DOE/EIA-M070(2001)

The Transportation Sector Model of the National Energy Modeling System

Model Documentation Report

February 2001

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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, Commercial Light Trucks, Freight Transport (truck, rail, and marine), Aircraft, 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, 2000.

Model Interfaces

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

Official Model Representative

John Maples
Energy Information Administration
Office of Integrated Analysis and Forecasting
Energy Demand and Integration Division
1000 Independence Avenue, SW
EI-84, Room 2F-094
Washington, DC 20585
Telephone: (202) 586-1757

Documentation

Model Documentation Report: *Transportation Sector Model of the National Energy Modeling System*, DOE/EIA-M070(01), January, 2001.

Archive Media and Installation Manual(s)

NEMS-2001 (Part of the National Energy Modeling System archival package for the *Annual Energy Outlook 2001*, DOE/EIA-0383(2001)).

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, 1990 through 2020.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants, pipeline fuel 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; CAFÉ 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 Transportation Sector Component Design Report, June, 1992, conducted by David L. Greene, Oak Ridge National Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- State Energy Data System (SEDS), DOE/EIA-0214(97) Sept. 1999.
- Short Term Energy Outlook (STEO), DOE/EIA-0202(00/3Q)

Non-DOE Input Sources:

- National Energy Accounts
- Federal Highway Administration, Highway Statistics, FHWA-PL-99-017, Nov. 1999
- Department of Transportation Air Travel Statistics
- U.S. Department of Transportation, Bureau of Transportation Statistics: Air Carrier Traffic Statistics Monthly, December 1997/1996.
- National Highway Traffic and Safety Administration, Mid-Year Fuel Economy Report, 1999
- Oak Ridge National Laboratory, Transportation Energy Data Book Ed. 20, ORNL-6959, Oct. 2000
- Oak Ridge National Laboratory, Fleet Vehicles in the U.S., 1992.
- Federal Aviation Administration, FAA Aviation Forecasts: Fiscal Years 1993-2004, February 1998.
- Department of Commerce, Bureau of the Census, Truck Inventory and Use Survey, 1992.
- California Air Resources Board, Proposed Regulations for Low-Emission Vehicles and Clean Fuels, Staff Report, August 13, 1990.

1. INTRODUCTION

1A. 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.

1B. 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 2020 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.

1C. 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 design to estimate criteria emissions from the transportation sector. The components of the six active modules are briefly described in turn below.

1C-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 fourteen 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.

1C-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.

1C-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.

1C-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.

1D. Model Archival Citation

Archived as part of the NEMS production runs for the *Annual Energy Outlook 2001*.

1E. 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 2020, 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, fuel economy, and emissions by transport mode and vehicle type 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.

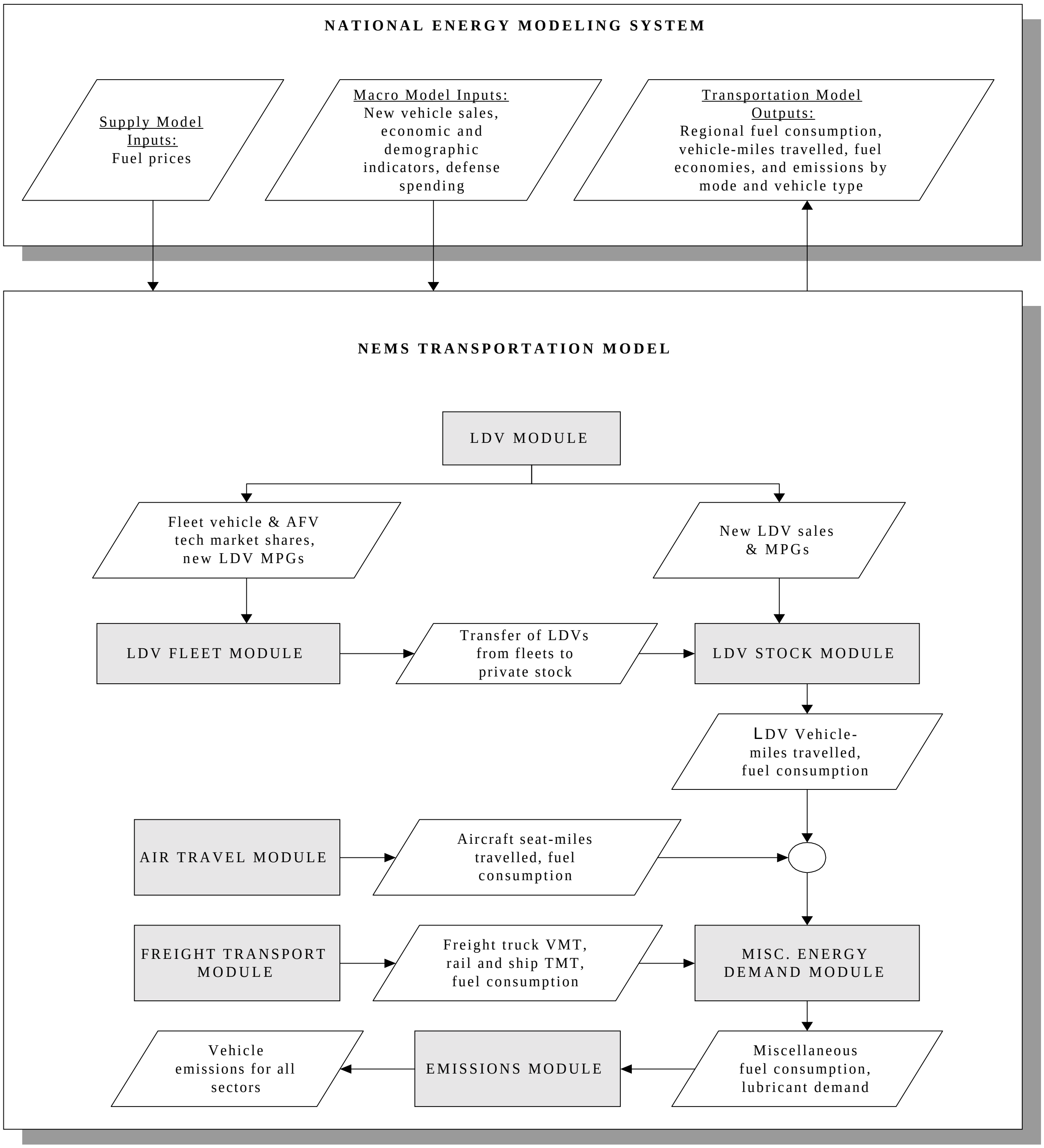
The LDV Stock Module uses vintage-dependent constants such as vehicle survival and relative driving rates, and fuel economy degradation factors to obtain estimates of stock efficiency.

