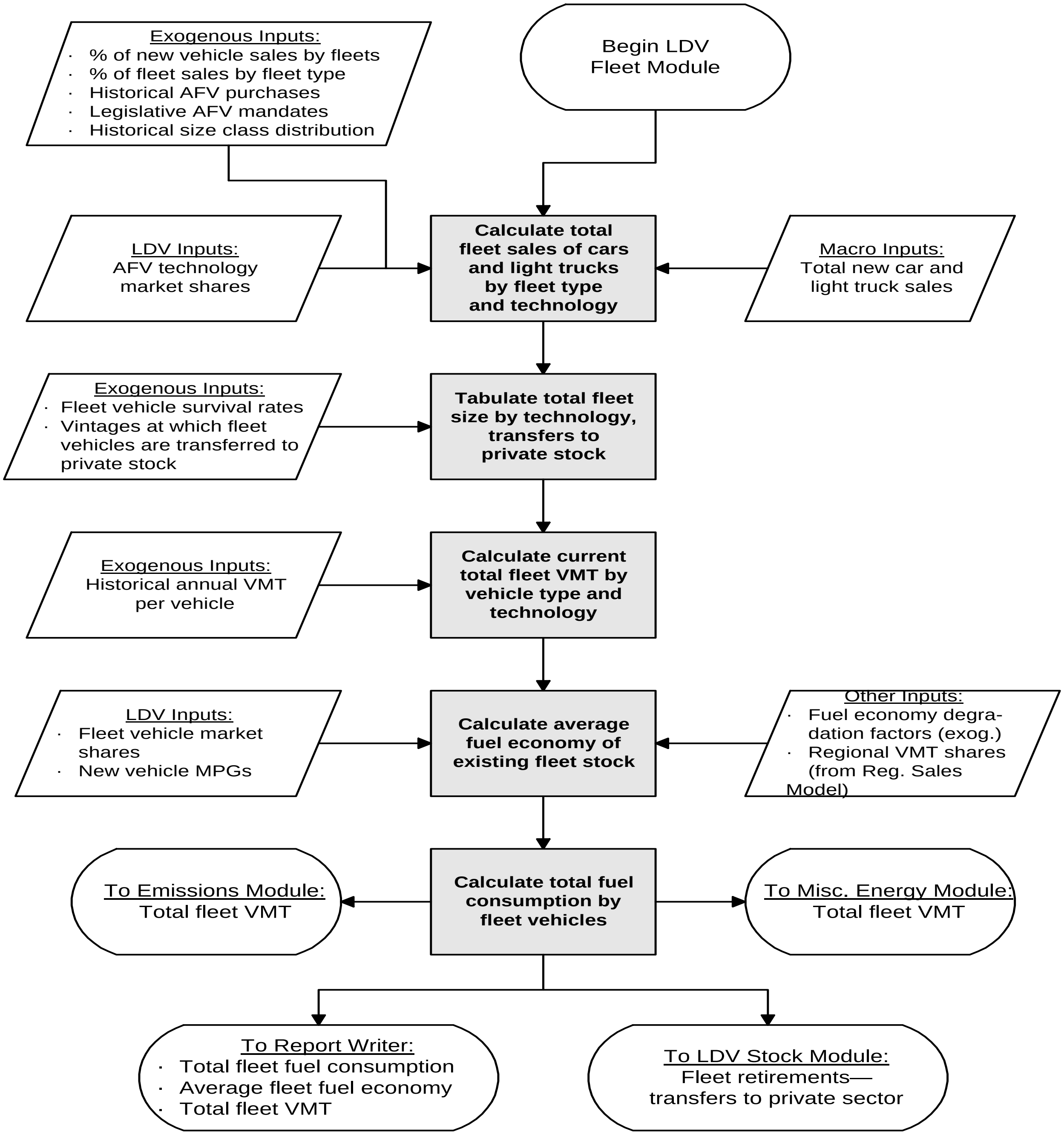
3B-1. LDV Fleet Module

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

This model uses the same variable names for cars and light trucks and 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 model consists of three stages: determine total vehicle purchases, surviving fleet stocks and travel demand, calculate the fuel efficiency of fleet vehicles, and estimate the consequent fuel consumption.

The flowchart for the Light Duty Vehicle Fleet Module is presented below in Figure 3B-1. Additional flowcharts outlining major LDV Fleet calculations in more detail are presented throughout this section.

Figure 3B-1. Light Duty Vehicle Fleet Module



Note: the emissions module is currently inactive.

Calculate Fleet Sales and Stocks

Calculate fleet acquisitions of cars and light trucks, see Figure 3B-2, below:

$$FLTSAL_{vt=1,flt,Year} = FLTCRAT_{Year} * NEWCARS_{Year} * FLTCSHR_{flt,Year}$$

and **(122)**

$$FLTSAL_{vt=2,flt,Year} = FLTTRAT_{Year} * NEWCLS12A_{Year} * FLTTSHR_{flt,Year}$$

where:

FLTSAL = Sales to fleets by vehicle and fleet type
FLTCRAT = Fraction of total car sales attributed to fleets
FLTTRAT = Fraction of total truck sales attributed to fleets
NEWCARS = Total new car sales in a given year
NEWCLS12A = Total new light truck sales in a given year
FLTCSHR = Fraction of fleet cars purchased by a given fleet type
FLTTSHR = Fraction of fleet trucks purchased by a given fleet type
vt = Index of vehicle type: 1 = cars, 2 = light trucks
flt = Index of fleet type: 1 = business, 2 = government, 3 = utility

For cars only: separate the business fleet sales into covered and uncovered strata, reflecting the fact that EPACT regulations cover federal, state, and fuel provider fleet vehicles, and do not cover any other fleet vehicles. This separation is based on an extrapolation of historical trends in business fleets, using an assumed upper limit.

$$BFLTFRAC_{Year} = BFLTFRACMIN + (BFLTFRACMAX - BFLTFRACMIN) * e^{(KBUS \cdot (Year + 1989 - 1971))} \quad \textbf{(123)}$$

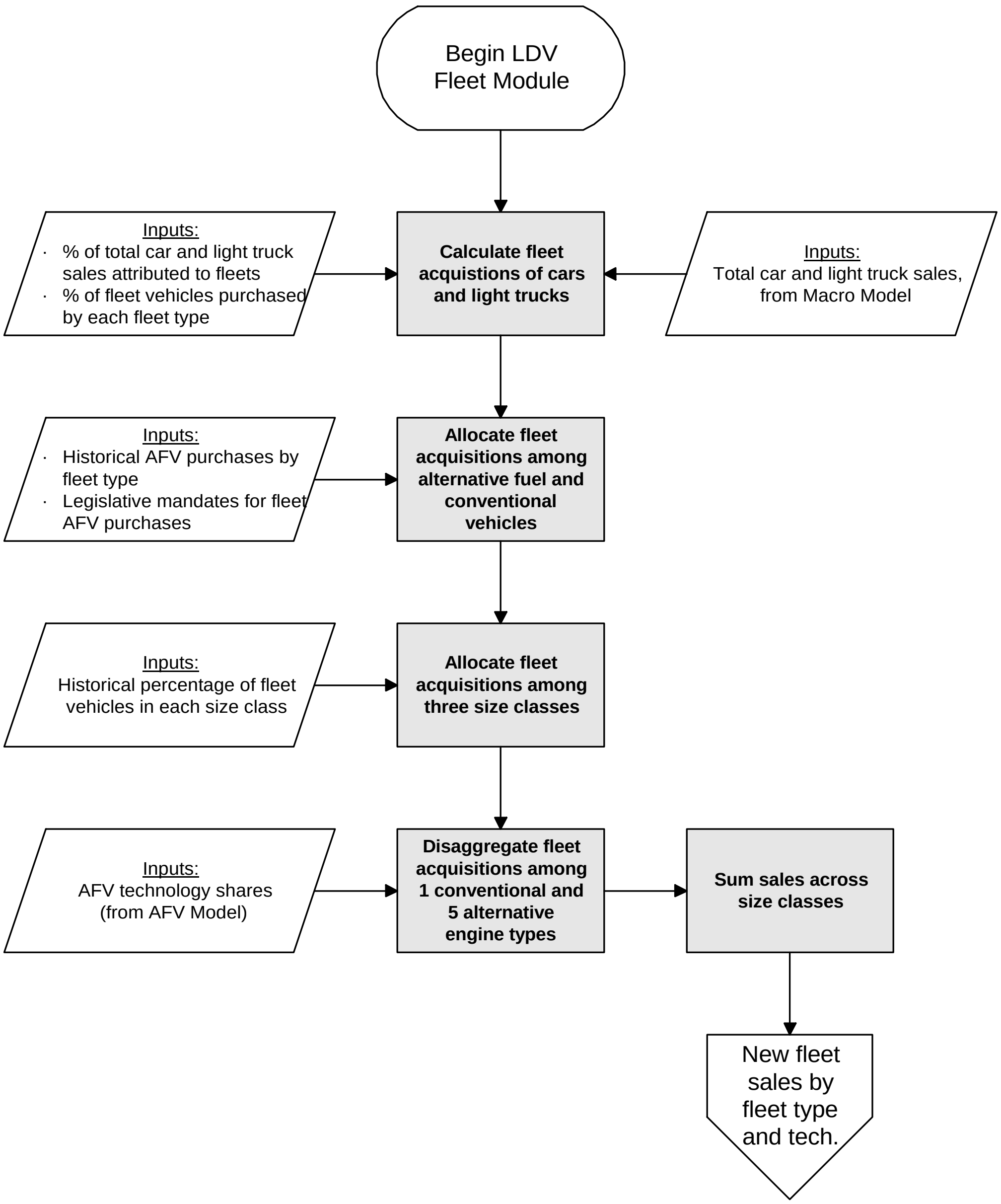
and:

$$BUSCOV_{Year} = FLTSAL_{vt=1,flt=1,Year} * BFLTFRAC_{Year} \quad \textbf{(124)}$$

where:

BUSCOV = Business fleet acquisitions covered by EPACT provisions
BFLTFRAC = Fraction of business fleet purchases covered by EPACT provisions in year , *Year*
KBUS = exponential coefficient, estimated to be -0.0404
BFLTFRACMIN = Minimum fraction of business fleet purchases, assumed to be 0.4
BFLTFRACMAX = Maximum fraction of business fleet purchases, assumed to be 0.612

Figure 3B-2: LDV Fleet Module 1: Process New Fleet Acquisitions



Calculate the percentage of fleet vehicle sales which go to fleets of 50 or more vehicles:

For cars:

$$FLTPCT_{vt=1,flt=1} = k_3 \left[\frac{1}{Ln\,(50)} \right] \tag{125}$$

For light trucks:

$$FLTPCT_{vt=2,flt=1,3} = (50)^{k_{2,flt}} \tag{126}$$

where:

k_3 = Normalized proportionality constant for automobile fleets, estimated to be 1.386.
$k_{2,flt}$ = Proportionality constant for business and utility fleets, -0.747 and -0.111, respectively.

Calculate the number of alternative vehicles sold for each fleet and vehicle type under EPACT mandates, taking into consideration the geographic and central-refueling constraints. These constraints are constant, and are tabulated below.

Geographic Constraints, by Fleet Type			
	Business (flt= 1)	**Government (flt = 2)**	**Utility (flt = 3)**
CTLREFUEL	50%	100%	100%
MSA	90%	63%	90%
FLT20	75%	90%	90%

For cars:

$$FLTALTE_{vt=1,flt=1,Year} = BUSCOV_{Year} * FLTPCT_{vt,flt} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year}$$

$$and \tag{127}$$

$$FLTALTE_{vt=1,flt\neq 1,Year} = FLTSAL_{vt,flt,Year} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year}$$

For light trucks:

$$FLTALTE_{vt=2,flt=1,3,Year} = FLTSAL_{vt,flt,Year} * FLTPCT_{vt,flt} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year}$$

$$and \tag{128}$$

$$FLTALTE_{vt=2,flt=2,Year} = FLTSAL_{vt,flt,Year} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year}$$

where:

FLTALTE = AFV sales to fleets under EPACT mandates

EPACT3 = Sales-weighted aggregation of EPACT purchase requirements, reflecting impacts on three fleet types.

CTLREFUEL = The percentage of fleet vehicles which are capable of being centrally refueled.

MSA = The percentage of fleetslocated within urban areas of 250,000 population.

FLT20 = The percentage of 50+ fleet vehicles that are 20+ within urban areas.

The number of alternative-fuel vehicles which would result from a continuation of historical purchase patterns is also calculated, representing a minimum acquisition level:

$$FLTALTH_{vt,flt,Year} = FLTSAL_{vt,flt,Year} * FLTAPSHR1_{flt,Year} \quad \textbf{(129)}$$

where:

FLTALTH = Fleet AFV purchases, using constant historical shares.

FLTAPSHR1 = Fleet percentage of AFV's, by fleet type.

Determine total alternative fuel fleet vehicle sales, using the maximum of the market-driven and legislatively mandated values :

$$FLTALT_{vt,flt,Year} = MAX\left[FLTALTE_{vt,flt,Year}\ ,\ FLTALTH_{vt,flt,Year}\right] \quad \textbf{(130)}$$

where:

FLTALT = Number of AFV's purchased by each fleet type in a given year

FLTALTH = Fraction of each fleets purchases which are AFV's, from historical data

FLTALTE = Legislative mandates for AFV purchases, by fleet type

The difference between total and AFV sales represents conventional sales:

$$FLTCONV_{vt,flt,Year} = FLTSAL_{vt,flt,Year} - FLTALT_{vt,flt,Year} \quad \textbf{(131)}$$

where:

FLTCONV = Fleet purchases of conventional vehicles

FLTSAL = Sales to fleets by vehicle and fleet type

FLTALT = Number of AFV's purchased by each fleet type in a given year

Fleet purchases are subsequently divided by size class:

$$FLTSLSCA_{vt,flt,class,Year} = FLTALT_{vt,flt,Year} * FLTSSHR_{flt,class,vt}$$

and: **(132)**

$$FLTSLSCC_{vt,flt,class,Year} = FLTCONV_{vt,flt,Year} * FLTSSHR_{flt,class,vt}$$

where:

FLTSLSCA = Fleet purchases of AFV's, by size class, *class*
FLTSLSCC = Fleet purchases of conventional vehicles, by size class, *class*
FLTSSHR = Percentage of fleet vehicles in each size class, from historical data

A new variable is then established, *FLTECHSAL*, disaggregating AFV sales by engine technology fuel type, *engtech*, namely (neat fuels, 1-5) ethanol, methanol, electric, cng, and lpg, and (conventional fuel, 6) gasoline:

$$FLTECHSAL_{vt,flt,class,engtech \neq 6} = FLTSLSCA_{vt,flt,class,Year} * FLTECHSHR_{engtech \neq 6,flt}$$

and: **(133)**

$$FLTECHSAL_{vt,flt,class,engtech = 6} = FLTSLSCC_{vt,flt,class,Year}$$

where:

FLTECHSAL = Fleet sales by size, technology, and fleet type
FLTECHSHR = Alternative technology shares by fleet type
engtech = Index of fuel types: 1-5 = alternative fuels (neat), 6 = gasoline

Sales are then summed across size classes:

$$FLTECH_{vt,flt,engtech} = \sum_{class=1}^{6} FLTECHSAL_{vt,flt,class,engtech} \qquad \textbf{(134)}$$

where:

FLTECH = Vehicle purchases by fleet type and technology

The next step is to modify the array of surviving fleet stocks from previous years, and to add these new acquisitions, see Figure 3B-3 below. This is done by applying the appropriate survival factors to the current vintages and inserting FLTECH into the most recent vintage:

$$FLTSTKVN_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint-1,Year-1} * SURVFLTT_{vt,vint-1}$$
$$and:$$
$$FLTSTKVN_{vt,flt,engtech,vint=1,Year} = FLTECH_{vt,flt,engtech} \qquad \textbf{(135)}$$

where:

FLTSTKVN = Fleet stock by fleet type, technology, and vintage
SURVFLTT = Survival rate of a given vintage
vint = Index referring to vintage of fleet vehicles

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

$$OLDFSTK_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint,Year} \qquad \textbf{(136)}$$

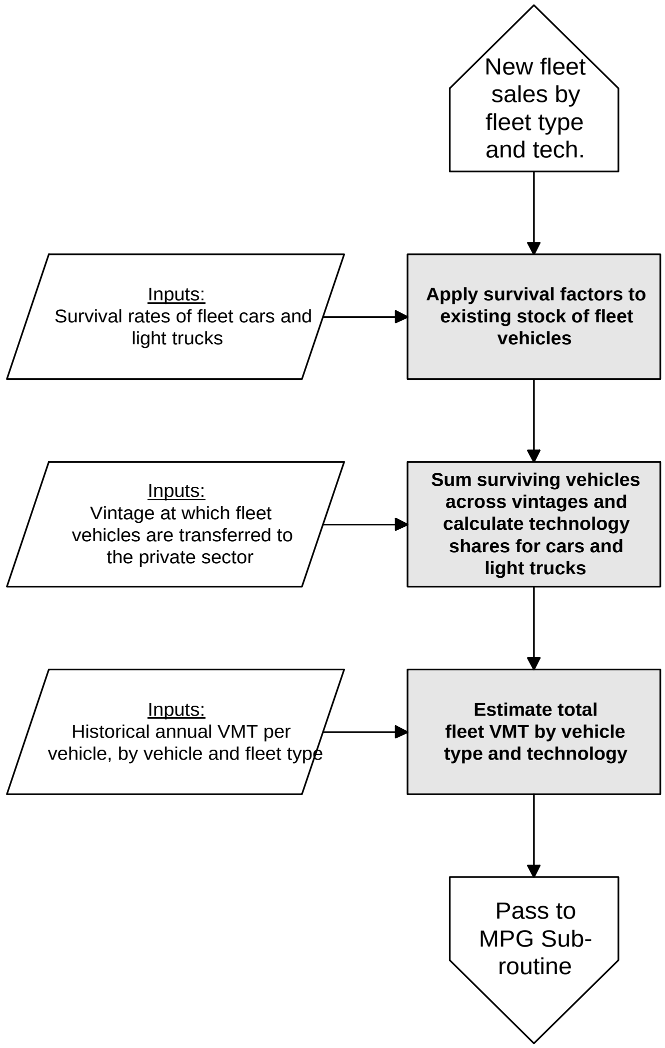
where:

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

The variable OLDFSTK is subsequently sent to the LDV Stock Model 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 below.