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 and modal shares.

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 addresses fourteen size classes (seven for both car and light truck), while the Stock and the AFV Modules consider twelve separate 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 fifty-eight separate technologies within each of fourteen vehicle market classes, four corporate average fuel economy (CAFÉ) groups, and fifteen fuel types. Table 3-1 lists the fourteen size classes and provides a brief definition and example of each. The seven automobile market classes include five classes based on interior passenger volume, ranging from "minicompact" to "large", and classes for "sports" and "luxury" cars. The seven classes of light truck are based mainly on utility and inertia weight and include vans, pickups, utility vehicles and mini-trucks. The four groups for which CAFÉ 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 fourteen 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:

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).

---

[1]U.S. Department of Energy, Energy Information Administration, Updates to the Fuel Economy Model, provided by Energy and Environmental Analysis, 1998.

Table 3-1. Light Duty Vehicle Market Classes

CLASS	DEFINITION	EXAMPLE MODEL
AUTOMOBILES (Domestic and Import)		
Minicompact	Interior passenger volume < 79 ft^3	Geo Metro
Subcompact	Passenger volume between 79 ft^3 and 89 ft^3	Nissan Sentra, Honda Civic, GM Saturn, Ford Escort
Sports	Two door high performance cars costing less than $25,000	Honda Prelude, Chevy Camaro, Ford Mustang
Compact	Passenger volume between 89 and 95 ft^3	Honda Accord, Toyota Camry, Ford Focus, Pontiac Grand Am
Intermediate	Passenger volume between 96 and 105 ft^3	Nissan Maxima, Ford Taurus, Chevy Lumina
Large	Passenger volume >105 ft^3	Ford Crown Victoria, Pontiac Bonneville (no imports)
Luxury	Cars over $25,000	Lincoln Continental, Cadillac, all Mercedes, Lexus LS400
LIGHT TRUCKS (Domestic and Import)		
Compact Pickup	Trucks with inertia weight between 2750 and 4000 lbs.	All import trucks, Ford Ranger, GM S-10/15
Compact Van	Vans with inertia weight between 3000 and 4250 lbs.	All import vans, Dodge Caravan, Ford Windstar
Compact Utility	Utility vehicles with inertia weight between 3000 and 4250 lbs.	Nissan Pathfinder, Toyota 4Runner, Ford Explorer, Jeep Cherokee
Standard Pickup	Trucks with inertia weight over 4000 lbs.	GM C-10, Ford F-150
Standard Van	Vans with inertia weight over 4250 lbs.	GM C15 van, Ford E-150 (no imports)
Standard Utility	Utility vehicles with inertia weight over 4250 lbs.	Toyota Land Cruiser, GM Suburban, Ford Expedition
Mini-truck	Utility/trucks below 2750 lbs. inertia weight	Suzuki Grand Vitara

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 fifty-eight automotive technologies whose availability and cost-effectiveness are either well-documented or conservatively estimated. The second, identified as the "High Technology Scenario", augments the Standard Scenario with five additional technologies, and 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 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. This relationship is 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 7 car classes and the 7 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 Corporate Average Fuel Economy (CAFÉ) standards by year, and of differential standards for domestic and import vehicles, as well as the penalty (in dollars) per car per mile per gallon below the standard. The standards are accounted for in the 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 CAFÉ standards as a cost-minimizing strategy, as may occur if penalties are set at unrealistic levels relative to the difficulty of achieving the CAFÉ standards.

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

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 1994 Tier I emission standards as well as the 2001+ Tier II emission standards, but does *not* envisage that the California "Low Emission Vehicle" standards will be adopted only in those states that have adopted similar programs. 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 seven 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 except for the addition of sports and luxury classes that are not defined on the basis of interior volume. In addition, the classes utilized here are based on passenger volume, not passenger and trunk volume as per EPA, which results in some hatchback models differing in classification. Truck classification is essentially identical to the EPA classification. This leads to a total of 28 possible classes (7 classes x 2 vehicle types x 2 manufacturer types) but some have no vehicles, e.g., there are no domestic minicompact cars. The net result is 22 different classes which are individually forecast to 2020.

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 1995. 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.

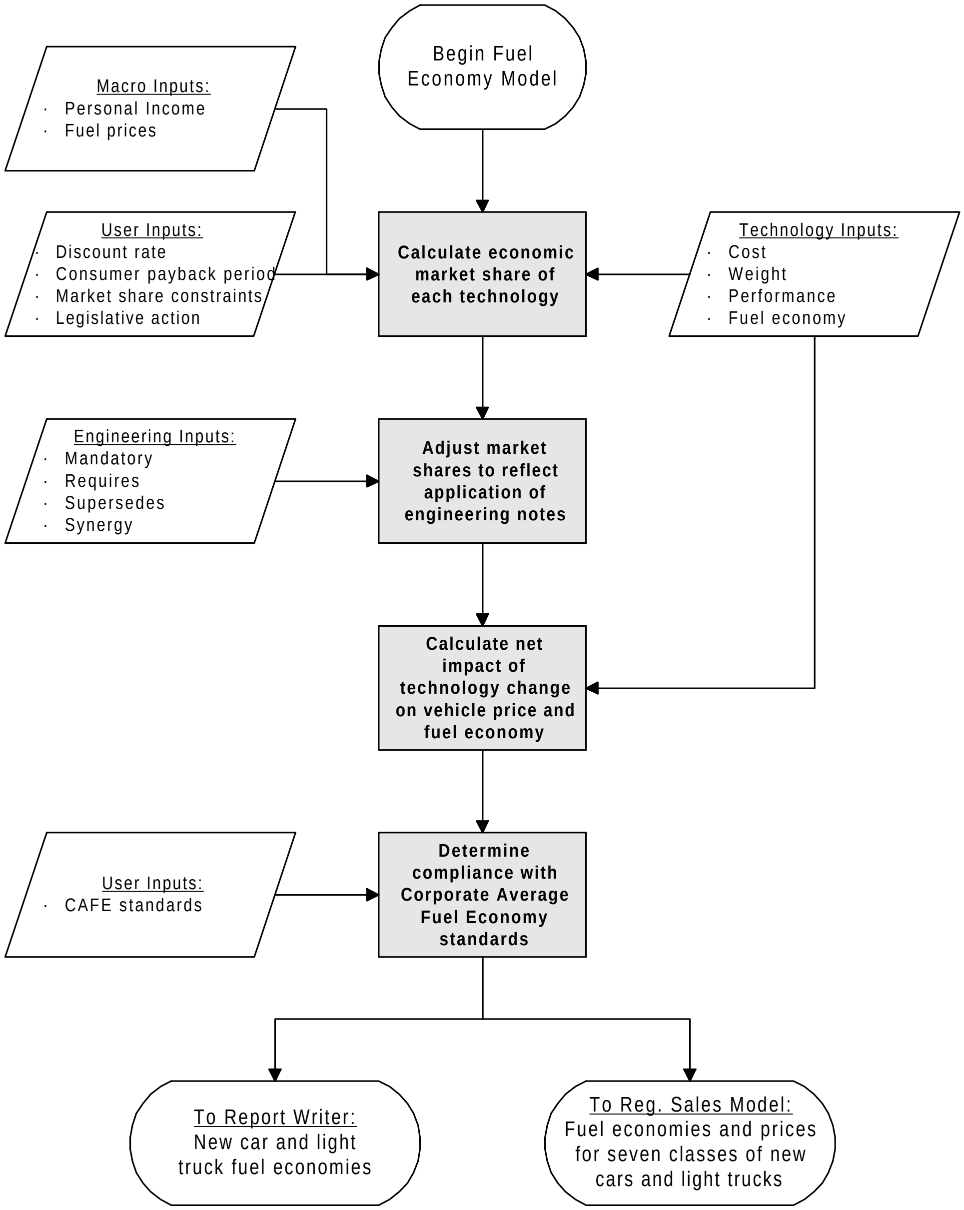
In certain cases there are adjustments which must be made to the calculated market shares. Some of these adjustments reflect engineering limitations to what may be adopted. Other adjustments reflect external forces that require certain types of technologies; safety and emissions technologies are both 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, based on income, fuel economy, fuel cost, and vehicle class, a performance-change adjustment is 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 Corporate Average Fuel Economy (CAFÉ) 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 to meet the CAFÉ 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 this second pass, the technology cost effectiveness calculation is modified to include the benefit of not having to pay the fine for failing to meet CAFÉ. After this second pass the CAFEs are recalculated. No further action is taken to force CAFÉ compliance; vehicles in failing groups are assumed to simply pay the fine.

Figure 3A-1. Fuel Economy Model



ESTABLISH AFV CHARACTERISTICS RELATIVE TO CONVENTIONAL GASOLINE

The initialization subroutine, AFVADJ, calculates the base year price, weight, fuel economy and horsepower for the alternative fuel vehicles. 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.

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

a) Mini, Sub-Compact, Sports and Compacts at 2,500 units/year:

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

where:

$AFVADJPR_{Fuel\ Type,\ 1}$ = the incremental price adjustment for a low production AFV car.

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

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

where:

$AFVADJPR_{Fuel\ Type,\ 1}$ = Incremental price adjustment for a low production AFV car

$AFVADJPR_{Fuel\ Type,\ 2}$ = Incremental price adjustment for a low production AFV truck.

c) Luxury vehicles at 2,500 units/year:

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + 2 * AFVADJPR_{FuelType,1} \quad \textbf{(3)}$$

d) Mini, Sub-Compact, Sports and Compacts at 25,000 units/year:

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

where:

$AFVADJPR_{Fuel\ Type,\ 3}$ = Incremental price adjustment for a high production AFV car.

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

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + \frac{AFVADJPR_{FuelType,3} + AFVADJPR_{FuelType,4}}{2} \quad \textbf{(5)}$$

where:

$AFVADJPR_{Fuel\ Type,\ 3}$ = Incremental price adjustment for a high production AFV car

$AFVADJPR_{Fuel\ Type,\ 4}$ = Incremental price adjustment for a high production AFV truck.

f) Luxury at 25,000 units/year:

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + 2 * AFVADJPR_{FuelType,3} \quad \textbf{(6)}$$

Calculate AFV base year values for light duty truck prices at different production levels.

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

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + AFVADJPR_{FuelType,2} \quad \textbf{(7)}$$

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

$$PRICE_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + \frac{AFVADJPR_{FuelType,1} + AFVADJPR_{FuelType,2}}{2} \quad \textbf{(8)}$$

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

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + AFVADJPR_{FuelType,4} \quad \textbf{(9)}$$

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

$$PRICEHI_{BaseYear,FuelType} = PRICE_{BaseYear,Gasoline} + \frac{AFVADJPR_{FuelType,3} + AFVADJPR_{FuelType,4}}{2} \quad \textbf{(10)}$$

Calculate base 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:

$$PRICE_{BaseYear,ElectricHybrid} = PRICE_{BaseYear,Gasoline} + \left(NIMHY\$COST_{BaseYear} * AFVADJPR_{ElectricHybrid,3} * \frac{WEIGHT_{Year,Gasoline}}{WEIGHT_{Midsize,BaseYear,Gasoline}} \right) \quad \textbf{(11)}$$

where:

$AFVADJPR_{ElectricHybrid,\ 3}$ = Incremental price adjustment for a midsize car EV/Hybrid
$WEIGHT_{Midsize}$ = Weight of a midsize car in the base year
$WEIGHT_{Year\ Gasoline}$ = Weight of a midsize car in year *t*
$NIMHY\$COST_{Base\ Year}$ = Cost reduction learning curve for a Ni-MH battery