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

Figure 3B-3. LDV Fleet Module 2: Determine Characteristics of Existing Fleets



Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{vt,flt,engtech,Year} = \sum_{vint=1}^{6} FLTSTKVN_{vt,flt,engtech,vint,Year} \qquad \textbf{(137)}$$

where:

TFLTECHSTK = Total stock within each technology and fleet type

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

$$VFSTKPF_{vt,flt,engtech,Year} = \frac{TFLTECHSTK_{vt,flt,engtech,Year}}{\sum_{vt=1}^{2}\sum_{flt=1}^{3}\sum_{engtech=1}^{6} TFLTECHSTK_{vt,flt,engtech,Year}} \qquad \textbf{(138)}$$

where:

VFSTKPF = Share of fleet stock by vehicle type and technology

Vehicle sales and market shares are then adjusted to reflect the California's legislative mandates on sales of zero-emission vehicles (ZEV's) and ultra-low emission vehicles (ULEV's), which have also been tentatively adopted by New York, Massachusetts, Maine, and Vermont.

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

$$VSALES_{vt=1,class,REG,FuelType,Year} = APSHR44_{vt=1,class,REG,FuelType,Year} * NCS_{REG,class,Year}$$

$$and \qquad \textbf{(139)}$$

$$VSALES_{vt=2,class,REG,FuelType,Year} = APSHR44_{vt=2,class,REG,FuelType,Year} * NLTS_{REG,class,Year}$$

where:

APSHR44 = Share calculated from equation 121

NCS = Regional non-fleet car sales by size class, calculated in equation 99.

NLTS = Regional non-fleet light truck sales by size class, calculated in equation 100.

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

$$ZEVST_{st} = TTLZEV_{Year} * \left(COEF1_{st} * NEWCARS_{Year} + COEF2_{st} * NEWCLS12A_{Year}\right) \tag{140}$$

where:

TTLZEV = Total mandated sales of ZEV's, from input file, trninput.wk1
ZEVST = State-mandated sales of ZEV's, and ZEVST = ZEVMA, ZEVNY, ZEVCA
st = Index of participating state: CA = California, NY = New York
MA = Maine, Massachusetts, and Vermont
vt = Index of vehicle type: 1 = cars, 2 = light trucks
NEWCARS = Total new car sales, from
NEWCLS12A = Total new light truck sales, from
COEF1 = Fraction of total new car sales by state
COEF2 = Fraction of total new light truck sales by state

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

$$TOTCRED_{REG} = \sum_{vt=1}^{2} \left(VSALES\_EVGH_{vt,REG} + VSALES\_EVDH_{vt,REG} + VSALES\_CNG_{vt,REG} + VSALES\_FCM_{vt,REG} + VSALES\_FCG_{vt,REG}\right) \tag{141}$$

where:

VSALES_EVGH = gasoline hybrid vehicle sales = $VSALES_{FuelType=14}$, summed over size classes
VSALES_EVDH = diesel hybrid vehicle sales = $VSALES_{FuelType=8}$, summed over size classes
VSALES_CNG = cng vehicles sales = $VSALES_{FuelType=5}$, summed over size classes
VSALES_FCM = fuel cell methanol vehicles sales = $VSALES_{FuelType=11}$, summed over size classes
VSALES_FCG = fuel cell gasoline vehicle sales = $VSALES_{FuelType=13}$, summed over size classes
TOTCRED = total available ZEV credit sales from either hybrid, fuel cell, or cng vehicles
REG = census region 1 (participating state MA), 2 (NY),and 9 (CA)

If the total sales of hybrids, fuel cell (excluding hydrogen fuel cells) and cng vehicles, TOTCRED, is less than the total maximum allowable Low Emission Vehicle Program (LEVP) credits, then scale the vehicle sales to meet the mandates:

$$AVSALES_{vt,class,REG,FuelType} = VSALES_{vt,class,REG,FuelType} * [\frac{(ZEVSALES_{REG} * PZEV_{Year})}{TOTCRED_{REG} - VSALES\_EVGH_{vt,REG}}] \quad \textbf{(142)}$$

where:

AVSALES = total vehicle sales, for hybrids, fuel cells excluding hydrogen, and cng vehicles
ZEVSALES = total ZEV sales that are mandated in census region, REG=1,2, and 9
= ZEVST for REG=1 (state=MA), REG=2 (state=NY), and REG=9 (state=CA)
PZEV = percent of total ZEV's that are the maximum allowable LEVP credits, in trninput.wk1

4) Calculate the total sales of ZEV's for fuel cell, hydrogen, and electric vehicles:

$$TZEVSAL_{REG} = \sum_{vt=1}^{2} \left(VSALES\_FCH_{vt,REG} + VSALES\_EV_{vt,REG}\right) \quad \textbf{(143)}$$

where:

TZEVSAL = ZEV sales of hydrogen fuel cell, VSALES_FCH, and dedicated electric vehicles, VSALES_EV

If the total sales of electric dedicated and hydrogen fuel cell vehicles is less than the remaining percent, *ZEV*, of the original ZEV sales mandate, scale the EV and fuel cell sales to meet mandates:

$$AVSALES_{vt,class,REG,FuelType} = VSALES_{vt,class,REG,FuelType} * \frac{(ZEVSALES_{REG} * ZEV_{Year})}{TZEVSAL_{REG}} \quad \textbf{(144)}$$

where:

AVSALES = final total vehicle sales by engine technology; for electric dedicated and hydrogen fuel cell

5) All of the additional sales of vehicles resulting from scaling up the above alternative fuel technology vehicle sales are subtracted from the gasoline vehicles:

$$AVSALES_{vt,class,REG,Gasoline} = VSALES_{vt,class,REG,Gasoline} - DEL\_TECH_{vt,class,REG,FuelType} \quad \textbf{(145)}$$

where:

DEL_TECH = the additional vehicle sales needed to meet the maximum credits
= $AVSALES_{vt,class,REG,FuelType}$ - $VSALES_{vt,class,REG,FuelType}$
FuelType = hybrid, fuel cell, cng, and electric engine fuel technologies

Sum adjusted vehicle sales across technologies:

$$AVSALEST_{vt,class,REG} = \sum_{FuelType=1}^{16} AVSALES_{vt,class,REG,FuelType} \quad \textbf{(146)}$$

where:

AVSALEST = Total regional adjusted vehicle sales by size class

Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{vt,class,REG,FuelType} = \frac{AVSALES_{vt,class,REG,FuelType}}{AVSALEST_{vt,class,FuelType}} \tag{147}$$

where:

APSHR55 = Absolute regional market shares of adjusted vehicle sales

6) Finally, calculate new car and light truck sales using market shares:

$$NCSTECH_{REG,class,FuelType} = NCS_{REG,class} * APSHR55_{vt=1,class,REG,FuelType}$$

and **(148)**

$$NLTECH_{REG,class,FuelType} = NLTS_{REG,class} * APSHR55_{vt=2,class,REG,FuelType}$$

where:

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

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

Calculate Fleet VMT

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

$$FLTVMT_{Year} = \sum_{vt=1}^{2} \sum_{flt=1}^{3} \sum_{engtech=1}^{6} \left(TFLTECHSTK_{vt,flt,engtech,Year} * FLTVMTYR_{flt,Year,vt} \right) \qquad \textbf{(149)}$$

where:

FLTVMT = Total VMT driven by fleet vehicles
FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type, from trninput.wk1
TFLTECHSTK = total stock within each technology and flrrt type, calculated in equation 137

Total VMT is then disaggregated by vehicle type and technology:

$$FLTVMTECH_{vt,flt,engtech,Year} = FLTVMT_{Year} * VFSTKPF_{vt,flt,engtech,Year} \qquad \textbf{(150)}$$

where:

FLTVMTECH = Fleet VMT by technology, vehicle type, and fleet type
VFSTKPF = Share of fleet stock, calculated in equation 138

Calculate Fleet Stock MPG

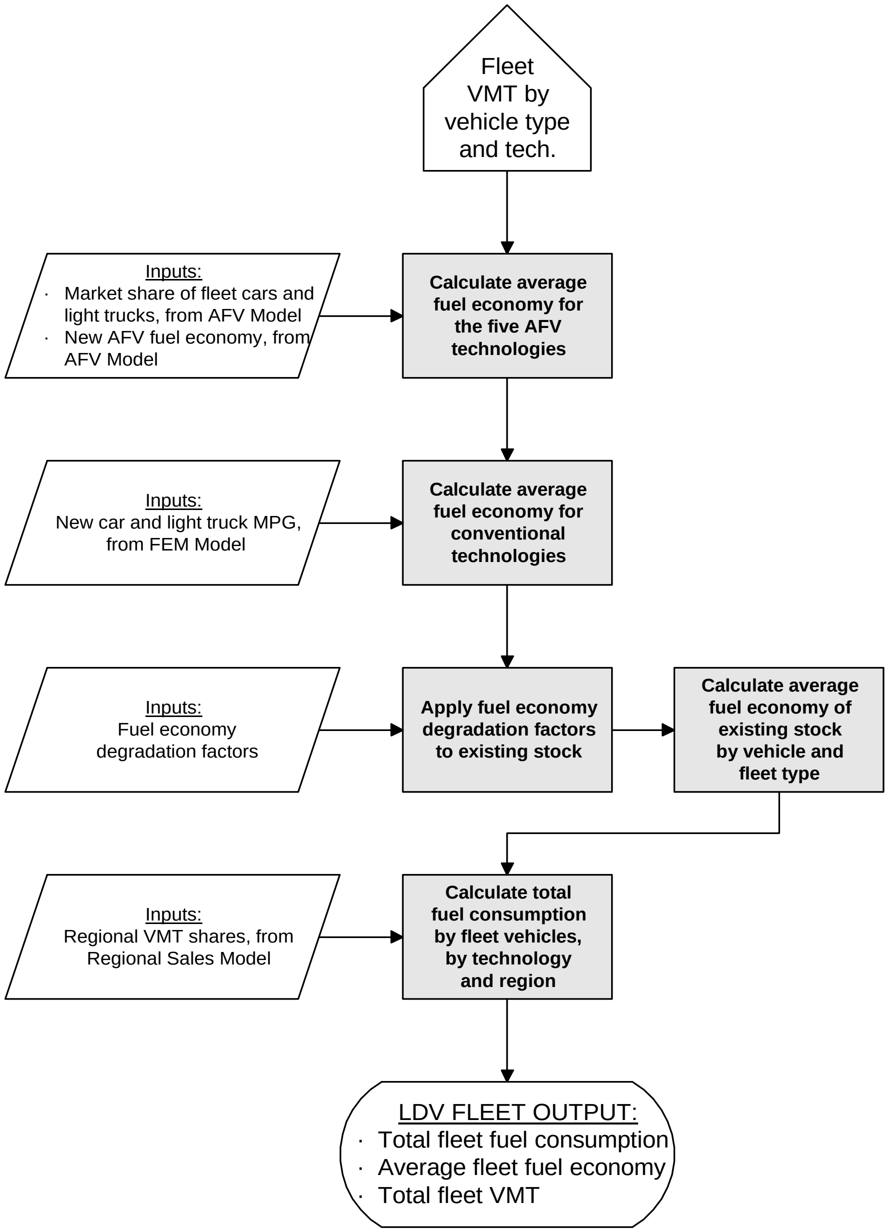
The average efficiencies of the five non-gasoline technologies (ethanol, methanol, electric, CNG, and LPG) and conventional gasoline ICE technology are calculated as follows (see Figure 3B-4, below):

$$FLTMPG_{vt,flt,engtech} = \left[\frac{\sum_{class=1}^{6} FLTECHSAL_{vt,flt,class,engtech}}{\sum_{class=1}^{6} \frac{FLTECHSAL_{vt,flt,class,engtech}}{MPG_{vt,FuelType,class}}} \right] \qquad \textbf{(151)}$$

where:

FLTMPG = New fleet vehicle fuel efficiency, by fleet type and engine technology fuel type, *engtech*
FuelType = Index which matches technologies in the AFV model to corresponding *engtech* fuel types
flt = Fleet types referring to business, government, or utility
class = 6 EPA size classes

Figure 3B-4. LDV Fleet Module 3: Determine Fleet Fuel Economy and Consumption



Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{vt} = \left[\frac{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} FLTECH_{vt,flt,engtech}}{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} \frac{FLTECH_{vt,flt,engtech}}{FLTMPG_{vt,flt,engtech}}} \right] \tag{152}$$

where:

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

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 = 1,7*.

For vint=1:

$$CMPGFSTK_{flt,engtech,vint,Year} = FLTMPG_{vt=1,flt,engtech,Year}$$

$$\text{and} \tag{153}$$

$$TMPGFSTK_{flt,engtech,vint,Year} = FLTMPG_{vt=2,flt,engtech,Year}$$

where:

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

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

For vint=2,7:

$$CMPGFSTK_{flt,engtech,vint,Year} = CMPGFSTK_{flt,engtech,vint-1,Year-1}$$

$$\text{and} \tag{154}$$

$$TMPGFSTK_{flt,engtech,vint,Year} = TMPGFSTK_{flt,engtech,vint-1,Year-1}$$

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

$$MPGFLTSTK_{vt=1,flt,engtech} = \left[\frac{\sum_{vint=1}^{maxvint} \left(FLTSTKVN_{vt=1,flt,engtech,vint} \right)}{\sum_{vint=1}^{maxvint} \left(\frac{FLTSTKVN_{vt=1,flt,engtech,vint}}{CMPGFSTK_{flt,engtech,vint} * CDFRFG} \right)} \right]$$

and **(155)**

$$MPGFLTSTK_{vt=2,flt,engtech} = \left[\frac{\sum_{vint=1}^{maxvint} \left(FLTSTKVN_{vt=2,flt,engtech,vint} \right)}{\sum_{vint=1}^{maxvint} \left(\frac{FLTSKTVN_{vt=2,flt,engtech,vint}}{TMPGFSTK_{flt,engtech,vint} * LTDFRFG} \right)} \right]$$

where:

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

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

CDFRFG = degredation factor for cars

LTDFRFG = degredation factor for light trucks

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

$$FLTTOTMPG_{vt} = \left[\frac{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} TFLTECHSTK_{vt,flt,engtech}}{\sum_{flt=1}^{3} \sum_{engtech=1}^{6} \frac{TFLTECHSTK_{vt,flt,engtech}}{MPGFLTSTK_{vt,flt,engtech}}} \right] \qquad \textbf{(156)}$$

where:

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

Calculate Fuel Consumption by Fleet Vehicles

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

$$FLTLDVC_{vt,flt,engtech} = \frac{FLTVMTECH_{vt,flt,engtech}}{MPGFLTSTK_{vt,flt,engtech}} * QBTU_{engtech} \quad \textbf{(157)}$$

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:

$$FLTFCLDVBTU_{vt,engtech,Year} = \frac{FLTVMTECH_{vt,flt,engtech,Year}}{MPGFLTSTK_{vt,flt,engtech}} \quad \textbf{(158)}$$

where:

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

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

$$FLTFCLDVBUTR_{REG,engtech,Year} = \sum_{vt=1}^{2} FLTFCLDVBTU_{vt,engtech,Year} * RSHR_{REG} \quad \textbf{(159)}$$

where:

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology

RSHR = Regional VMT shares, from the Regional Sales Model

REG = Index of regions

3B-2. Class 2b Vehicle Module

The Class 2b Vehicle Module provides an accounting of sales, stocks, fuel economy and energy use for vehicles weighting 8,500 to 10,000 pounds gross vehicle weight (GVW)[8]. The model tracks travel and fuel efficiency for twenty vehicle vintages. The primary thrust of this model is to provide a stratification mechanism to allocate the stock and new sales of Class 2b vehicles among the various major-use groups considered in this model. This involves using the distribution of trucks reported in the 1997 Vehicle Inventory and Use Survey (VIUS) to estimate the fraction of trucks that fall into the 8,500 to 10,000 pound weight category, and subsequently distribute them according to the principal products carried. Historical stock numbers are derived from Polk Company data from the Oak Ridge National Laboratory study [9], and new sales are obtained from the macroeconomic model. VIUS provides data distributing VMT by major use to estimate total annual miles within each strata of Macroeconomic values.

Class 2b Vehicle Model Equations

Calculate the new Class 2b vehicle sales:

$$NEWCLS2B_{Year} = (MC\_SQTRCARS_{Year} + MC\_SQDTRUCKSL_{Year} * LTCLS2B_{Year} * 10^6 \qquad \textbf{(160)}$$

where:

NEWCLS2B = Sales of light trucks 8,500 to 10,000 pounds gross vehicle weight
MC_SQTRCARS = Total sales of cars, from the Macro Model
MC_SQTRUCKSL = Total sales of light trucks (up to 14,000 pounds gross vehicle weight), from the Macro Model
LTCLS2B = Fraction of Light Duty Trucks with a gross vehicle weight of 8,500 to 10,000 pounds

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:

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

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

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

and **(161)**

$$CLTSTK_{vint,Year} = CLTSTK_{vint-1,Year-1} * CLTSURV_{vint-1}$$

where:

CLTSTK = Class 2b vehicle stock, by vintage
CLTSURV = Percentage of previous year's stock which gets carried over
vint = vintage or age of vehicle = 2,.., 20;

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

$$CLTVMT_{vint,Year} = CLTSTK_{vint,Year} * CLTVMTV_{vint,1995} * \left[\frac{growth2_{Year}}{growth1_{Year}}\right]^{Year-1995} \quad \textbf{(162)}$$

where:

CLTVMTV = Class 2b vehicle miles traveled per truck for 1995, from trninput.wk1
growth1 = annual growth in Class 2b vehicle miles traveled
= $sum_{vint=1,20}(cltvmt_{vint,Year}) / sum_{vint=1,20}(cltvmt_{vint,Year-1})$
growth2 = annual growth in industry sector output weighted by Class 2b vehicle travel distribution by industry, for industry groups: 1 = Agriculture; 2 = Mining; 3 = Construction; 4 = Trade; 5 = Utilities; 6 = Personal

Estimate Class 2b vehicle fuel economy by vintage:

$$CLTMPG_{vint,Year} = CLTMPGV_{vint}\ , \ vint=1,...,20, \quad Year=1995$$

and

$$CLTMPG_{vint,Year} = CLTMPG_{vint,Year-1}\ , \ vint=1, \quad Year>1995$$

(163)

and

$$CLTMPG_{vint,Year} = CLTMPG_{vint-1,Year-1} * \left[\frac{MPGT_{gasoline,Year}}{MPGT_{gasoline,Year-1}}\right], \ vint\geq 2, \quad Year>1995$$

where:

MPGT = Light-duty truck miles per gallon (gasoline technology), from the LDV Stock Module
CLTMPGV = Base year light-duty truck miles per gallon (gasoline technology)
vint = vintage of vehicle, Year = model calendar year

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

$$CLTGAL_{Year} = \left[\sum_{vint=1}^{20} \frac{CLTVMT_{vint,Year}}{CLTMPG_{vint,Year}} \right]$$

$$and \qquad \textbf{(164)}$$

$$CLTBTU_{Year} = CLTGAL_{Year} * \frac{5.253}{42}$$

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

$$CLTMPGT_{Year} = \left[\frac{\sum_{vint=1}^{20} CLTVMT_{vint,Year}}{CLTGAL_{Year}} \right] \qquad \textbf{(165)}$$

3C. LDV Stock Module

The Light Duty Vehicle Stock Module takes sales and efficiency estimates for new cars and light trucks from the LDV Module, and returns the number and characteristics of the total surviving fleet of light-duty vehicles, along with regional estimates of LDV fuel consumption.

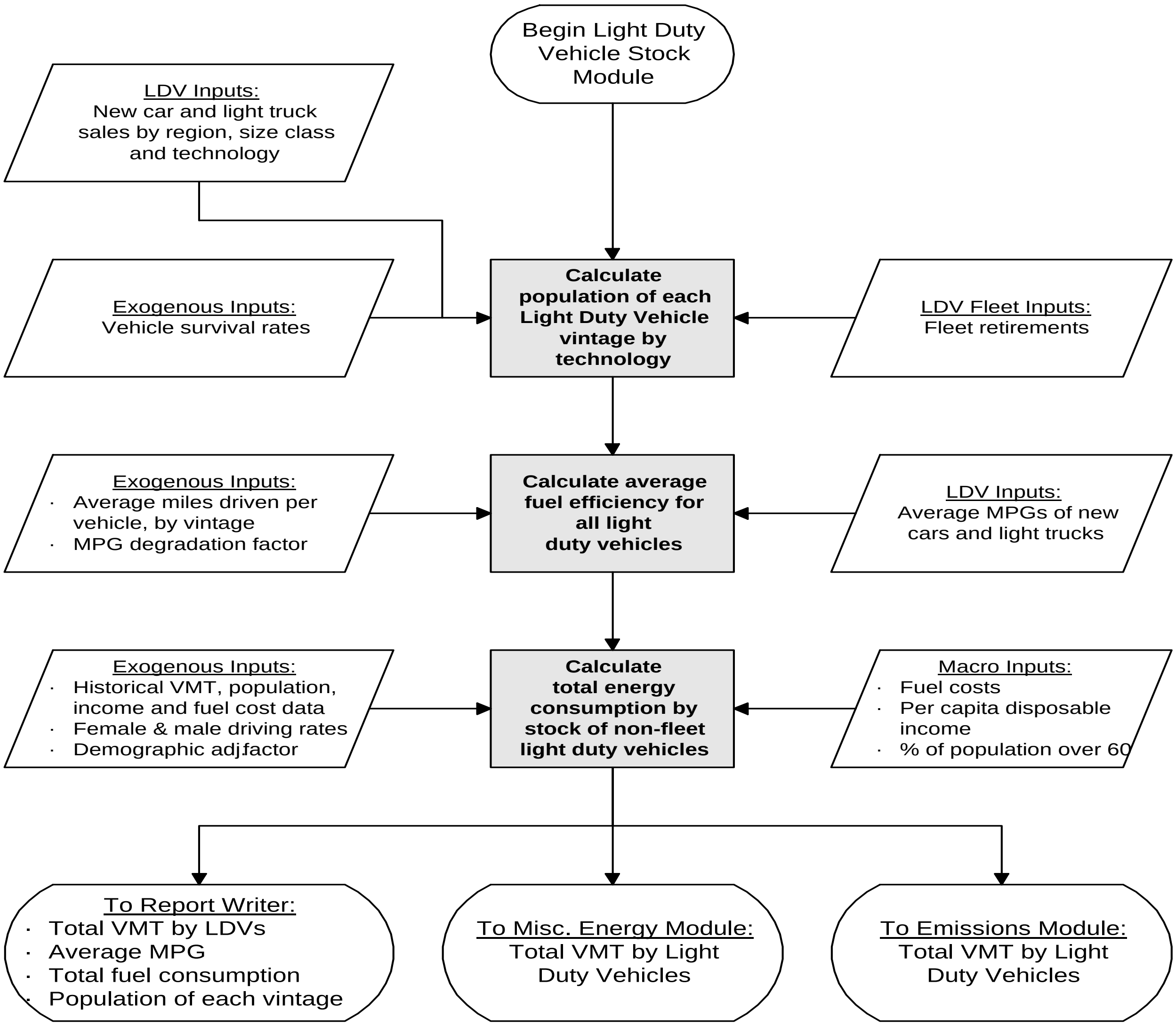
The Light Duty Vehicle Stock Module flowchart is presented in Figure 3C-1 below. More detailed diagrams of LDV Stock calculations are presented at the end of Section 3C.

3C-1. LDV Stock Accounting Model

The LDV stock model is perhaps the most important transportation sector model, since by far the largest portion of transportation energy consumption is accounted for by light duty vehicles that are at least a year old. The LDV Stock Accounting Module takes the results of the LDV Module, i.e., the number and characteristics of newly purchased cars and light trucks, and integrates those into the existing stock of vehicles, taking into account vehicle retirements and vehicles which 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 Model, which determines the average number of miles driven by each vehicle in the current year. The product then becomes the regional fuel consumption estimate.

Figure 3C-1. Light Duty Vehicle Stock Module



Note: the emissions module is currently inactive.

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

$$TECHNCS_{FuelType} = \sum_{class=1}^{6} \sum_{REG=1}^{9} NCSTECH_{REG,class,FuelType}$$

and **(166)**

$$TECHNLT_{FuelType} = \sum_{class=1}^{6} \sum_{REG=1}^{9} NLTECH_{REG,class,FuelType}$$

where:

TECHNCS = Total new car sales, by engine technology fuel type
TECHNLT = Total new light truck sales, by engine technology fuel type
NCSTECH = New car sales, by region, size class, and technology, from the AFV Model
NLTECH = New light truck sales, by region, size class, and technology, from the AFV Model

These variables are assigned to the first vintages of the automobile and light truck stock arrays, and the population of subsequent vintages are calculated:
For *vint* = 2-19:

$$PASSTK_{FuelType,vint,Year} = PASSTK_{FuelType,vint-1,Year-1} * SSURVP_{vint-1}$$

and **(167)**

$$LTSTK_{FuelType,vint,Year} = LTSTK_{FuelType,vint-1,Year-1} * SSURVLT_{vint-1}$$

For *vint* = 20:

$$PASSTK_{FuelType,vint=20,Year} = \left(PASSTK_{FuelType,vint=19,Year-1} * SSURVP_{vint=19}\right) + \left(PASSTK_{FuelType,vint=20,Year-1} * SSURVP_{vint=20}\right)$$

and **(168)**

$$LTSTK_{FuelType,vint=20,Year} = \left(LTSTK_{FuelType,vint=19,Year-1} * SSURVLT_{vint=19}\right) + \left(LTSTK_{FuelType,vint=20,Year-1} * SSURVLT_{vint=20}\right)$$

where:

PASSTK = Surviving automobile stock, by technology and vintage
LTSTK = Surviving light truck stock, by technology and vintage
SSURVP = Fraction of a given vintage's automobiles which survive

SSURVLT = Fraction of a given vintage's light trucks which survive
vint = Index of vehicle vintage (1-20)
FuelType = Engine technology fuel types (1-16)

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

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

$$PASSTK_{FuelType,vint} = PASSTK_{FuelType,vint} + OLDFSTK_{car,flt,FuelType,vint}$$

and **(169)**

$$LTSTK_{FuelType,vint} = LTSTK_{FuelType,vint} + OLDFSTK_{truck,flt,FuelType,vint}$$

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
flt = Type of fleet vehicle: Business, Government, or Utility

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

$$STKCAR = \sum_{vint=1}^{20} \sum_{FuelType=1}^{16} PASSTK_{FuelType,vint}$$

and **(170)**

$$STKTR = \sum_{vint=1}^{20} \sum_{FuelType=1}^{16} LTSTK_{FuelType,vint}$$

where:

STKCAR = Total stock of non-fleet automobiles

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[10] *Motor Vehicle Stocks, Scrappage, and Sales,* Alan Greenspan and Darrel Cohen, October 30, 1996.

STKTR = Total stock of non-fleet light trucks

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

$$VSPLDV_{FuelType} = \frac{\sum_{vint=1}^{20} \left(PASSTK_{FuelType,vint} + LTSTK_{FuelType,vint} \right)}{STKCAR + STKTR} \quad \textbf{(171)}$$

where:

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

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

Calculate Stock Efficiencies for Cars and Light Trucks

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

Sum new car and light truck sales across regions:

$$NVSALES_{vt=1,class,FuelType} = \sum_{REG=1}^{9} NCSTECH_{REG,class,FuelType}$$

and **(172)**

$$NVSALES_{vt=2,class,FuelType} = \sum_{REG=1}^{9} NLTECH_{REG,class,FuelType}$$

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

$$MPGC_{FuelType,Year} = \left[\frac{\displaystyle\sum_{class=1}^{6} \frac{NVSALES_{vt=1,class,FuelType}}{MPG_{vt=1,FuelType,class}}}{\displaystyle\sum_{class=1}^{6} NVSALES_{vt=l,class,FuelType}} \right]^{-1}$$

and **(173)**

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

where:

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

The overall fuel efficiency of cars and light trucks is then calculated across the twenty vintages addressed in the model.[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]

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

and **(174)**

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

where:

TOTMICT = Total miles driven by cars
TOTMITT = Total miles driven by light trucks
PVMT = Average miles driven by each vintage of automobile, from RTECS
LVMT = Average miles driven by each vintage of light truck, from RTECS

[11] Initial (1990) values for on-road car and light truck fleet MPG are obtained from the Federal Highway Administration, *Highway Statistics, 1991*, U.S. Department of Transportation (1992).

[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.

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:

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

and **(175)**

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

where:

CMPGT = Automobile stock MPG
TMPGT = Light truck stock MPG
CDFRFG = Automobile fuel efficiency degradation factor
LTDFRFG = Light truck fuel efficiency degradation factor

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

$$SCMPG = \frac{TOTMICT}{CMPGT}$$

and **(176)**

$$STMPG = \frac{TOTMITT}{TMPGT}$$

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

$$MPGFLT = \frac{TOTMICT + TOTMITT}{CMPGT + TMPGT} \quad \textbf{(177)}$$

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

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

and **(178)**

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

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

3C-2. VMT Model

The travel demand component of the NEMS Transportation Model is a sub-component of the Light Duty Vehicle Stock Module which uses NEMS estimates of fuel price and personal income, along with population projections to generate a forecast of the demand for personal travel, expressed in vehicle-miles traveled (VMT) per driver. This is subsequently combined with forecasts of automobile fleet efficiency to estimate fuel consumption.

Model Structure

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

Growth in Female Driving Rates

An important issue is the VMT gap between males and females, and how this will change in the future. Females have historically driven far fewer miles per year, on average, than males, but they have been closing the gap rapidly in recent years. According to the 1969, 1977, and 1983 NPTS results, the per capita female/male driving ratio has generally hovered around 45 percent. The 1990 and 1995 NPTS data suggest a significant deviation from this trend, with women's average VMT growing to approximately 60 percent of men's. This may be at least partly attributable to the increased participation of women in the labor force.

The rate of convergence is essentially arbitrary, and has been chosen to ensure that 70 percent of parity is achieved in 2010. This assumed trend is depicted in the equation below. The trend line represents a logistic curve, anchored at the 1977 NPTS value, reaching 50 percent of difference ($PrFem_{max}$ - $PrFem_{1977}$) in 1994 (T_{50}), and achieving 99 percent of $PrFem_{max}$ in 2010(T_{99}). Or, in equation form:

$$PrFem_{Year} = PrFem_{1977} + \left(PrFem_{Max} - PrFem_{1977} \right) * \left[\frac{1}{1 + e^{(k(Year - Year_{50}))}} \right]$$

$$where: \qquad \textbf{(179)}$$

$$k = \frac{Ln(.01)}{(Year_{99} - Year_{50})}$$

where:

$PrFem_{max}$ = The maximum female/male driving ratio of 0.70, or 70 percent

Updating Data Inputs

Annual vehicle stock, VMT, and fuel consumption data has been made available from FHWA. All macroeconomic inputs are calculated based on a chain-weighted average, replacing the fixed-weight methodology previously used. These new data sets permit the re-estimation of the generalized difference equation adopted for the NEMS VMT forecasting model:

$$VMTPD_{Year} - \rho VMTPD_{Year-1} = \alpha(1-\rho) + \sum_{N=1}^{3} \beta_N (X_{N,Year} - \rho X_{N,Year-1}) \qquad \textbf{(180)}$$

where:

VMTPD = per driver travel demand for the driving age population, and
$X_{N = 1,..,3}$ = the input variables.

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

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

$$VMTPD_{Year} = \rho\, VMTPD_{Year-1} + 2.249\,(1-\rho) - 0.075\,(CPM96_{Year} - \rho\, CPM96_{Year-1}) + 2.37 x 10^{-4}\,(YPC96_{Year} - \rho\, YPC96_{Year-1}) + 6.42\,(PrFem_{Year} - \rho\, PrFem_{Year-1}) \quad \textbf{(181)}$$

where:

VMTPD = the vehicle miles traveled per driver
CPM96 = the fuel cost of driving a mile, expressed in 1996 dollars.
YPC96 = the disposable personal income per capita, expressed in 1996 dollars.
PrFem = the ratio of per capita female driving to per capita male driving.
ρ = the lag factor, estimated using the Cochrane-Orcutt iterative procedure to be 0.76.

The coefficient for the cost of driving per mile has been altered to increase to a maximum level of -.35, which is the equivalent of a -.40 fuel price elasticity. The additional fuel price elasticity is used when the fuel price exceeds the highest fuel price in the base case scenario up to approximately 50 percent above the base case scenario fuel price, at which point the maximum value of -.35 is used.

3D. Air Travel Module

The air travel component of the NEMS Transportation Model comprises two separate submodels: the Air Travel Demand Model and the Aircraft Fleet Efficiency Model. These models use NEMS forecasts of fuel price, macroeconomic activity, and population growth, as well as assumptions about aircraft retirement rates and technological improvements to generate forecasts of passenger and freight travel demand and the fuel required to meet that demand.

3D-1. Air Travel Demand Model

The Air Travel Demand Model produces forecasts of passenger travel demand, expressed in revenue passenger-miles (RPM), and air freight demand, measured in revenue ton-miles (RTM). These are combined into a single demand for seat-miles (SMD), and passed to the Aircraft Fleet Efficiency Model, which adjusts aircraft stocks to meet that demand.