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

$$PRICEHI_{BaseYear,ElectricHybrid} = PRICE_{BaseYear,Gasoline} + \left(NIMHY\$COST_{BaseYear} * AFVADJPR_{ElectricHybrid,3} * \frac{WEIGHT_{Year,Gasoline}}{WEIGHT_{Midsize,BaseYear,Gasoline}} \right) \quad \textbf{(12)}$$

Calculate base year values for such AFV characteristics as fuel economy, weight, and horsepower.

a) Fuel Economy Calculation:

$$FE_{BaseYear,FuelType} = FE_{BaseYear,Gasoline} * (1 + AFVADJFE_{FuelType}) \quad \textbf{(13)}$$

where:

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

b) Weight Calculation:

$$WEIGHT_{BaseYear,FuelType} = WEIGHT_{BaseYear,Gasoline} * (1 + AFVADJWT_{FuelType}) \quad \textbf{(14)}$$

where:

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

Horsepower Calculation:

$$HP_{BaseYear,FuelType} = HP_{BaseYear,Gasoline} * (1 + AFVADJHP_{FuelType}) \quad \textbf{(15)}$$

where:

AFVADJHP = Horsepower adjustment, relative to gasoline, 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 twice. 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 CAFÉ standards. During this pass, the cost effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFÉ[3]. If a vehicle group continues to fail to meet CAFÉ standards after the second pass, no further adjustments to technology market shares are made. Rather, it is assumed that the manufacturers simply pay the penalty.

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

[3] See the variable REGCOST in Equation 21.

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 Type. In the interest of legibility, these dimensions are not shown in the subscripts.

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-4. These are addressed in turn below.

Fuel Savings Value

The "expected" price of fuel is based on the rate of change of fuel prices over a two year period extending from three to five years prior to the year when the technology adoption decision is made. 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. The expected present value of fuel savings is dependant 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:

$$PSLOPE = \frac{MAX\ (0, FUELCOST_{YEAR-3} - FUELCOST_{YEAR-5})}{2} \qquad \textbf{(16)}$$

where:

FUELCOST = The cost 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):

$$PRICE\$EX_i = PSLOPE * (i+2) + FUELCOST_{YEAR-3} \quad \textbf{(17)}$$

3) Calculate the expected present value of fuel savings (FUELSAVE) over the payback period:

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{YEAR-1}} - \frac{1}{(1 + DEL\$FE_{itc} * FE_{YEAR-1})} \right) * PRICE\$EX_i * (1 + DISCOUNT)^{-i} \quad \textbf{(18)}$$

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 dependant 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 dependant component is associated with the material substitution technologies. In these technologies a heavy material is replaced with a lighter one. 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 both components, although in practice one or the other term is always zero:

$$TECHCOST_{itc} = DEL\$COSTABS_{itc} + [DEL\$COSTWGT_{itc} * (SIGN * DEL\$WGTWGT_{itc}) * WEIGHT_{baseyear}] \quad \textbf{(19)}$$

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 ($/lb)
DEL$WGTWGT = The fractional change in weight associated with technology *itc*
WEIGHT = The original vehicle weight
SIGN = +1 if DEL$WGTWGT is greater than or equal to zero, -1 if DEL$WGTWGT is less than zero

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. In addition, purchasers of sports and luxury vehicles tend to place a higher value on performance:

$$VAL\$PERF_{itc} = VALUEPERF_{itc} * \frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} * \frac{FE_{YEAR-1} * (1 + DEL\$FE_{itc})}{FE_{YEAR-1}} * \frac{FUELCOST_{YEAR-1}}{PRICE\$EX_1} * DEL\$HP_{itc} \quad \textbf{(20)}$$

where:

VAL\$PERF = The dollar value of performance of technology *itc*
VALUEPERF = The value associated with an incremental change in performance
FE = The vehicle's fuel economy
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 previous year)

Economic Market Share

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

$$COSTEF\$FUEL_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + \left(REGCOST * FE_{YEAR-1} * DEL\$FE_{itc}\right)}{ABS\left(TECHCOST_{itc}\right)} \quad \textbf{(21)}$$

$$COSTEF\$PERF_{itc} = \frac{VAL\$PERF_{itc} - TECHCOST_{itc}}{ABS\left(TECHCOST_{itc}\right)} \quad \textbf{(22)}$$

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

$$MKT\$PERF_{itc} = \frac{1}{1 + e^{-2 * COSTEF\$PERF_{itc}}} \quad \textbf{(24)}$$

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*

and the two separate market shares are combined to determine the actual market share for the technology. Note the MIN function which constrains the result to one hundred percent of the market.