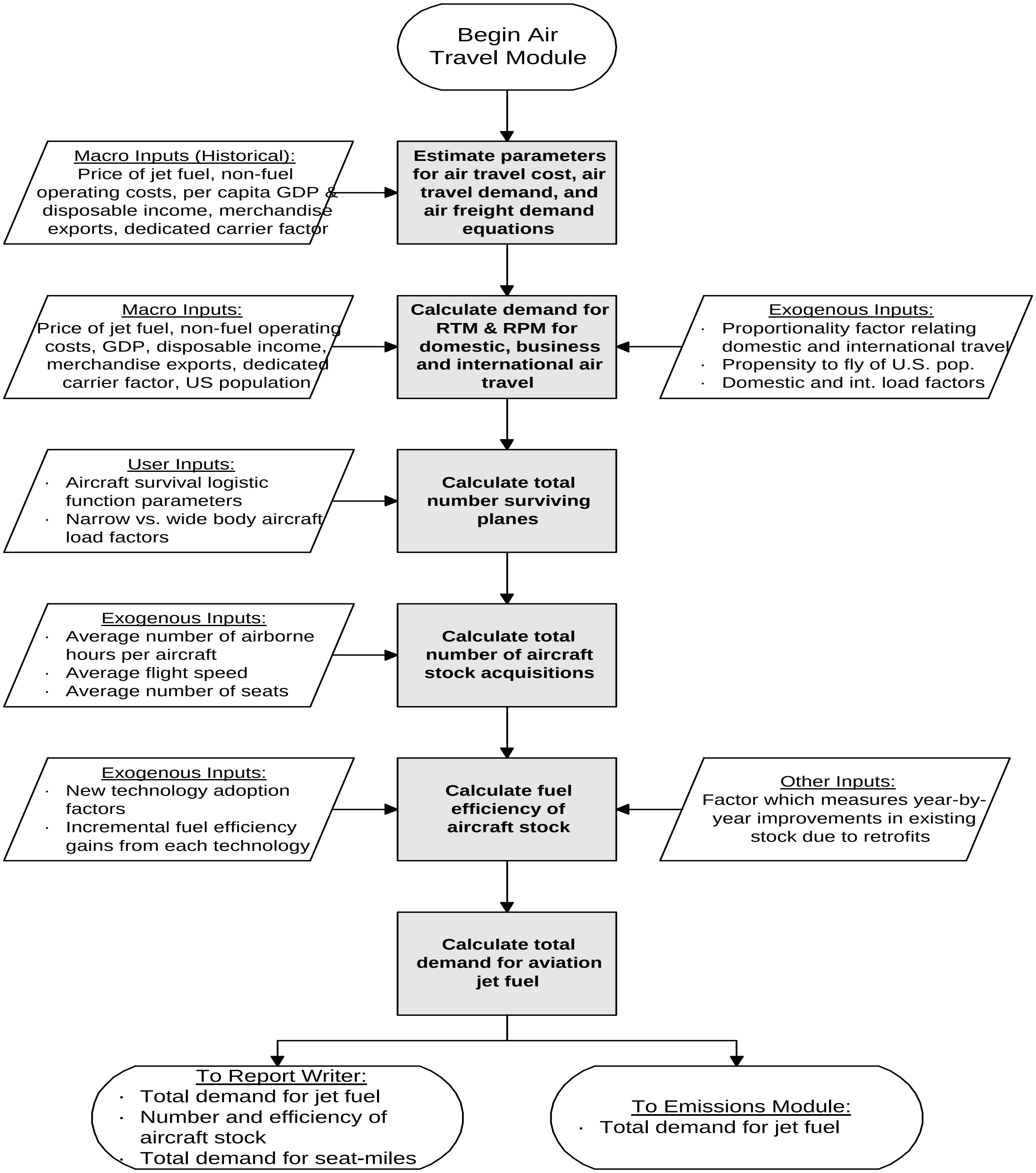
To increase the sensitivity of the forecast to economic and demographic parameters, the model incorporates separate treatment of business, personal, and international passenger travel. Separate forecasts of domestic passenger and freight travel are generated, influenced by economic, demographic and fuel price factors, and are combined into an aggregate estimate of air travel demand.

The Air Travel Demand Model is based on several assumptions about personal behavior and the structure of the airline industry. Of greatest significance is the assumption that the deregulation of the industry has substantially altered the dynamics of passenger travel; model parameters have therefore been estimated using only post-deregulation data. It is assumed that business and personal travel are motivated by different measures of economic conditions, and should be modeled separately. It is further assumed that personal travel demand is influenced by demographic conditions, and forecasts of this demand should be adjusted to reflect the changing age and gender characteristics of the U.S. population. Finally, it is assumed that growth in air travel demand is constrained by airport infrastructure and capacity, and forecasts for each type of travel should not exceed system capacity.

MODEL STRUCTURE

The Air Travel Demand Model, as implemented in NEMS, is a series of linear equations estimated over the period 1979-2001. As noted above, it is assumed that domestic business and personal travel are motivated by different economic measures, and that personal travel is further affected by the demographic makeup of the United States. Key model relationships are presented below, in order of their appearance. Where numbers appear in place of variable names, parameters have been estimated statistically from historical trends. Also presented below in Figure 3D-1 is the flowchart for the Air Travel Module. At the end of this section are additional flowcharts which depict the calculations in the Air Travel Demand and Aircraft Fleet Efficiency models in more detail.

Figure 3D-1. Air Travel Module



Note: the emissions module is currently inactive.

1) Calculate the cost of flying:

$$YIELD_{Year} = 14.03 + (.47 * PJFTR_{Year}) - 0.153 * (10 + Year) \tag{182}$$

where:

YIELD = Cost of air travel, expressed in cents per RPM
PJFTR = Price of jet fuel, in 1996 dollars per million Btu
base year= 1990

1A) Re-compute the cost of flying if total revenue-passenger miles exceed supply constraint (see (6) for discussion on supply constraint)

$$YIELD^{/} = YIELD_{Year} * \left(1 + \frac{DEL\_RPMTOT}{550{,}000}\right) \tag{183}$$

where:

YIELD' = Re-computed cost of air travel, expressed in cents per RPM
YIELD = Cost of air travel, expressed in cents per RPM (eq.182)
DEL_RPMTOT = Difference between total RPM (business, personal, and international travel) and Supply Constraint

2) Calculate the revenue passenger-miles per capita for each type of travel.

Business:

$$RPMBPC_{Year} = 41.38 + \left(26.69 * \frac{MC\_GDP96C_{Year}}{TMC\_POPAFO_{Year}}\right) - (7.038 * YIELD_{Year}) \tag{184}$$

Personal:

$$RPMPPC_{Year} = -76.69 + \left(56.64 * \frac{MC\_YD96C_{Year}}{MC\_POPAFO_{Year}}\right) - (21.56 * YIELD_{Year}) \tag{185}$$

International:

$$RPMIPC_{Year} = PCTINTT_{Year} * (RPMBPC_{Year} + RPMPPC_{Year}) \tag{186}$$

where:

MC_GDP96C = Gross domestic product, in 1996 dollars.

MC_YD96C = Total disposable personal income, in 1996 dollars.

MC_POPAFO = U.S. population

PCTINTT = Proportionality factor relating international to domestic travel levels and is an extrapolation of historic trends to a maximum of 0.5.

2A) Calculate total revenue-passenger miles if supply constraint is violated (see (6) for discussion on supply constraint)

$$RPM\_MAXTOT = RPM\_MAXCAP_{Year} * \left(\frac{(LF\_DOM_{Year} * RPMD_{Year} + LFINTER_{Year} * RPMI_{Year}) \; / \; (RPMD_{Year} + RPMI_{Year})}{(LF\_DOM_{2000} * RPMD_{2000} + LFINTER_{2000} * RPMI_{2000}) \; / \; (RPMD_{2000} + RPMI_{2000})} \right) \quad \textbf{(187)}$$

where:

RPM_MAXTOT = Maximum total revenue-passenger miles demanded after correcting for differences in load-factors between base year of 2000 and re-computed year.

RPM_MAXCAP = Maximum capacity available with year 2000 load factors (see (6) for derivation)..

LF_DOM = Domestic (business+personal) load-factor in re-computed year.

RPMD = Domestic (business+personal) revenue passenger miles calculated before re-computation

LF_INTER = International load-factor in re-computer year.

RPMI = International revenue-passenger miles calculated before re-computation

LF_DOM_{2000} = Domestic (business+personal) load factor in 2000

$RPMD_{2000}$ = Domestic (business+personal) revenue passenger miles in year 2000

LF_INTER_{2000} = International load-factor in year 2000

$RPMI_{2000}$ = International revenue-passenger miles in 2000

2B) Re-compute revenue-passenger miles per capita for each type of travel if supply constraint is violated (see (6) for discussion on supply constraint)

Business:

$$RPMB^{/} = RPMB_{Year} - \left(\frac{RPMB_{Year} - RPMB_{Year-1}}{RPMGRT} \right) * (RPMTOT - RPM\_MAXTOT) \quad \textbf{(188)}$$

where:

RPMB = Business revenue passenger miles

RPMGRT = Growth rate in total revenue passenger miles over previous year

RPMTOT = Total domestic (personal+business) plus international revenue passenger miles

Personal:

$$RPMP^{/} = RPMP_{Year} - \left(\frac{RPMP_{Year} - RPMP_{Year-1}}{RPMGRT} \right) * (RPMTOT - RPM\_MAXTOT) \quad \textbf{(189)}$$

where:

RPMP = Personal revenue passenger miles

RPMGRT = Growth rate in total revenue passenger miles over previous year

RPMTOT = Total domestic (personal+business) plus international revenue passenger miles

International:

$$RPMI^{/} = RPMI_{Year} - \left(\frac{RPMI_{Year} - RPMI_{Year-1}}{RPMGRT} \right) * (RPMTOT - RPM\_MAXTOT) \quad \textbf{(190)}$$

where:

RPMI = International revenue passenger miles

RPMGRT = Growth rate in total revenue passenger miles over previous year

RPMTOT = Total domestic (personal+business) plus international revenue passenger miles

3) Calculate the dedicated revenue ton-miles (RTM) of air freight:

$$RTM_{Year} = 4{,}760.5 + (-491.04 * PJFTR_{Year}) + (31.48 * MC\_EXDAN96C_{Year}) - BELLYFRT_{Year} \quad \textbf{(191)}$$

where:

MC_EXDAN96C = Value of merchandise exports, in 1996 dollars

BELLYFRT = Freight ton-miles transported in the belly of the commercial passenger carriers, and is assumed to grow over time at the same rate as revenue passenger miles

4) Calculate total revenue passenger-miles flown for each category of travel, subsequently combining business and personal travel into a final domestic travel category:

$$RPMP_{Year} = RPMPPC_{Year} * MC\_POPAFO_{Year} * DI_{Year} \quad \textbf{(192)}$$

$$RPMD_{Year} = RPMB_{Year} + RPMP_{Year} \qquad \textbf{(194)}$$

$$RPMB_{Year} = RPMBPC_{Year} * MC\_POPAFO_{Year} \qquad \textbf{(193)}$$

$$RPMI_{Year} = RPMIPC_{Year} * MC\_POPAFO_{Year} \qquad \textbf{(195)}$$

where:

RPMB = Revenue passenger miles for business travel
RPMP = Revenue passenger miles for personal travel
RPMI = Revenue passenger miles for international travel
RPMD = Revenue passenger miles for all domestic travel
DI = Exogenously determined demographic index, reflecting the public's propensity to fly, and ranges over time, from 0.97 to 1.02

5) Calculate the total demand for seat-miles, incorporating the estimated load factors of domestic and international travel, and converting ton-miles of freight into an equivalent seat-mile demand:

$$SMDEMD_{Year} = \left(\frac{RPMD_{Year}}{LFDOM_{Year}} \right) + \left(\frac{RPMI_{Year}}{LFINTER_{Year}} \right) + (RTM_{Year} * EQSM) \qquad \textbf{(196)}$$

where:

SMDEMD = Total demand for available seat-miles
LFDOM = Exogenously determined load factor for domestic travel, ranging over time from 0.70 to 0.76
LFINTER = Exogenously determined load factor for international travel, ranging over time from 0.76 to 0.79
EQSM = Equivalent seat-miles conversion factor; used to transform freight RTM's

6) Derivation of Supply Constraint:

The Air Travel Demand Model supply constraint is based on data from the *FAA Airport Capacity Benchmark Report 2001*. Variables used to establish constraint on total revenue passenger miles are:

- Optimal Flights per Hour
- Utilization of airports (amount of time airport operates at “optimal” capacity)
- Load-Factors

Based on these data, a supply curve for airport capacity is calculated:

$$RPM\_MAXCAP_{Year} = (RPMTOT_{2000} + 514.0) * (1 + e^{\ln(.07/13)*(n-13)}) \quad \textbf{(197)}$$

where:

$RPMTOT_{2000}$ = Total revenue passenger miles demanded in the year 2000
n = Index to year (base year: 2000, n = 0)

3D-2. Aircraft Fleet Efficiency Model

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

The intent of this component is to provide a quantitative approach for estimating aircraft fleet energy efficiency. To this end, the model estimates surviving aircraft stocks and average characteristics at a level of disaggregation which is supportable by available data, and projects the fuel efficiencies of new acquisitions under different sets of economic and technological scenarios. The resulting fleet average efficiencies are returned to the Air Travel Demand Module to support the forecast of commercial passenger and freight carriers' jet fuel consumption to the year 2025.

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

Total fleet efficiency is based on separate estimates of the stock and efficiency of the two types of aircraft considered by the model—narrow body and wide body[13]. The development of the hub and

[13] Narrow body aircraft, such as the Boeing 727, have seating for approximately 120-150 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

spoke system lead airlines to invest in smaller aircraft for years, but increasing airport congestion provided the impetus for investments in larger craft. In 1990, narrow body aircraft accounted for approximately 56 percent of total available seat-miles, and wide body aircraft accounted for the remaining 44 percent. By 2000, narrow body aircraft accounted for approximately 52% of total available seat-miles, and wide body aircraft accounted for the remaining 48%.

MODEL STRUCTURE

The model operates in two stages: the first stage estimates the total fleet of each type of aircraft required to meet projected demand in any given year; the second stage determines the stock efficiency, given assumptions about the retirement rate of aircraft and the incorporation of energy-efficient technologies in new acquisitions.

Stock Estimation

This component first determines the demand for new commercial aircraft, based on the growth of travel demand and the retirement of older planes. Travel demand, expressed as a demand for equivalent seat-miles, is obtained from the Air Travel Demand Model, and is subsequently allocated between the two aircraft types considered by this model. The first step is to determine the fraction of seat miles attributable to each aircraft type. This is calculated using the fraction of total available seat miles provided by each type of aircraft in the previous year, adjusted by a constant which represents the effects of airport congestion:

$$SMFRAC_{Narrow,Year} = \left(\frac{ASMDEMD_{Narrow,Year-1}}{SMDEMD_{Year-1}} \right) * (1+\delta) \tag{198}$$

where:

SMFRAC = Narrow seat mile fraction
ASMDEMD = Total seat-mile demand, by narrow, in year, *Year*.
SMDEMD = Total seat-mile demand, in year, *Year*.

This specification represents the shifting of a fraction of passenger load from one aircraft type to another, at a rate, δ, which is -0.01 in the base case, but may be exogenously set. It is believed that the most probable value for this factor is negative—increasing the wide body market share—due, in addition to airport congestion, to the growth in the long-haul market, coupled with the longer range and lower seat-mile cost of wide body aircraft.

The next step is to allocate the current year seat-miles demanded (calculated in the Air Travel Demand Model) among aircraft types:

$$ASMDEMD_{Narrow,Year} = SMFRAC_{Narrow,Year} \cdot SMDEMD_{Year}$$

and **(199)**

$$ASMDEMD_{Wide,Year} = (1 - SMFRAC_{Narrow,Year}) \cdot SMDEMD_{Year}$$

The survival rates of aircraft are subsequently estimated:

$$SURVPCT_{IVINT} = \left[1 + e^{(SURVK * (T50 - IVINT))}\right]^{-1}$$

and **(200)**

$$SSURVPCT_{IVINT} = \frac{SURVPCT_{IVINT}}{SURVPCT_{IVINT-1}}$$

where:

IVINT = Index of aircraft vintage
SURVPCT = Survival rate of planes of a given vintage *IVINT*
SSURVPCT = Marginal survival rate of planes of a given vintage
SURVK = User-specified proportionality constant
T50 = User-specified vintage at which stock survival is 50%

Because of the relatively small size of the U.S. commercial fleet--slightly over seven thousand six hundred aircraft[14]--it is important to provide an accurate portrayal of the age distribution of airplanes. This distribution determines the number of aircraft retired from service each year, and consequently has a strong influence over the number of new aircraft acquired to fulfill the demand for air travel. It should be noted that, due to the international nature of the market for aircraft, constructing a survival algorithm using only domestic deliveries and stocks is not feasible. This is 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 which had originally been domestically delivered. The problem is mitigated by assuming that the scrappage rate of aircraft on a worldwide basis also characterizes that of domestic aircraft. Having established

[14] Bureau of Transportation Statistics, *National Transportation Statistics*, U.S. Department of Transportation(1999), page 13.

the number of surviving aircraft by type, the available aircraft capacity is calculated. Surviving aircraft capacity is calculated as follows:

$$SMSURV_{IT,Year} = \sum_{IVINT=2}^{Max\_age} NPCHSE_{IT,IVINT-1,Year-1} * SSURVPCT_{IVINT} * ASMP_{IT,Year} \quad \textbf{(201)}$$

where:

SMSURV = Surviving seat-miles, by aircraft type
NPCHSE = Surviving aircraft stock, by vintage and aircraft type
ASMP = The available seat-miles per plane, by aircraft type
IT = The aircraft type (narrow or wide)
IVINT = Vintage, or age, of surviving aircraft, in years, reflecting 60 years in the model.
Max_ag*e* = 60 years, maximum age in the model.

Surviving aircraft capacity is then compared with the travel demand estimates described above. The difference represents the additional capacity required to meet demand. Dividing this difference by the available seat-miles per plane gives the number of aircraft of each type to add to the fleet:

$$NPCHSE_{IT,IVINT=1,Year} = \left[\frac{ASMDEMD_{IT,Year} - SMSURV_{IT,Year}}{ASMP_{IT,Year}} \right] \quad \textbf{(202)}$$

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

The resulting number of new aircraft is then added to surviving stock, and the data table is updated to reflect the newest vintage:

$$NPCHSE_{IT,IVINT,Year} = NPCHSE_{IT,IVINT-1,Year-1} * SSURVPCT_{IVINT} \quad ; \quad IVINT = 2 - 60 \quad \textbf{(203)}$$

The sum across vintages gives an estimate of surviving aircraft stocks of each type:

$$NSURV_{IT,Year} = \sum_{IVINT=1}^{60} NPCHSE_{IT,IVINT,Year} \qquad \textbf{(204)}$$

This approach presumes that new aircraft are immediately available to meet demand. Actually, airlines' orders for planes are put in several years in advance of need based on estimates of air travel.

Fleet Efficiency

For simplicity, it is assumed that load factors do not vary with the age of the plane; the fraction of planes older than one year is therefore assumed to be solely dependent on the respective number of planes, as follows:

$$STKOLD_{IT,Year} = \frac{\left(NSURV_{IT,Year} - NPCHSE_{IT,IVINT=1,Year}\right)}{NSURV_{IT,Year}} \qquad \textbf{(205)}$$

Efficiency improvements of newly acquired aircraft are determined by technology choice which is, in turn, dependent on the year in question, the type of aircraft and the price of fuel. In order to model a smooth transition from old to new technologies, the efficiencies of new aircraft acquisitions are based on several logistic functions which reflect the commercial viability of each technology. The two arguments, the time effect (TIMEFX) and the price effect (COSTFX), are based on the assumption that the rate of technology incorporation is determined not only by the length of time in which the technology has been commercially viable, but also by the magnitude of a given technology's price advantage:

$$TIMEFX_{IFX,Year} = TIMEFX_{IFX,Year-1} + \left(TIMECONST * TPN_{IFX} * TYRN_{IFX}\right) \qquad \textbf{(206)}$$

where:

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

IFX = Index of technology improvements (1-6)

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

TPN = Binary variable (0,1) which tests whether current fuel price exceeds the considered techology's trigger price

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

$$COSTFX_{IFX,Year} = 10 * \left(\frac{TPJFGAL_{Year} - TRIGPRICE_{IFX}}{TPJFGAL_{Year}} \right) * TPN_{IFX} * TYRN_{IFX} * TPZ_{IFX} \quad \textbf{(207)}$$

where:

COSTFX = Factor reflecting the magnitude of the difference between the price of jet fuel and the trigger price of the considered technology

10 = Scaling factor

TPJFGAL = Price of jet fuel

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

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

Thus the overall effect of time and fuel price on implementing technology improvements:

$$TOTALFX_{IFX,Year} = TIMEFX_{IFX,Year} + COSTFX_{IFX,Year} - BASECONST \quad \textbf{(208)}$$

The BASECONST represents an adjustment which 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:

$$TECHPEN_{IFX,Year} = \left[1 + e^{(-TOTALFX_{IFX,Year})} \right]^{-1} \quad \textbf{(209)}$$

and the fractional fuel efficiency improvement for new aircraft, by type:

$$FRACIMP_{Narrow,Year} = 1.0 + EFFIMP_{IFX=1} * \left(TECHPEN_{IFX=1,Year} - TECHPEN_{IFX=2,Year}\right) + \sum_{IFX=2}^{6} EFFIMP_{IFX} * TECHPEN_{IFX,Year} \quad \textbf{(210)}$$

and

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

where:

EFFIMP = Fractional improvement associated with a given technology

The model also sets a lower limit for efficiency gains by new aircraft, based on the assumption that new planes will be at least five percent more efficient than the stock efficiency of surviving aircraft. This provision is triggered if the incorporation of new technologies fail to sufficiently increase the efficiencies of new acquisitions. Thus the average seat-miles per gallon of new aircraft is:

$$NEWSMPG_{IT,Year} = MAX\left[\left(FRACIMP_{IT,Year} * SMPG_{IT,Year_0},\right.\right.$$
$$\left.\left.\left((1.0 + \rho_{IT}) * SMPG_{IT,Year-1} * STKIMP\right)\right)\right] \quad \textbf{(211)}$$

where:

ρ = Average historic rate of growth of fuel efficiency

STKIMP = Stock efficiency improvement

SMPG = Aircraft fuel efficiency in initial year, $Year_0$, and previous year. SMPG in the current time period, *Year*, is defined below.

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.

Average fleet efficiency in seat-miles per gallon is estimated using a series of simplifying assumptions. First, the new stock efficiency is determined for each type of aircraft, using the following approach:

$$SMPG_{IT,Year} = \left[\left(\frac{STKOLD_{IT,Year}}{(1 + \rho_{IT}) * (SMPG_{IT,Year-1})}\right) + \left(\frac{\left(1 - STKOLD_{IT,Year}\right)}{NEWSMPG_{IT,Year}}\right)\right]^{-1} \quad \textbf{(212)}$$

where:

SMPG = Aircraft fuel efficiency in seat-miles per gallon

STKOLD = Fraction of seat-miles handled by existing stock

1-STKOLD = Fraction of seat-miles handled by newly acquired stock

ρ = Rate at which fuel efficiency of existing aircraft increases annually due to retrofitting

The factor multiplying the SMPG reflects the user's assumption that stock efficiency for each type of aircraft increases at a uniform annual rate of ρ due to the retrofit of older aircraft with new technology, and the retirement of obsolete planes. In the absence of user specification, the model will use default values of 0.44 percent and 0.18 percent for narrow and wide body aircraft, respectively. These figures are based on the average annual improvements in efficiency for each type of aircraft between 1980 and 1990.

Following the estimation of stock efficiency by body type, overall fleet efficiency is estimated in a similar manner:

$$SMPGT_{Year} = \left[\left(\frac{SMFRACN_{Year}}{SMPG_{Narrow,Year}} \right) + \left(\frac{\left(1 - SMFRACN_{Year}\right)}{SMPG_{Wide,Year}} \right) \right]^{-1} \qquad \textbf{(213)}$$

where, in this instance, the shares are not determined by the number of planes of each type, but by historical trends and expectations of total available seat miles offered by each type of aircraft. Changes in these trends are guided by assumptions concerning airport congestion, and the maturation of the hub and spoke system.

Estimating Fuel Consumption

Estimating the demand for jet fuel is simply a matter of combining the output of these two models and incrementing by 4% to reflect consumption by private aircraft:

$$JFGAL_{Year} = \frac{SMDEMD_{Year}}{SMPGT_{Year}} * 1.04 \qquad \textbf{(214)}$$

The demand for aviation gasoline is calculated as:

$$AGD_{Year} = BASEAGD + GAMMA * e^{\left(-KAPPA * (Year - 1979)\right)} \qquad \textbf{(215)}$$

where:

AGD = Demand for aviation gasoline, in gallons
BASEAGD = Baseline demand for aviation gasoline
GAMMA = Baseline adjustment factor
KAPPA = Exogenously-specified decay constant

Convert the jet fuel demand in gallons to Btu:

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

and **(216)**

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

Calculate the jet fuel and aviation gasoline demand by regions:

$$QJETR_{REG,Year} = JFBTU_{Year} * SEDSHR_{Jet_{Fuel},REG,Year}$$

and **(217)**

$$QAGR_{REG,Year} = AGDBTU_{Year} * SEDSHR_{AvGas_{Fuel},REG,Year}$$

where:

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

Calculate fractional changes in aircraft efficiency from base year:

$$XAIREFF_{Year} = \frac{SMPGT_{Year}}{SMPGT_{Year=1990}} \qquad (218)$$

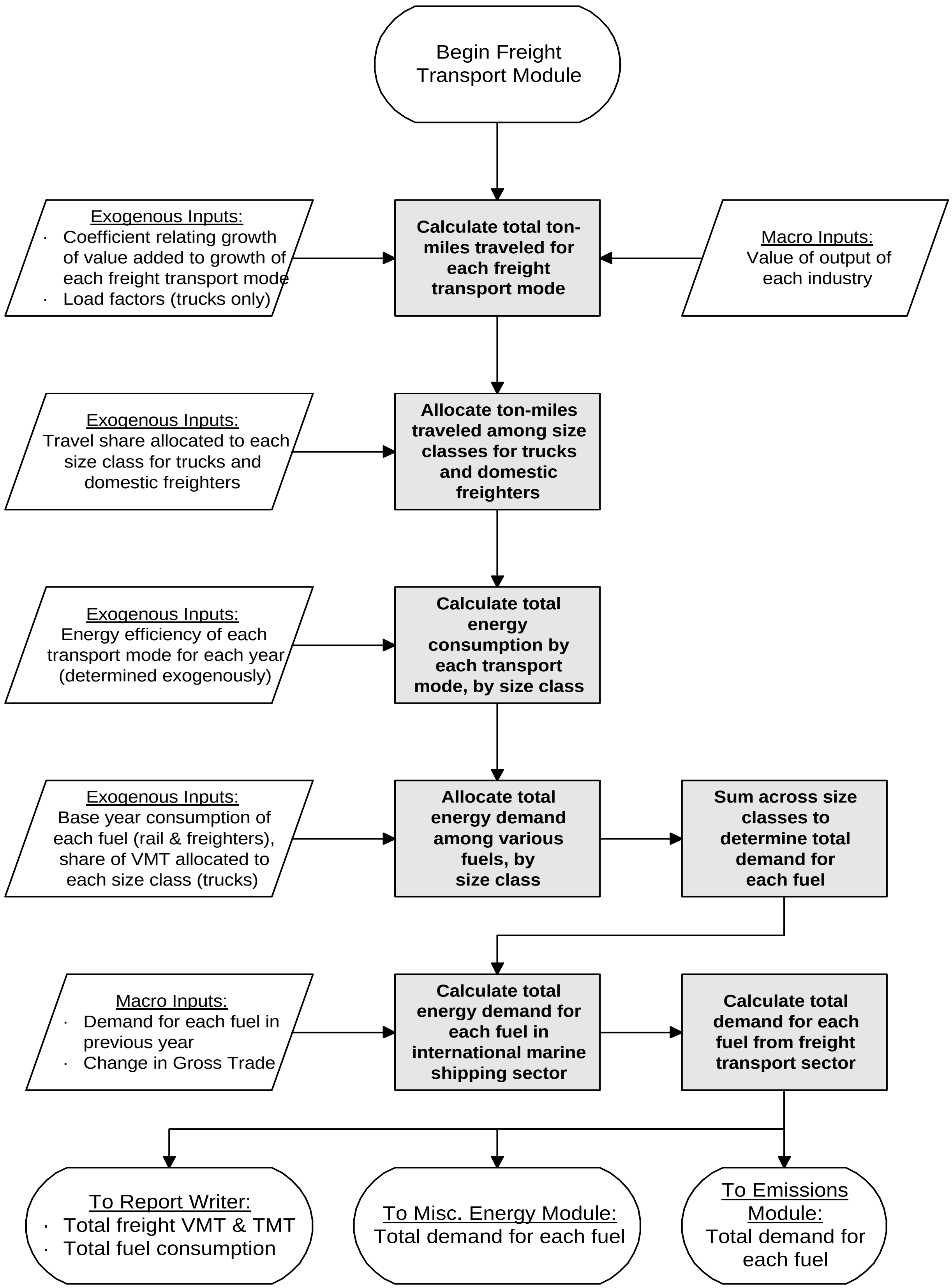
3E. Freight Transport Module

The freight component of the NEMS Transportation Model addresses the three primary modes of freight transport: truck, rail, and marine. This model uses NEMS forecasts of real fuel prices, trade indices, coal production, and forecasts of selected industries' output from the Macroeconomic Model to estimate travel demand for each freight mode, and the fuel required to meet that demand. The carriers in each of these modes are characterized, with the possible exception of trucks, by very long operational lifetimes, and the ability to extend these lifetimes through the retrofitting process. This results in a low turnover of capital stock and the consequent dampening of improvement in average energy efficiency. Given the long forecast horizon, however, this component will provide estimates of modal efficiency growth, driven by assumptions about systemic improvements modulated by fuel price forecasts.

Forecasts are made for each of the modes of freight transport: trucks, rail, and ships. In each case, travel forecasts are based on the industrial production of specific industries, travel growth in most cases being directly proportional to increases in value of goods produced. Rail additionally uses NEMS coal forecasts to account for part of the travel. This is then converted to energy demand using the average energy intensity for the mode in question. Total energy demand is subsequently shared out to the various types of fuel used for freight transport, under the assumption that relative shares remain constant. As each mode, except trucks, is considered in the aggregate, no distinction is drawn between classes of carrier.

The freight transport model developed for NEMS incorporates additional levels of detail. This is accomplished by stratifying the trucking sector according to size class and developing a stock adjustment model for each size class and fuel type. Parameters relating industrial output tonnage to changes in value of goods produced have been explicitly incorporated.

Figure 3E-1. Freight Transport Module



The NEMS Freight Transport Module aggregates the value of output from various industries into a reduced classification scheme, relating the demand for transport to the growth in the value of output of each industrial category. The relationships used for truck, rail, and waterborne freight are presented in sequence below. The flowchart for the Freight Transport Module is presented in Figure 3E-1 above. Additional flowcharts presenting Freight Module calculations in more detail can be found at the end of this section.

3E-1. Freight Truck Stock Adjustment Model

This section describes the methodology of the freight truck stock model which has been integrated into the Transportation Demand Sector Model of the National Energy Modeling System. The Freight Truck Stock Adjustment Model (FTSAM) allows for manipulation of a number of important parameters, including the market penetration of existing and future fuel-saving technologies as well as alternatively-fueled heavy-duty vehicles. The Freight Truck Stock Adjustment Model uses NEMS forecasts of real fuel prices and selected industries' output from the Macroeconomic Model to estimate freight truck travel demand, and purchases. Forecasts of retirements of freight trucks, important truck stock characteristics such as fuel technology market share and fuel economy, and fuel consumption come from the Transportation model.

Forecasts are made for three modes of freight transport: trucks, rail, and ships. In each case, travel forecasts are based on the industrial production of specific industries, travel growth in most cases being directly proportional to increases in value of goods produced. Rail additionally uses NEMS coal forecasts to account for part of the travel. The Rail and Ship models then convert ton miles traveled to energy demand using the average energy intensity for the mode in question. Total energy demand is subsequently shared out to the various types of fuel used for freight transport. The Freight Truck Stock Adjustment Model utilizes vintage, size class, sector and fuel technology-specific freight truck fuel economies to derive energy demand.

The Freight Truck Stock Adjustment Model forecasts the consumption of diesel fuel, motor gasoline, liquefied petroleum gas (LPG) and compressed natural gas (CNG) accounted for by freight trucks in each of twelve industrial sectors. Twenty truck vintages, three truck size classes and two fleet types are tracked throughout the model, each having its own average fuel economy and average number of miles driven per year. This section presents and describes the methodology used by the model to forecast each of these important variables.

There are six main procedures which are executed during each year of the model run to produce estimates of fuel consumption. In the first, fuel economies of the incoming class of new trucks are estimated through market penetration of existing and new fuel-saving technologies. Relative fuel economies are used in the second routine to determine the market share of each fuel technology in the current year's truck purchases. The third routine determines the composition of the existing truck population, utilizing the characteristics of the current year's class of new trucks along with exogenously estimated vehicle scrappage and fleet transfer rates. New truck sales data from the macroeconomic model are used to determine new truck purchases in the fourth routine. In the fifth routine, VMT demand is allocated among truck types and divided by fuel economy to determine fuel consumption. Finally, the truck stocks are rolled over into the next vintage, and the model is prepared for the next year's run.

1. Estimate New Truck Fuel Economies

The first step in the FTSAM is to determine the characteristics of the incoming class of truck purchases. Estimates of new light, medium heavy, and heavy truck fuel economies are generated endogenously and depend on the market penetration of specific fuel-saving technologies. Currently existing fuel-saving technologies are based on the *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory[15] and include drag reduction and advanced tires. Currently existing technologies gain market share via time-dependent exponential decay functions with exogenously determined maxima and minima, based on historical trends.

Future technologies are adapted from *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory[16], and include advanced transmissions, lightweight materials, synthetic gear lube, advanced drag reduction, advanced tires, electronic engine controls, turbocompounding, hybrid power trains, and port-injection. Place holders allow for the introduction of four additional technologies. Future technologies enter the market at various times throughout the model 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

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[15] *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1999.