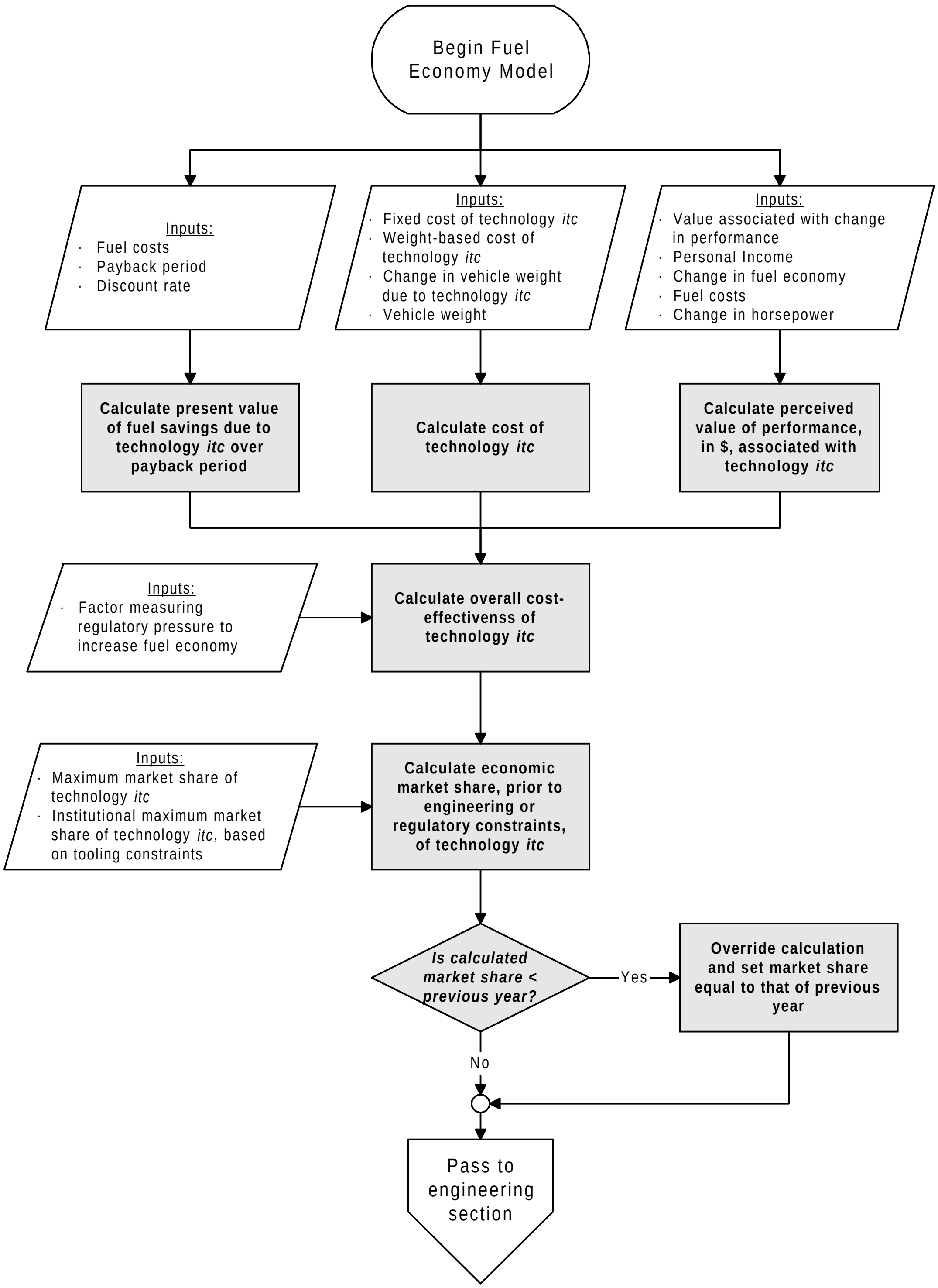
$$ACTUAL\$MKT_{itc} = MMAX_{itc} * PMAX_{itc} * MIN(1.0,(MKT\$FUEL_{itc} + MKT\$PERF_{itc})) \quad \textbf{(25)}$$

where:

ACTUAL\$MKT = The economic share, prior to consideration of engineering or regulatory constraints.
MMAX = The maximum market share for technology *itc*
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 3-2).

[4]During pass 1 REGCOST has a value of 0. During pass 2 it is set to REGCOST, which is a user input.

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



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:

$$ACTUAL\$MKT_{itc,YEAR} = MAX\,(\,ACTUAL\$MKT_{itc,YEAR-1}\,,\ ACTUAL\$MKT_{itc,YEAR}\,) \quad \textbf{(26)}$$

Table 3-2. Maximum Light Duty Vehicle Market Penetration Parameters

Previous Market Share	New PMAX (Automobiles)	New PMAX (Light Trucks)
≤ 1%	1%	1%
1.1-2%	2%	2%
2.1-3%	5%	5%
3.1-6%	12%	10%
6.1-10%	28%	22%
10.1-12%	32%	26%
12.1-14%	36%	30%
14.1-17%	41%	35%
17.1-20%	47%	40%
20.1-24%	53%	47%
24.1-27%	56%	50%
27.1-31%	60%	54%
31.1-35%	64%	58%
35.1-40%	68%	62%
40.1-45%	73%	67%
45.1-53%	78%	73%
53.1-62%	83%	79%
62.1-73%	88%	85%
73.1-85%	94%	92%
85.1-100%	100%	100%

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-5.

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 cost effectiveness calculations do not produce the mandated level of technology then those results are overridden as follows:

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

where:

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

Supersedes Notes

These are associated with newer technologies which replace older ones. For example, 5-speed automatic transmissions supersede 4-speed automatics. Once the cost effective market share for the newer technology (e.g. 5-speed automatics) has been calculated, the market share(s) of the older technology(ies) (e.g. 4-speed automatics) are reduced, if necessary, to force the total market shares for the old and new technologies to add up to 100 percent.

For example, given a group of competing technologies A, B, and C, suppose that C is the oldest technology while A is the newest. After calculating the economic market share for each technology, and applying the *mandatory* notes as described above, the following steps are then taken.

Affected technologies are grouped in a hierarchy, and 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:

$$TOT\$MKT = \sum_{ino=1}^{num\$sup} ACTUAL\$MKT_{ino} \qquad \textbf{(28)}$$

where:

TOT$MKT = The total market share of the considered group of technologies
ino = The index identifying the technologies in the superseding group
num$sup = The number of technologies in the superseding group

Identify the largest maximum market share for the group of technologies:

$$MAX\$SHARE = MAX\ (MKT\$MAX_{ino}) \quad \textbf{(29)}$$

where:

MKT\$MAX = The maximum market share for the considered technology, exogenously set
MAX\$SHARE = The maximum market share of the group, *ino*.

If the aggregate market share (TOT\$MKT) is greater than the maximum share (MAX\$SHARE), reduce the market shares of those technologies which are lower in the hierarchy:

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

$$DEL\$MKT = MIN\left((TOT\$MKT - MAX\$SHARE)\ ,\ ACTUAL\$MKT_{isno}\right) \quad \textbf{(30)}$$

where:

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

b) adjust total market share to reflect this decrement

$$TOT\$MKT = TOT\$MKT - DEL\$MKT \quad \textbf{(31)}$$

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

$$ACTUAL\$MKT_{isno} = ACTUAL\$MKT_{isno} - DEL\$MKT \quad \textbf{(32)}$$

Requires Notes

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, one of which

must be present for *itc* to be present.