[16] *The Projected Effect of Future Energy Efficiency and Emissions Improving Technologies on Fuel Consumption of Heavy Trucks*, Argonne National Laboratory, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1999.

separately for diesel, gasoline, LPG and CNG trucks.

The first step the model executes in each year is to calculate the average fuel price over the previous three years and a fuel trigger price at which the technology becomes economically viable:

$$CFAVPC_{Year,Frt\_Fuel} = \frac{(PRICE_{Year,Frt\_Fuel} + PRICE_{Year-1,Frt\_Fuel} + PRICE_{Year-2,Frt\_Fuel})}{3} \quad \textbf{(219)}$$

where:

Frt_Fuel = Index referring to fuel type, where *Frt_Fuel*=1 refers to diesel, *Frt_Fuel*=2 refers to gasoline, *Frt_Fuel*=3 refers to LPG and *Frt_Fuel*=4 refers to CNG
CFAVPC = Average price of fuel over three year period, in $ per MBtu
PRICE = Price of each fuel, in $ per MBtu

$$TGPRCXG_{Year,SC,Frt\_Fuel,Frt\_Tech} = \frac{CAPCXG_{SC,Frt\_Fuel,Frt\_Tech}}{\sum_{IP=1}^{PAYBKXG_{SC,Frt\_Tech}} \frac{MBTUTKXG_{SC} * MPGIPXG_{SC,Frt\_Fuel,Frt\_Tech}}{1+(DISCRTXG * .01)^{IP}}} \quad \textbf{(220)}$$

where:

PAYBKXG = Exogenous payback period for a given technology and size class, in years
TGPRCXG = Fuel trigger price at which a technology, *Frt_Tech*, becomes economically viable
CAPCXG = Capital cost of a technology
MBTUTKXG = Exogenously determined fuel usage
MPGIPXG = Exogenously determined incremental fuel improvement
DISCRTXG = Exogenously determined discount rate
IP = Index for payback periods
Frt_Tech = Freight truck technologies
SC = Size class

Whether a future technology enters the market during a particular year depends on the cost effective price of that technology relative to the average price of each fuel over the past three years.

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

$$PREFF_{Year,Frt\_Fuel,Frt\_Tech} = 1 + PRVRXG_{SC,Frt\_Fuel,Frt\_Tech} * \left[\frac{CFAVPC_{Year,Frt\_Fuel}}{TGPRCXG_{SC,Frt\_Fuel,Frt\_Tech}} - 1 \right] \quad \textbf{(221)}$$

where:

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

PRVRXG = Exogenously determined fuel price sensitivity parameter for each freight technology, representing the percent increase in technology market share if fuel price exceeds cost effective price by 100 percent

For each available technology, including existing technologies, each size class, and each fuel the model determines its share of the available market in the current year.

For each size class and technology, the market penetration over time is calculated, as an S-shaped logistical equation:

$$PEN_{Year} = MINP + (MAXP - MINP) * \frac{1}{1 + e^{-\frac{(Year - STYEAR - MIDPT)}{COEFF}}} \quad \textbf{(222)}$$

where:

MAXP = Exogenously determined market penetration parameter: final market share of freight technology

MINP = Exogenously determined market penetration parameter: market share of technology in 1992

MIDPT = Exogenous parameter for existing technologies

COEFF = Market penetration curve for existing technologies

STYEAR = First year technology is available

If this is an emission technology, or if the fuel price has reached the trigger price, then the technology share is as follows:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = PREFF_{Year,SC,Frt\_Fuel,Frt\_Tech} * PEN \quad \textbf{(223)}$$

where:

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

However, if this is a fuel efficiency technology, and if the fuel price has not reached the trigger price, but the previous years technology market share is non-zero, then the current years market share grows at the same rate as the market penetration price sensitivity multiplier:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = TECHSHR_{Year-1,SC,Frt\_Fuel,Frt\_Tech} * \frac{PREFF_{Year,Frt\_Fuel,Frt\_Tech}}{PREFF_{Year-1,Frt\_Fuel,Frt\_Tech}} \quad \textbf{(224)}$$

Finally, if this is a fuel efficiency technology, and if the fuel price has not reached the trigger price, and the previous years technology market share is zero, then the current years market share is as follows:

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = MINP \quad \textbf{(225)}$$

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

$$TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} = \left(1 - SPRSDEFF_{Year,SC,Frt\_Fuel,Frt\_Tech}\right) * TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech} \quad \textbf{(226)}$$

where:

SPRSDEFF = Superseding effect, equal to the market share of the superseding technology

Once the market shares in a given year are established, the effects of the technologies on the base fuel cost are tallied and combined to form a vector of "MPG Effects", which is used to augment the base fuel economy of new trucks of each size class and fuel type:

$$MPGEFF_{Year,SC,Frt\_Fuel} = \prod_{Frt\_Tech=1}^{40} \left(1 - MPGIPXG_{SC,Frt\_Fuel,Frt\_Tech} * TECHSHR_{Year,SC,Frt\_Fuel,Frt\_Tech}\right) \quad \textbf{(227)}$$

where:

MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in a given year

MPGIPXG= Exogenous factor representing percent improvement in fuel economy due to each technology

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

$$CFMPG_{Year,SC,AGE=1,Frt\_Fuel} = \frac{BSMPGXG_{SC,Frt\_Fuel}}{MPGEFF_{Year,SC,Frt\_Fuel}} \tag{228}$$

where:

BSMPGXG = Fuel economy of new freight trucks with no fuel-saving technologies

2. Determine the Share of Each Fuel Type in Current Year's Class of New Trucks

Another major characteristic of the current year's class of new trucks, the market share of each fuel type, is calculated in the second FTSAM routine. Market penetration of alternative fuel freight trucks is more likely to be driven by legislative and/or regulatory action than by strict economics. For this reason, separate trends are incorporated for fleet vehicles, which are assumed to be more likely targets of future legislation, and non-fleet vehicles. The fuel technology routine described below is intended to simulate economic competition among fuel technologies after the creation of a market for alternative fuel trucks by government action. The user specifies the market share alternative fuel trucks are likely to achieve if they have no cost advantage over conventional technologies. The inherent sensitivity of each fuel technology to the cost of driving is also specified exogenously. The latter parameter represents the commercial potential of each fuel technology over and above what is mandated by government, and serves to modify the exogenous trend based on relative fuel prices and fuel economies. Additional user-specified parameters include the year in which the market penetration curves are initiated and the length of the market penetration cycle.

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

$$FCOST_{Year,SC,Frt\_Fuel} = \frac{CFAVPC_{Year,Frt\_Fuel}}{CFMPG_{Year,SC,Frt\_Fuel}} * HTRATE \tag{229}$$

where:

FCOST	=	Fuel cost of driving a truck of fuel type *Frt_Fuel*, in dollars per mile
HTRATE	=	Heat rate of gasoline, in million Btu per gallon
Frt_Fuel	=	1, 3, 4 = non-gasoline trucks

Market Share of AFVs

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

$$DCOST_{Year,SC,Frt\_Fuel} = 1 - \left[\frac{FCOST_{Year,SC,Frt\_Fuel}}{FCOST_{Year,SC,Frt\_Fuel=1}} - 1 \right] * PRAFDFXG_{SC,Frt\_Fuel} \quad \textbf{(230)}$$

where:

DCOST	=	Fuel cost per mile of diesel relative to LPG and CNG
PRAFDFXG	=	Exogenously determined parameter representing inherent variation in AFV market share due to difference in fuel prices
	=	1, for LPG and CNG vehicles
Frt_Fuel	=	3, 4

The market penetration curve parameters are determined during a user-specified trigger year:

$$SLOPE_{SC,Frt\_Fuel,FLT} = \frac{\ln(0.01)}{\left[\frac{CYAFVXG_{SC,Frt\_Fuel,FLT}}{2} \right]}$$

$$and \quad \textbf{(231)}$$

$$MIDYR_{SC,Frt\_Fuel,FLT} = TRGSHXG_{SC,Frt\_Fuel,FLT} + \frac{CYAFVXG_{SC,Frt\_Fuel,FLT}}{2}$$

where:

FLT	=	Index referring to fleet type, where *FLT* = 1 refers to non-fleet trucks and *FLT* = 2 refers to fleet trucks
SLOPE	=	Endogenously determined logistic market penetration curve parameter
CYAFVXG	=	Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration
MIDYR	=	Logistic market penetration curve parameter representing "halfway point" to maximum market penetration
TRGSHXG	=	Exogenously determined year in which each alternative fuel begins to increase in market share, due to EPACT or other factors
Frt_Fuel	=	3, 4

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

$$MPATH_{Year,SC,Frt\_Fuel,FLT} = DCOST_{Year,SC,Frt\_Fuel} * \left[BFSHXG_{SC,Frt\_Fuel,FLT} + \frac{EFSHXG_{SC,Frt\_Fuel,FLT} - BFSHXG_{SC,Frt\_Fuel,FLT}}{1 + e^{SLOPE_{SC,Frt\_Fuel,FLT} \cdot (Year - MIDYR_{SC,Frt\_Fuel,FLT})}} \right] \quad \textbf{(232)}$$

where:

BFSHXG = Base year (1997) market share of each fuel type
EFSHXG = Exogenously determined final market share of each fuel type
Frt_Fuel = 3, 4

The market share of alternative fuel trucks is assumed never to dip below the historical level in each sector. The actual AFV market share is thus calculated as the maximum of historical and forecast shares:

$$FSHFLT_{Year,SC,Frt\_Fuel,FLT} = \max \left[BAFSHXG_{SC,Frt\_Fuel,FLT} \, , \, MPATH_{Year,SC,Frt\_Fuel,FLT} \right] \quad \textbf{(233)}$$

where:

BAFSHXG = Exogenously determined base year (1997) share of alternative fuels in truck purchases
Frt_Fuel = 3, 4

Market Share of Diesel Trucks

The share of diesel, *Frt_Fuel* = 1, in conventional truck sales is forecast through a time-dependent exponential decay function based on historical data:

$$MPATH_{Year,SC,Frt\_Fuel=1,FLT} = BFSHXG_{SC,Frt\_Fuel=1,FLT} + \left[EFSHXG_{SC,Frt\_Fuel=1,FLT} - BFSHXG_{SC,Frt\_Fuel=1,FLT} \right] * \left(1 - e^{CSTDXG_{SC,FLT} + CSTDVXG_{SC,FLT} * Year} \right) \quad \textbf{(234)}$$

where:

CSTDXG,CSTDVXG = Exogenously determined market penetration curve parameters for diesel trucks

Because of the potential for any fuel type to exceed the user-specified "maximum" due to cost advantages over other technologies, market penetration must be capped at one hundred percent.

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

$$FSHFLT_{Year,SC,Frt\_Fuel=1,FLT} = \min\left[\left(1 - \sum_{Frt\_Fuel=3}^{4} FSHFLT_{Year,SC,Frt\_Fuel,FLT}\right) * MPATH_{Year,SC,Frt\_Fuel=1,FLT}\ ,\ 1\right] \quad \textbf{(235)}$$

The remainder of truck purchases are assumed to be gasoline, *Frt_Fuel*=2:

$$FSHFLT_{Year,SC,Frt\_Fuel=2,FLT} = 1 - \sum_{Frt\_Fuel=1,3,4} FSHFLT_{Year,SC,Frt\_Fuel,FLT} \quad \textbf{(236)}$$

3. Determine Composition of Existing Truck Stock

Once the characteristics of the incoming class of new trucks are determined, the next step is to determine the composition of the stock of existing trucks. Scrappage rates are applied to the current truck population:

$$TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT} = TRKSTK_{Year-1,SC,AGE-1,Frt\_Fuel,FLT} * \left(1 - SCRAP_{SC,AGE-1}\right) \quad \textbf{(237)}$$

where:

TRKSTK = Existing stock of trucks
SCRAP = Exogenously determined factor which consists of the percentage of trucks of each vintage which are scrapped each year
AGE = 2, 20; AGE = 1 refers to new truck sales

A number of trucks are transferred in each year from fleet to non-fleet ownership. Note, only gasoline and diesel fuel vehicles are transferred. Transfers of conventional trucks are based on exogenously determined transfer rates:

$$TRF_{Year,SC,AGE,Frt\_Fuel} = TFFXGRT_{SC,AGE} * TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=2} \quad \textbf{(238)}$$

where:

TRF = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks
TFFXGRT = Exogenously determined percentage of trucks of each vintage to be transferred from fleets to non-fleets

The new existing population of trucks is simply the existing population (after scrappage) modified by fleet transfers:

$$
\begin{aligned}
TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=2} &= TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=2} - TRF_{Year,SC,AGE,Frt\_Fuel} \\
&\textit{and} \\
TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=1} &= TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT=1} + TRF_{Year,SC,AGE,Frt\_Fuel}
\end{aligned}
\tag{239}
$$

4. Calculate Purchases of New Trucks

New truck purchases are based on class 3 truck sales and on the macroeconomic models forecasts of classes 4-8 truck sales which is split between truck classes 4-6 and classes 7-8:

$$
\begin{aligned}
NEWTRUCKS_{SC=1} &= 0.24 * NEWTRUCKS\_TOT_{Year} \\
NEWTRUCKS_{SC=2} &= NEWCLS46_{Year} * NEWTRUCKS\_TOT_{Year} \\
NEWTRUCKS_{SC=3} &= (1.0 - NEWCLS46_{Year}) * NEWTRUCKS\_TOT_{Year}
\end{aligned}
\tag{240}
$$

where:

NEWTRUCKS_TOT = Total new truck sales for classes 4-8, from the Macroeconomic model.

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

SC = 1 refers to class 3; *SC* = 2 refers to class 4-6; *SC* = 3 refers to class 7-8

Calculate new truck sales, *AGE* = 1;

$$
TRKSTK_{Year,SC,AGE=1,Frt\_Fuel,FLT} = NEWTRUCKS_{SC} * FSHFLT_{SC,Frt\_Fuel,FLT} \tag{241}
$$

5. Calculate Fuel Consumption

The next stage of the model takes the total miles driven by trucks of each size class, fuel type and age and divides by fuel economy to determine fuel consumption.

The aggregate VMT growth by economic sector, *SEC*, is estimated. First, calculate Freight Adjustment coefficient, FOUT, which represents the relationship between the value of industrial output and freight demand in terms of VMT. It is used to factor industry growth to get VMT growth:

$$FOUT_{SEC} = FAC\_T0_{SEC} + \frac{1 - FAC\_T0_{SEC}}{1 + e^{FAC\_K * [FAC\_T5 - Year]}} \quad \textbf{(242)}$$

where:

FAC_T0 = Base year freight adjustment coefficient, by sector, exogenously determined
FAC_K = log(9.0) / (FAC_T9 - FAC_T5)
FAC_T5 = Year of 50 percent freight adjustment coefficient decay = 2002
FAC_T9 = Year of 90 percent freight adjustment coefficient decay = 2007

Now calculate the adjustment VMT per truck;

$$VMTADJ_{Year} = \frac{\sum_{SEC=1}^{12} VMTDMD_{Year-1,SEC} * [1 + OUTPUT_{Year,SEC}] * FOUT_{SEC}}{\sum_{SC,AGE,Frt\_Fuel,FLT} [ANNVMT_{SC,AGE,Frt\_Fuel} * TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT}]} \quad \textbf{(243)}$$

where:

V*MTDMD* = Annual sectoral VMT based on base year FHWA estimates of VMT
A*NNVMT* = Base year VMT per truck by 3 freight size classes.

Finally, adjust VMT to obtain VMT across all sectors:

$$VMTFLT_{Year,SC,AGE,Frt\_Fuel,FLT} = ANNVMT_{SC,AGE,Frt\_Fuel} * VMTADJ_{Year} * TRKSTK_{Year,SC,AGE,Frt\_Fuel,FLT} \quad \textbf{(244)}$$

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

$$FUELDMD_{Year,SC,Frt\_Fuel,FLT} = \sum_{AGE=1}^{20} \frac{VMTFLT_{Year,SC,AGE,Frt\_Fuel,FLT}}{CFMPG_{Year,SC,AGE,Frt\_Fuel}} \quad \textbf{(245)}$$

where:

FUELDMD = Total freight truck fuel consumption by size class and fuel type, in gallons of gasoline equivalent

CFMPG = Fuel economy of freight trucks, by size class, fuel, and vintage

= $CFMPG_{Year,SC,AGE=1,Frt\_Fuel}$

Converting from gasoline equivalent to trillion Btu is an application of the heat rate of gasoline:

$$FUELBTU_{Year,SC,Frt\_Fuel,FLT} = FUELDMD_{Year,SC,Frt\_Fuel,FLT} * HTRATE * 10^{-12} \quad \textbf{(246)}$$

where:

FUELBTU = Total fleet truck fuel consumption by size class and fuel type, in trillion Btu

3E-2. Rail Freight Model

Rail forecasts represent a simplification of the freight trucking approach, in that only one class of freight rail and vehicle technology is considered. Projections of energy use by rail are driven by forecasts of coal production and of ton-miles traveled for each of the industrial categories used in the trucking sector. The algorithm is similar to the one used for trucks:

$$COALT_{Year} = \sum_{Coal\_Reg=1}^{2} \left(COALP_{Coal\_Reg,Year} * COALD_{Coal\_Reg}\right) \quad \textbf{(247)}$$

where:

COALT = Total ton-miles traveled for coal in region, *Coal_Reg*, (east/west) in a given year
COALP = The production of coal in region, *Coal_Reg*, in a given year in tons
COALD = Distance coal has to travel in region, *Coal_Reg*.