2) Sum the market shares of the matching technologies (*req*):

$$REQ\$MKT = MIN\left(\sum_{req} ACTUAL\$MKT_{req} \ , \ 1.0\right) \tag{33}$$

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*: $ACTUAL\$MKT_{itc}$.

$$ACTUAL\$MKT_{itc} = MIN\left(ACTUAL\$MKT_{itc} \ , \ REQ\$MKT\right) \tag{34}$$

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.

$$MKT\$PEN_{itc,year} = ACTUAL\$MKT_{itc,year} \tag{35}$$

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. For each synergistic pair of technologies the fuel economy is adjusted as follows:

$$FE_{YEAR} = FE_{YEAR} + \left(MKT\$PEN_{itc1,YEAR} - MKT\$PEN_{itc1,YEAR-1}\right) * \left(MKT\$PEN_{itc2,YEAR} - MKT\$PEN_{itc2,YEAR-1}\right) * SYNR\$DEL_{itc1,itc2} \quad \textbf{(36)}$$

where:

FE = Fuel economy, by size class and group, initialized to the previous year's value and subsequently modified with each iteration of the model.

itc1 = First synergistic technology

itc2 = Second synergistic technology

SNR$DEL = The synergistic effect of two technologies on fuel economy.

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 dependant on these results and must be calculated subsequently. For a given technology *itc*, the change in market share since the last period (DELTA$MKT) is calculated as follows:

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,YEAR} - MKT\$PEN_{itc,YEAR-1} \quad \textbf{(37)}$$

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

Fuel Economy

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

$$FE_{YEAR} = FE_{YEAR} + \sum_{itc=1}^{NUMTECH} FE_{YEAR-1} * DELTA\$MKT_{itc} * DEL\$FE_{itc} \quad \textbf{(38)}$$

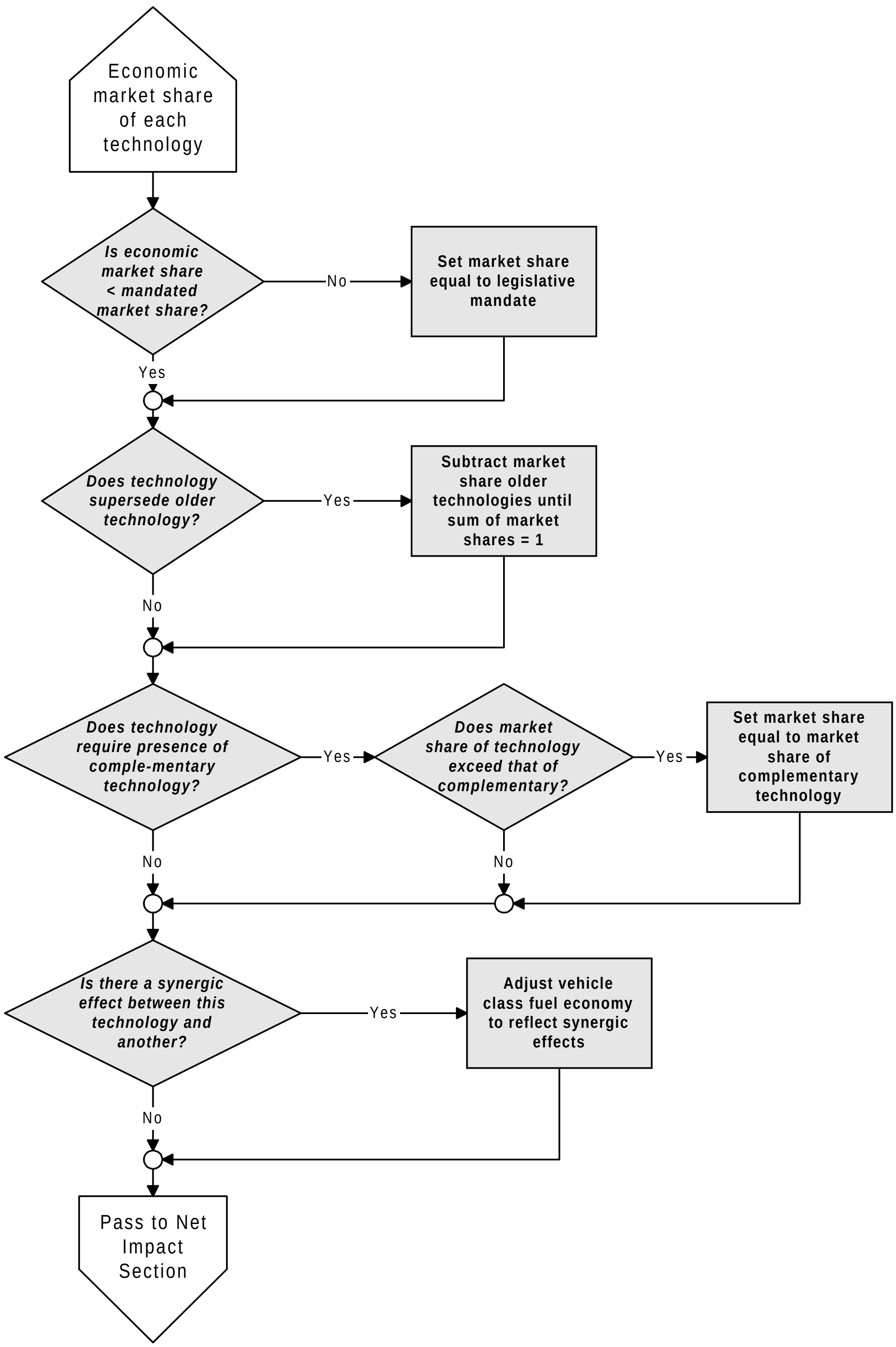
where:

NUMTECH = Number of newly adopted technologies

Vehicle Weight

Current weight for a vehicle class is calculated as the current weight plus the sum of incremental changes due to newly adopted technologies. As with the technology cost equation, the weight

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



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 dependant terms in the summation expression. For any given technology, one term or the other will be zero.

$$WEIGHT_{YEAR} = WEIGHT_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \left[DEL\$WGTABS_{itc} + \left(WEIGHT_{BASEYR} * DEL\$WGTWGT_{itc} \right) \right] \quad \textbf{(39)}$$

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 and group, 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 current price plus the sum of incremental changes due to newly adopted technologies. As with the weight equation, the price equation has both absolute and variable components. Most technologies add a fixed cost to the price of a vehicle. For the material substitution technologies, cost depends on the amount of new material used, which is in turn dependent on the original weight of the vehicle. The price equation includes both absolute and weight dependant terms in the summation expression. For any given technology, one term or the other will be zero. This calculation if used to equally scale up both low and high volume price.

$$PRICE_{YEAR} = PRICE_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \left[DEL\$COSTABS_{itc} + DEL\$COSTWGT_{itc} * (-1.) * DEL\$WGTWGT_{itc} * WEIGHT_{BASEYR} \right] \quad \textbf{(40)}$$

where:

DEL\$COSTABS = The cost of technology *itc*

DEL\$COSTWGT = The weight-based change in cost of technology *itc* (\$/lb)

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 judgement on the part of the model developers.

1) Weight and cost of a lead acid battery

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

$$and \qquad \textbf{(41)}$$

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

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

2) Weight and cost of a nickel metal hydride battery

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

$$and \qquad \textbf{(42)}$$

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

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

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

$$BATTERY1\$COST = BATTERY1\$COST * LEADACID\$COST_{Year}$$
$$and \qquad (43)$$
$$BATTERY2\$COST = BATTERY2\$COST * NIMHY\$COST_{Year}$$

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

$$BATTERY_{Year,Electric\,Vehicle} = BATTERY1\$COST * (1 - NIMHY\$MKTSH_{Year}) + BATTERY2\$COST * NIMHY\$MKTSH_{Year} \qquad (44)$$

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

$$PRICE_{Year,ElectricVehicle} = PRICE_{Year,ElectricVehicle} + BATTERY_{Year,ElectricVehicle} \qquad (45)$$

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

$$WEIGHT_{Year,ElectricVehicle} = \frac{BATTERY1\$WT}{0.375} * (1 - NIMHY\$MKTSH_{Year}) + \frac{BATTERY2\$WT}{0.22} * NIMHY\$MKTSH_{Year} \qquad \textbf{(46)}$$

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

$$FE_{Year,ElectricVehicle} = \left[\frac{0.8 \cdot (2{,}200)}{0.16 \cdot WEIGHT_{Year,ElectricVehicle}} \right] \qquad \textbf{(47)}$$

Electric Hybrid Vehicles (EVH)

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

$$PRICE_{YEAR,Evh} = PRICE_{YEAR,Gasoline} + NIMHY\$COST_{YEAR} * AFVADJPR_{YEAR,Evh} * \frac{WEIGHT_{YEAR,\ kclass}}{WEIGHT_{YEAR,\ mid-size}} \qquad \textbf{(48)}$$

Fuel Cell Vehicles

The subroutines FCMCALC, FCHCALC, and FCGCALC calculate fuel cell cost, vehicle price (low and high volume sales), 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 Fuel Cell.

1) Fuel Cell Cost

$$FUELCELL_{Year,FC} = 30 * \frac{WEIGHT_{Year,Gasoline}}{2200} * FUELCELL\$COST_{Year,FC} \quad \textbf{(49)}$$

where:

FUELCELL = Cost of the fuel cell
FUELCELL$COST = Exogenous input for the cost of the fuel cell in $/kw

2) Battery Power Required to start vehicle

$$BATTERY\$POWER = 20 * \frac{WEIGHT_{Year,Gasoline}}{2200} \quad \textbf{(50)}$$

where:

BATTERY$POWER = Required battery power in Kw

3) Weight of Battery

$$BATTERY\$WT = 2.2 * \frac{BATTERY\$POWER}{0.5} \quad \textbf{(51)}$$

where:

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

4) Cost of Battery

$$BATTERY_{Year,FC} = 2.30 * BATTERY\$WT * LEADACID\$COST_{Year} \quad \textbf{(52)}$$

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

$$FUELCELL_{Year,FC} = (FUELCELL_{Year,FC} + BATTERY_{Year,FC} + HTANK_{FC}) * 1.75 + 1500 \quad \textbf{(53)}$$

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

$$PRICE_{Year,FC} = PRICE_{Year,Gasoline} + FUELCELL_{Year,FC} \quad \textbf{(54)}$$

7) Fuel Cell Fuel Economy (gasoline equivalent mpg)

$$FE_{Year,FC} = \frac{1}{CONSTANT * \frac{WEIGHT_{Year,Gasoline}}{1000}} \quad \textbf{(55)}$$

where:

CONSTANT = 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 two step process. See Figure 3A-6. First, horsepower is calculated on the basis of weight; this step assumes no change in performance. This initial estimate simply maintains the weight to horsepower ratio observed in the base year:

Unadjusted Horsepower

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

$$HP_{YEAR} = HP_{BASEYR} * \frac{WEIGHT_{YEAR}}{WEIGHT_{BASEYR}} \quad \textbf{(56)}$$

where:

HP = Vehicle horsepower
WEIGHT = Vehicle weight

Adjustment Factor

The second step adjusts horsepower for changes in performance. Adjustments to horsepower are done separately for cars and light trucks at the size class and AFV technology level, although EV dedicated vehicles receive no adjusted horsepower. This calculation is based on household income, vehicle price, fuel economy, fuel cost, and the perceived desire for performance (PERFFACT):

$$ADJHP = PERFFACT * \left[\left(\frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} \right)^{0.9} * \left(\frac{PRICE_{YEAR-1}}{PRICE_{YEAR}} \right)^{0.9} * \left(\frac{FE_{YEAR}}{FE_{YEAR-1}} \right)^{0.2} * \left(\frac{FUELCOST_{YEAR-1}}{FUELCOST_{YEAR}} \right)^{0.2} - 1 \right] \quad \textbf{(57)}$$

where:

ADJHP = Vehicle horsepower adjustment factor

Note that if income, vehicle price, fuel economy and fuel cost remain the same, the expression in parentheses resolves to: (1*1*1*1 - 1) = 0. Thus, unless there is some change in the economics, there will be no change in horsepower due to a desire for more performance. In an economic status quo, the only changes in horsepower will be those required to maintain the base year weight-to-horsepower ratio calculated above.