Ton-miles traveled is calculated:

$$RTMT_{ISIC,Year} = RTMT_{ISIC,Year_0} * FACR_{ISIC} * \left[\frac{OUTPUT_{ISIC,Year}}{OUTPUT_{ISIC,Year_0}}\right] \quad \textbf{(248)}$$

where:

RTMT = Total rail ton-miles traveled for industry, *ISIC=1,10*, in year, *Year*
OUTPUT = Value of output of industry *ISIC*, in base year, $Year_0$, dollars

FACR = Coefficient relating growth of value of goods produced with growth of rail transport

Grow coal by product and region, and calculate aggregated ton-miles traveled:

$$RTMT\_C_{ISIC=10,Year} = \left(.1 * RTMT_{ISIC=10,Year}\right) + \left(.9 * RTMT_{ISIC=10,Year_0} * \frac{COALT_{Year}}{COALT_{Year_0}}\right) \quad \textbf{(249)}$$

$$RTMTT_{Year} = \sum_{ISIC=1}^{10} RTMT_{ISIC,Year} + RTMT\_C_{ISIC=10,Year} \quad \textbf{(250)}$$

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

$$TQRAILT_{Year} = FERAIL_{Year} * RTMTT_{Year} \quad \textbf{(251)}$$

where:

TQRAILT = Total energy consumption by freight trains
FERAIL = Exogenously determined rail energy efficiency

Rail efficiency gains resulting from technological development and increased system efficiency are based on an exogenous analysis of trends.

This aggregate energy demand is used to estimate the demand for the various fuels used for rail transport, adjusting the previous year's demand for a given fuel by the fractional increase in overall energy requirements:

$$TQRAIL_{Rail\_Fuel,Year} = TQRAIL_{Rail\_Fuel,Year-1} * \left(\frac{TQRAILT_{Year}}{TQRAILT_{Year-1}}\right) \quad \textbf{(252)}$$

where:

TQRAIL = Total demand for each fuel by rail freight sector in year, *Year*

This is based on the assumption that the relative shares of each fuel remains constant across the forecast horizon, and that there is little or no room for fuel substitution as prices vary.

Fuel consumption is then allocated to each region:

$$TQRAILR_{Rail\_Fuel,REG,Year} = TQRAIL_{Rail\_Fuel,Year} * SEDSHRXX_{REG,Year} \qquad \textbf{(253)}$$

where:

$TQRAILR_{FUEL,Year}$ = Total regional fuel consumption for each technology

$SEDSHRXX_{REG,Year}$ = Regional share of rail freight fuel consumption, from SEDS, by fuel, XX=DS (distillate), XX=RS (residual), XX=EL(electricity)

Calculate fractional change in fuel efficiency:

$$XRAILEFF_{Year} = \frac{FERAIL_{Year}}{FERAIL_{Year_0}} \qquad \textbf{(254)}$$

where:

XRAILEFF = Growth in rail efficiency from base year, $Year_0$

3E-3. Waterborne Freight Model

Two classes of waterborne transit are considered in this component: domestic marine traffic and freighters conducting foreign trade. This is justified on the grounds that vessels which comprise freighter traffic on rivers and in coastal regions have different characteristics than those which ply international waters.

Domestic Marine

The estimation of total domestic waterborne travel demand is driven by forecasts of industrial output:

$$STMTT_{Year} = \sum_{ISIC=1}^{10} STMT_{ISIC,Year_D} * FACS_{ISIC} * \left[\frac{OUTPUT_{ISIC,Year}}{OUTPUT_{ISIC,Year_D}}\right] \quad \textbf{(255)}$$

where:

STMT = Total ton-miles of waterborne freight for industry, *ISIC*, in year, *Year.*
OUTPUT = Value of output of industry, *ISIC*, in base year dollars
FACS = Exogenous determined coefficient relating growth of value added with growth of shipping transport
$Year_D$ = Year of most recent data update

Fuel use is subsequently estimated, using the average energy efficiency:

$$SFDT_{Year} = FESHIP_{Year} * STMTT_{Year} \quad \textbf{(256)}$$

where:

SFDT = Domestic ship energy demand
FESHIP = Average fuel efficiency

Estimated changes in energy efficiency are exogenous. The next step is to allocate total energy consumption among three fuel types (distillate fuel, residual fuel oil and gasoline):

$$SFD_{Ship\_Fuel,Year} = SFDT_{Year} * SFSHARE_{Ship\_Fuel,Year} \quad \textbf{(257)}$$

where:

SFD = Domestic ship energy demand, by fuel
SFSHARE = Domestic shipping fuel allocation factor
Ship_Fuel = Index referring to the three shipping fuel types

The factor which allocates energy consumption among the three fuel types is based on 1998 data and is held constant throughout the run period[17].

Total energy demand is then regionalized:

$$TQSHIPR_{Ship\_Fuel,REG,Year} = SFD_{Ship\_Fuel,Year} * SEDSHR_{Ship\_Fuel,REG,Year} \quad \textbf{(258)}$$

where:

TQSHIPR = Total regional energy demand by domestic freighters
SEDSHR = Regional shares of fuel demand, from SEDS

Calculate fractional change in domestic ship travel and fuel efficiency:

$$XSHIPEFF_{Year} = \frac{FESHIP_{Year}}{FESHIP_{Year_0}} \quad \textbf{(259)}$$

where:

XSHIPEFF = Growth in ship efficiency from base year, $Year_0$

International Marine

Fuel demand in international marine shipping is directly estimated, linking the level of international trade with the lagged consumption of the fuel in question:

$$ISFDT_{Year} = ISFDT_{Year-1} + \left[\frac{GROSST_{Year}}{GROSST_{Year-1}} - 1 \right] * O.5 * ISFDT_{Year-1} \quad \textbf{(260)}$$

where:

ISFDT = Total international shipping energy demand in year, *Year*
GROSST = Value of Gross Trade (imports + exports), from Macro Model

Total energy demand is then allocated among the various fuels as above:

[17] Oak Ridge National Laboratory, Center for Transportation Analysis, Transportation Energy Data Book Edition 21, September 2001, Oak Ridge, TN, Table 2.5.

$$ISFD_{Ship\_Fuel,Year} = ISFDT_{Year} * ISFSHARE_{Ship\_Fuel,Year} \quad \textbf{(261)}$$

where:

ISFD = International freighter energy demand, by fuel
ISFSHARE = International shipping fuel allocation factor

Regional fuel consumption is then calculated:

$$TQISHIPR_{Ship\_Fuel,REG,Year} = ISFD_{Ship\_Fuel,Year} * SEDSHR_{Ship\_Fuel,REG,Year} \quad \textbf{(262)}$$

where:

TQISHIPR = Total regional energy demand by international freighters
SEDSHR = Regional shares of fuel demand, from SEDS

Figure 3E-2. Highway Freight Model

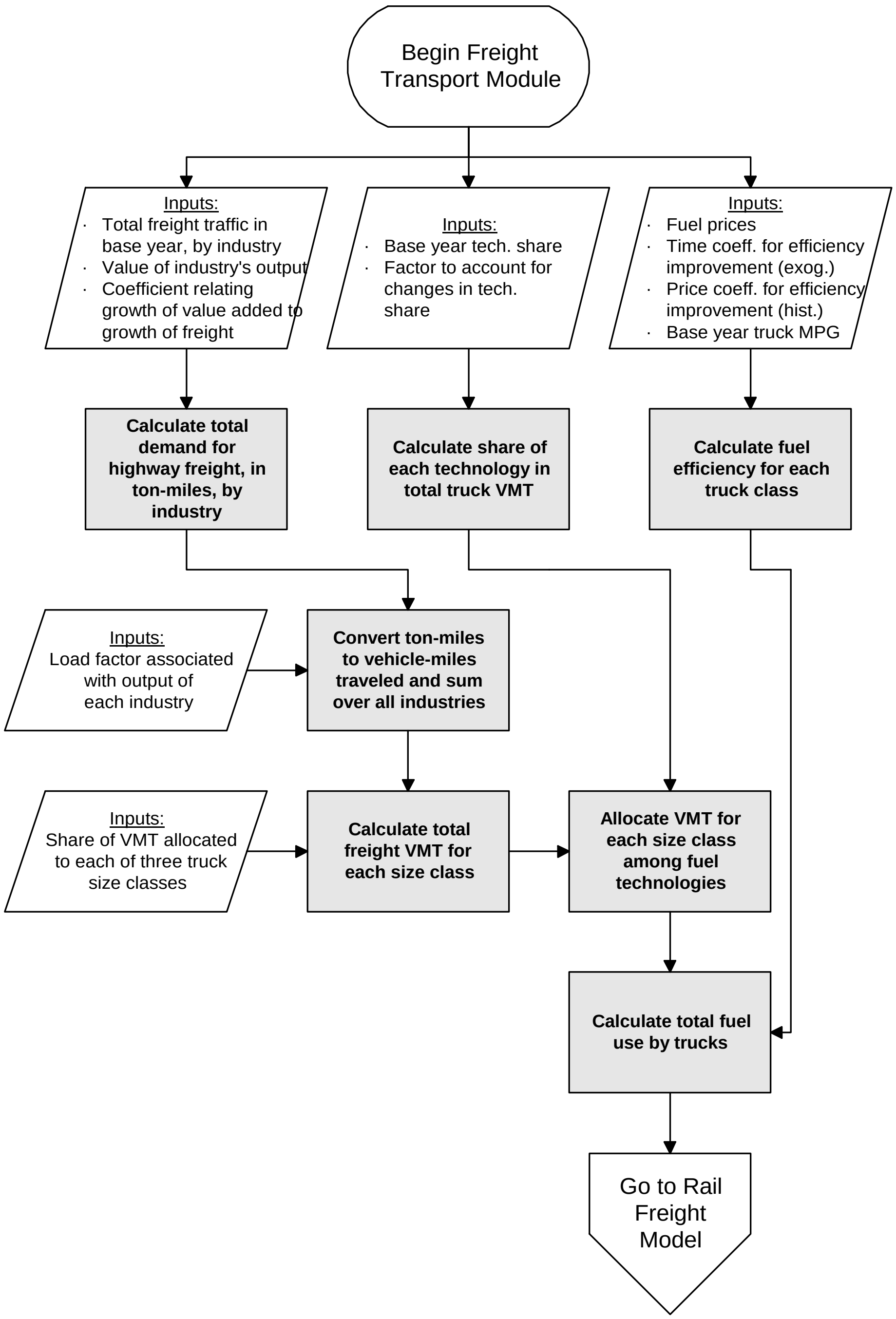


Figure 3E-3. Rail Freight Model

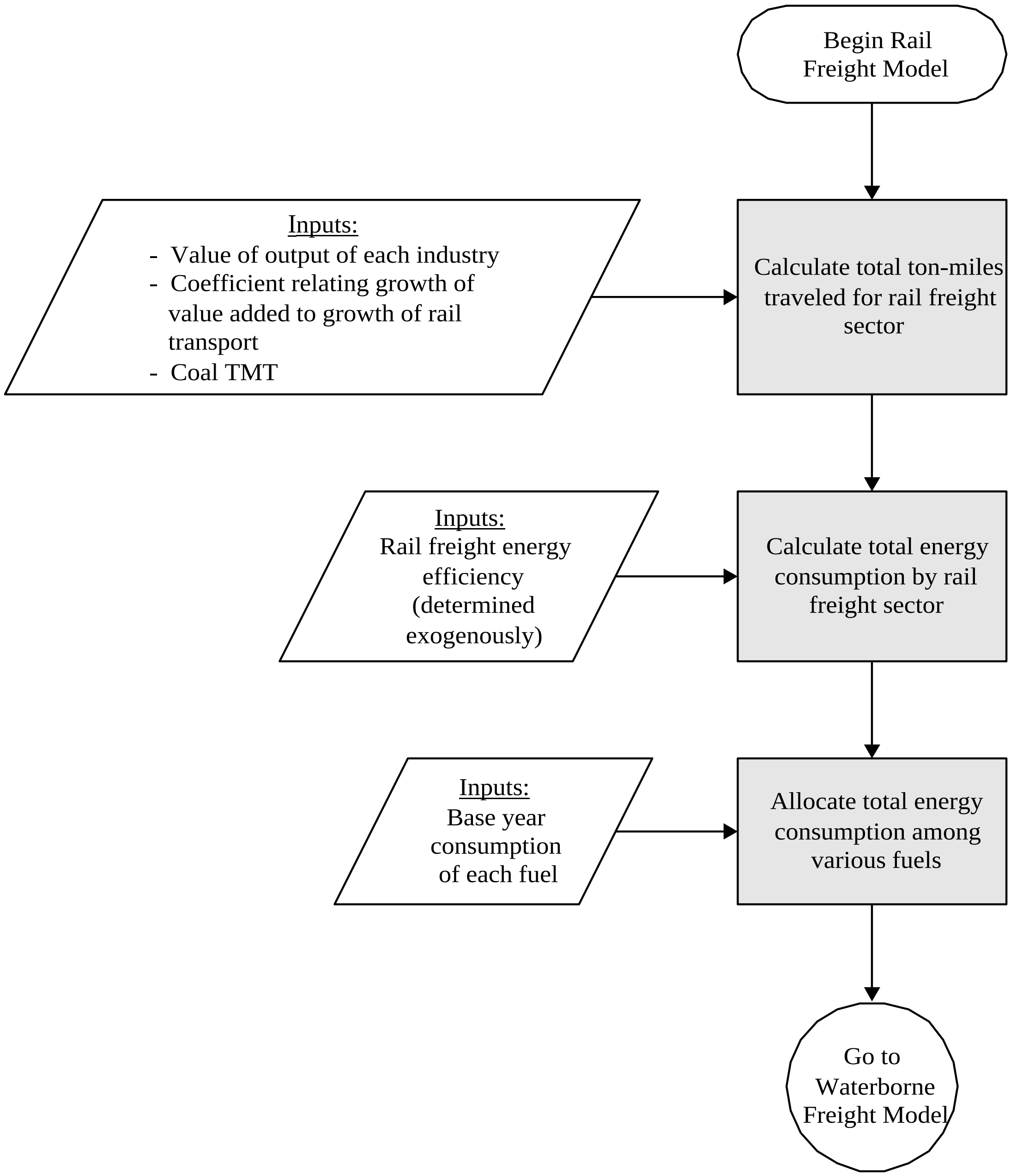
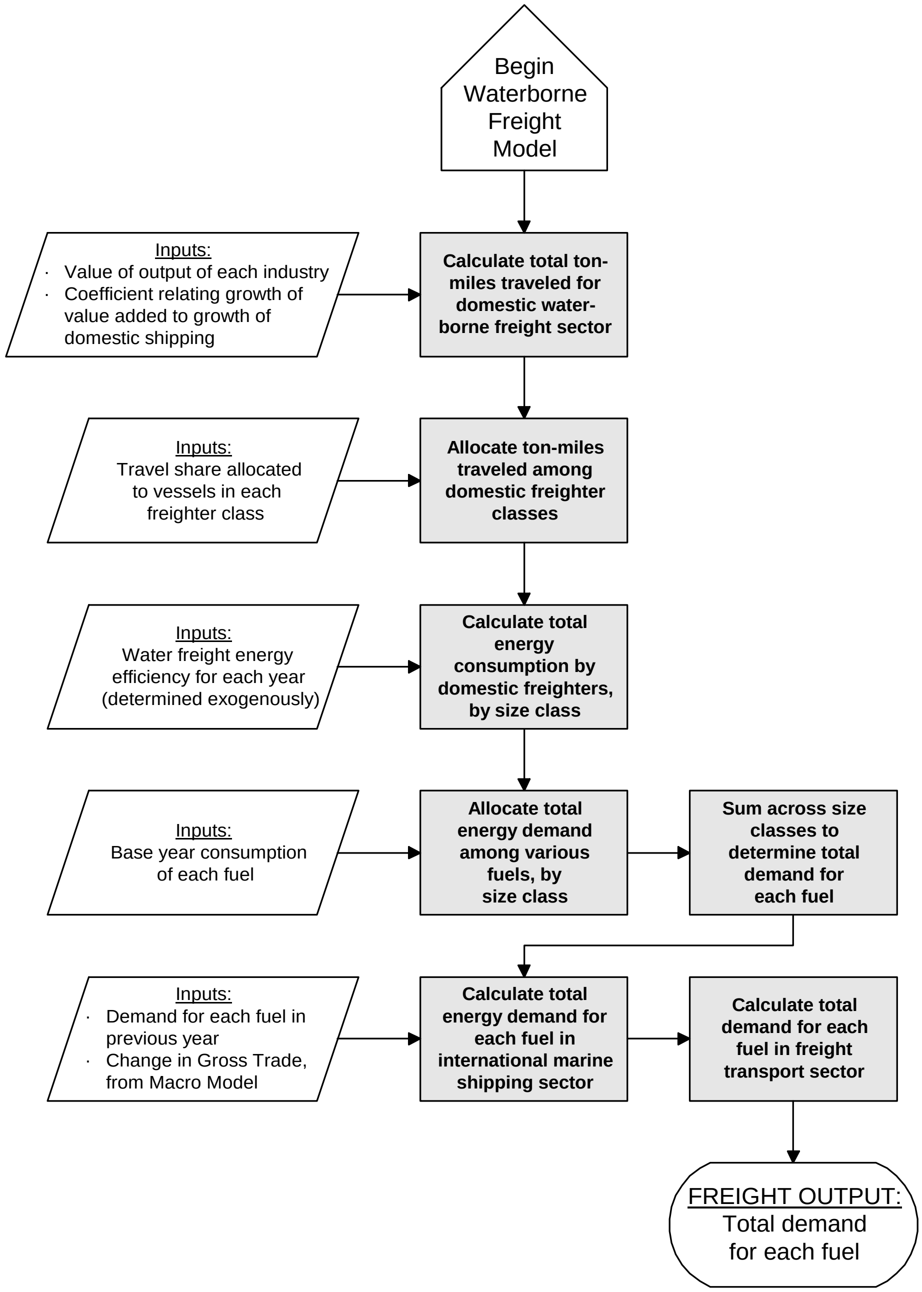


Figure 3E-4. Waterborne Freight Model

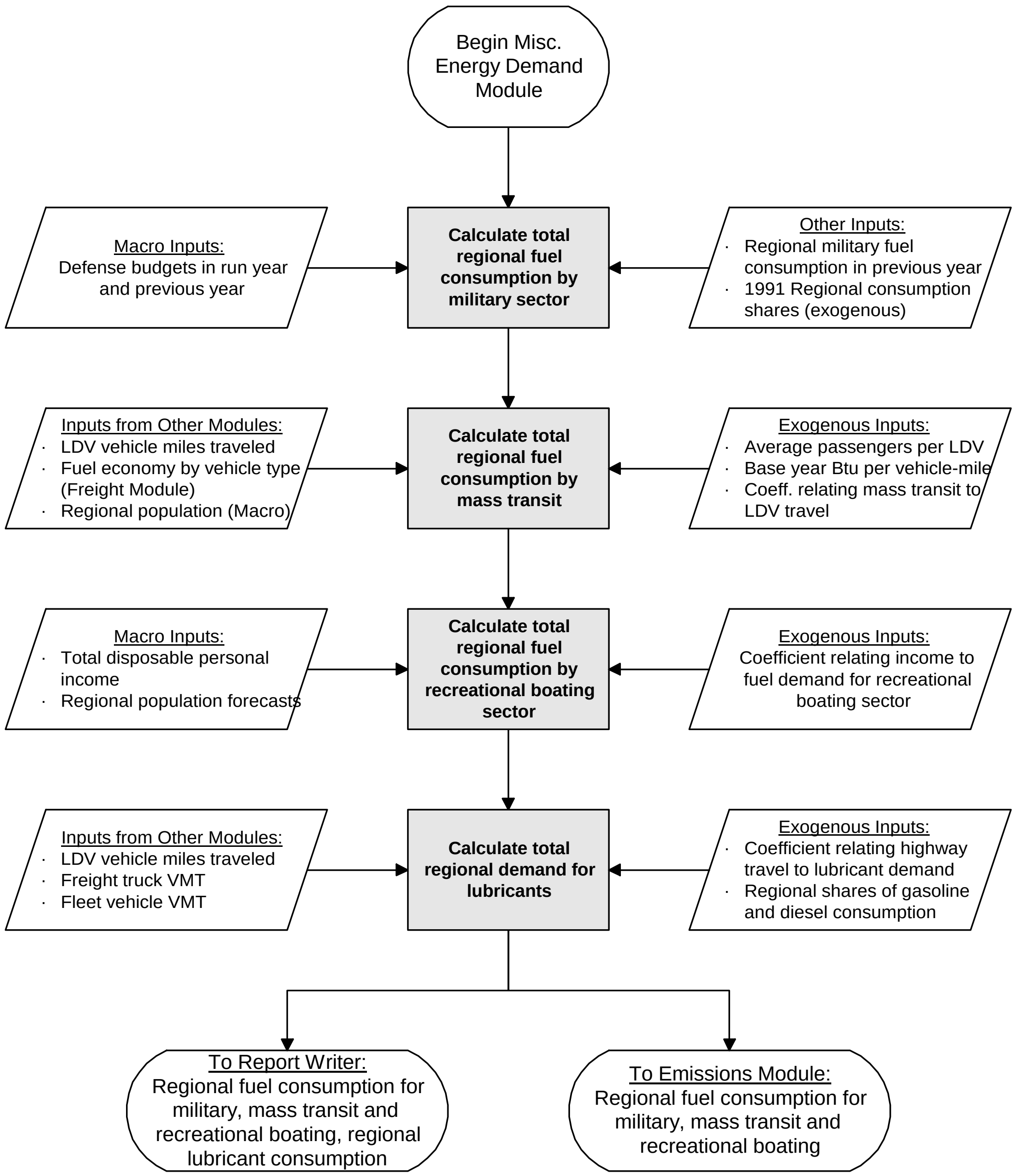


3F. Miscellaneous Energy Demand Module

The Miscellaneous Energy Demand (MED) module addresses the projection of demand for several transportation fuels and end-use categories. These categories include military operations, mass transit (passenger rail and buses), recreational boating, and lubricants used in all modes of transportation.

The flowchart for the Miscellaneous Energy Demand Module is presented below. Additional flowcharts portraying Miscellaneous Energy Demand Module calculations in more detail can be found at the end of this section.

Figure 3F-1. Miscellaneous Energy Demand Module



Note: the emissions model is currently inactive

3F-1. Military Demand Model

Fuel demand for military operations is considered to be proportional to the projected military budget. The fractional change in military budget is first calculated:

$$MILTARGR_{Year} = \frac{TMC\_GFML_{Year}}{TMC\_GFML_{Year-1}} \qquad \textbf{(263)}$$

where:

MILTARGR = The growth in the military budget from the previous year
TMC_GFML = Total defense budget in year, *Year*, from the macroeconomic model in NEMS

Total consumption of each of four fuel types is then determined:

$$MFD_{Mil\_Fuel,Year} = MFD_{Mil\_Fuel,Year-1} * MILTARGR_{Year} \qquad \textbf{(264)}$$

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:

$$QMILTR_{Mil\_Fuel,REG,Year} = MFD_{Mil\_Fuel,Year} * MILTRSHR_{Mil\_Fuel,REG} \qquad \textbf{(265)}$$

where:

QMILTR = Regional fuel consumption, by fuel type, in Btu
MILTRSHR = Regional consumption shares, from 1991 data, held constant

3F-2. Mass Transit Demand Model

The growth of passenger-miles in each mode of mass transit is assumed to be proportional to the growth of passenger-miles in light duty vehicles. This is determined from the output of the VMT module and the load factor for LDV's, held constant at 1989 levels:

$$TMOD_{IM=1,Year} = VMTEE_{Year}$$

and:

$$TMOD_{IM\neq 1,Year} = TMOD_{IM\neq 1,Year-1} * \left[\frac{TMOD_{IM=1,Year}}{TMOD_{IM=1,Year-1}}\right]^{BETAMS} \tag{266}$$

where:

TMOD = Passenger-miles traveled, by mode
VMTEE = LDV vehicle-miles traveled, from the VMT module
BETAMS = Coefficient of proportionality, relating mass transit to LDV travel
IM = Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail

Fuel efficiencies, in Btu per vehicle-mile, are obtained from the Freight Module for buses and rail; and mass transit efficiencies, in Btu per passenger-mile, are calculated:

$$TMEFF_{IM,Year} = \left[TMEFF_{IM,Year-1} * \left(\frac{FMPG_{TYPE,Year}}{FMPG_{TYPE,Year-1}}\right)\right] \tag{267}$$

where:

TMEFF = Btu per passenger-mile, by mass transit mode
FMPG = Fuel efficiency, by vehicle type, from the Freight Module
TYPE = Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail

Total fuel consumption may then be calculated and distributed among regions according to their populations:

$$QMODR_{IM,REG,Year} = TMOD_{IM,Year} * TMEFF_{IM,Year} * \left[\frac{TMC\_POPAFO_{REG,Year}}{\sum_{REG=1}^{9} TMC\_POPAFO_{REG,Year}}\right] \tag{268}$$

where:

QMODR = Regional consumption of fuel, by mode
TMC_POPAFO = Regional population forecasts, from the Macro Module

3F-3. Recreational Boating Demand Model

The growth in fuel use by recreational boats is considered to be proportional to the growth in disposable personal income:

$$RECFD_{Year} = RECFD_{Year-1} * \left[\frac{TMC\_YD_{Year}}{TMC\_YD_{Year-1}} \right]^{BETAREC} \qquad \textbf{(269)}$$

where:

RECFD = National recreational boat gasoline consumption in year, *Year*
TMC_YD = Total disposable personal income, from the Macro Module
BETAREC = Coefficient of proportionality relating income to fuel demand for boats

Regional consumption is calculated according to population, as with mass transit, above:

$$QRECR_{REG,Year} = RECFD_{Year} * \left[\frac{TMC\_POPAFO_{REG,Year}}{\sum_{REG=1}^{9} TMC\_POPAFO_{REG,Year}} \right] \qquad \textbf{(270)}$$

where:

QRECR = Regional fuel consumption by recreational boats in year, *Year*

3F-4. Lubricant Demand Model

The growth in demand for lubricants is considered to be proportional to the growth in highway travel by all types of vehicles. Total highway travel is first determined:

$$HYWAY_{Year} = VMTEE_{Year} + FTVMT_{Year} + FLTVMT_{Year} \qquad \textbf{(271)}$$

where:

HYWAY = Total highway VMT
FTVMT = Total freight truck VMT, from the Freight Module
FLTVMT = Total fleet vehicle VMT, from the Fleet Module

Lubricant demand is then estimated:

$$LUBFD_{Year} = LUBFD_{Year-1} * \left[\frac{HYWAY_{Year}}{HYWAY_{Year-1}}\right]^{BETALUB} \qquad \textbf{(272)}$$

where:

LUBFD = Total demand for lubricants in year, *Year*
BETALUB = Constant of proportionality, relating highway travel to lubricant demand

Regional allocation of lubricant demand is finally determined by regional weighting of all types of highway travel:

$$QLUBR_{REG,Year} = LUBFD_{Year} * \left[\frac{\left(\left(VMTEE_{Year} + FLTVMT_{Year}\right) * SHRMG_{REG,Year}\right) + \left(FTVMT_{Year} * SHRDS_{REG,Year}\right)}{HYWAY_{Year}}\right] \qquad \textbf{(273)}$$

where:

QLUBR = Regional demand for lubricants in year, *Year*, in Btu
SHRMG = Regional share of motor gasoline consumption, from SEDS
SHRDS = Regional share of diesel consumption, from SEDS

Figure 3F-2. Military Demand Model

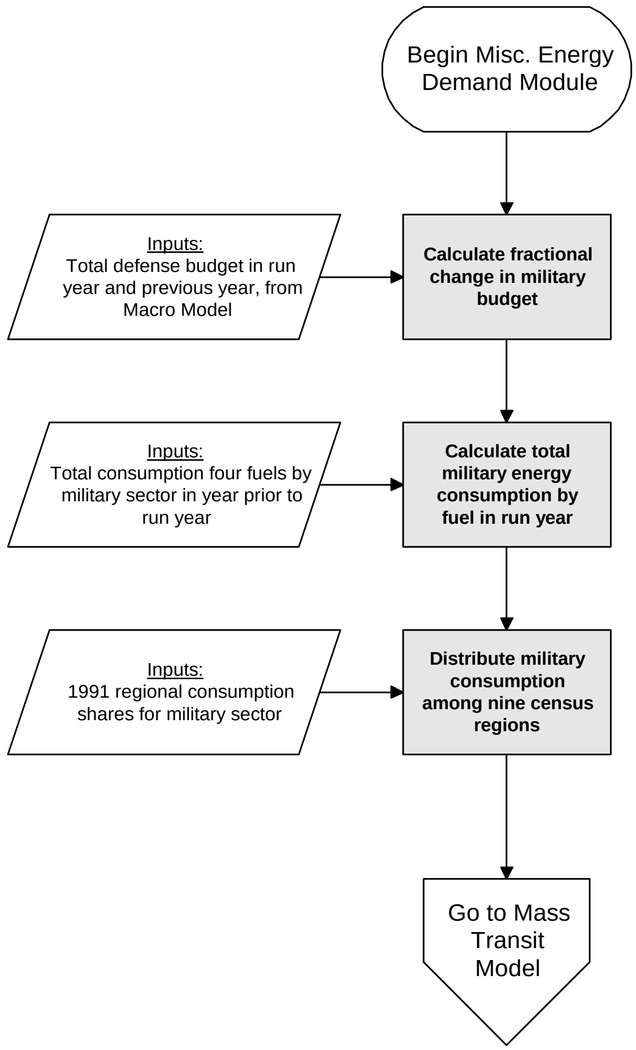


Figure 3F-3. Mass Transit Demand Model

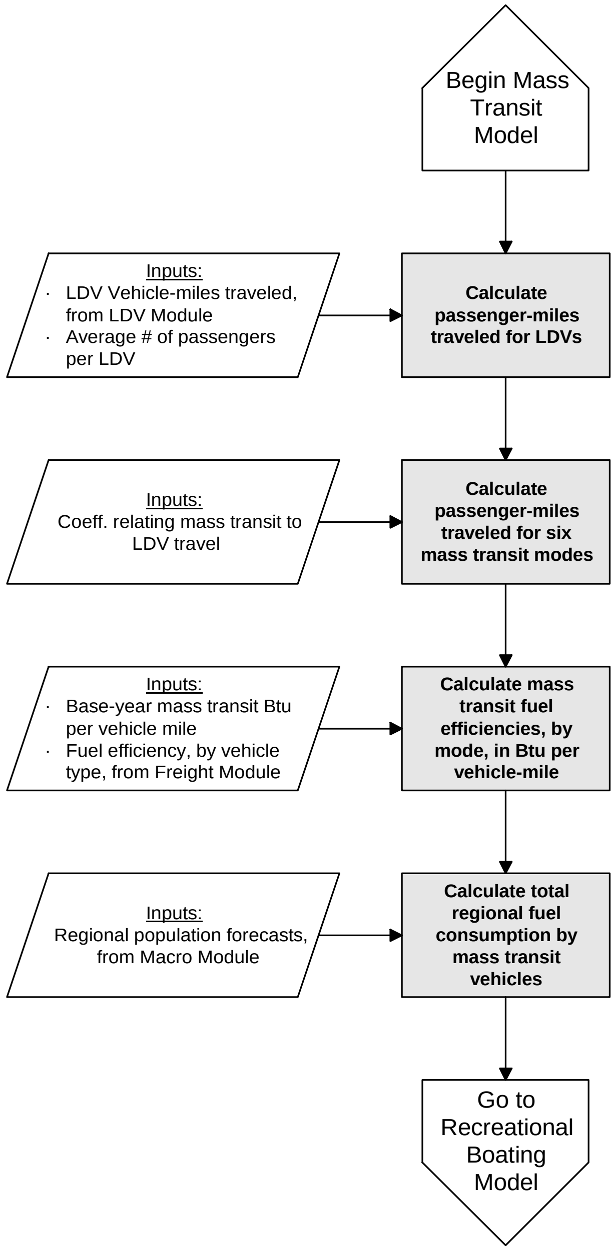


Figure 3F-4. Recreational Boating Demand Model

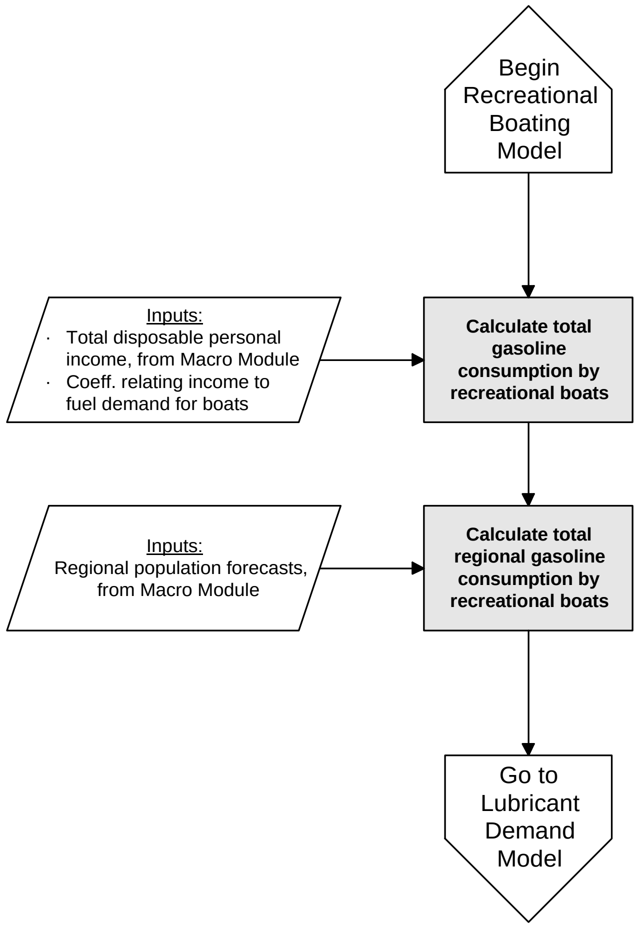


Figure 3F-5. Lubricant Demand Model