Adjusted Horsepower

The current year horsepower is then calculated as follows:

$$HP_{YEAR} = HP_{YEAR} * \left(1 + \sum_{1995}^{YEAR} ADJHP_{YEAR} \right) \quad \textbf{(58)}$$

Note that this equation uses the sum of horsepower adjustments to date. This is necessary because the first step of the adjustment ignores the previous period result (HP_{YEAR-1}) and calculates current horsepower using the base year weight-to-horsepower ratio. The summation term incorporates all horsepower adjustments due to economic changes which occur in the intervening forecast periods. The final HP estimate is then checked to see if it meets the minimum driveability criterion which are set at WT/HP = 30 for all cars except sports and luxury for which the criterion is WT/HP = 25. These minima are derived from the experience of the early 1980's.

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

The fractional change in fuel economy based on the fractional change in horsepower is first calculated (ADJFE). This is an engineering relationship expressed by the following equation:

$$\begin{aligned} ADJFE_{YEAR} &= -0.22 * ADJHP_{YEAR} - 0.560 * ADJHP_{YEAR}^2 \quad ; \quad ADJHP_{YEAR} \geq 0 \\ ADJFE_{YEAR} &= -0.22 * ADJHP_{YEAR} + 0.560 * ADJHP_{YEAR}^2 \quad ; \quad ADJHP_{YEAR} < 0 \end{aligned} \qquad \textbf{(59)}$$

Adjusted Fuel Economy

The final vehicle fuel economy is then determined as follows:

$$FE_{YEAR} = FE_{YEAR} * (1 + ADJFE_{YEAR}) \qquad \textbf{(60)}$$

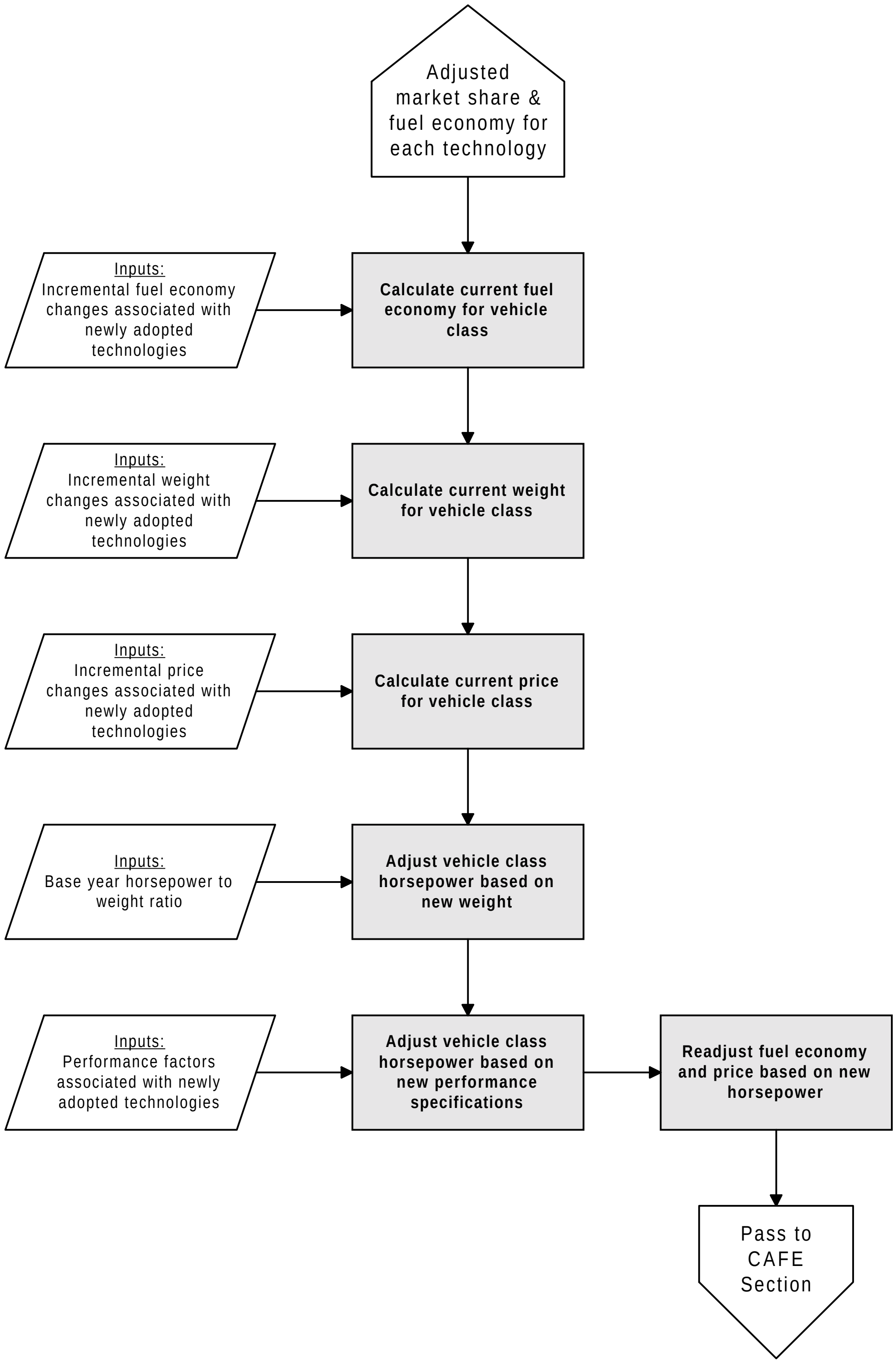
Adjusted Vehicle Price

Vehicle price is finally estimated:

$$PRICE_{YEAR} = PRICE_{YEAR} + ADJHP_{YEAR} * VALUEPERF_{YEAR} \qquad \textbf{(61)}$$

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

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



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.

Estimate Vehicle Range (in subroutine FEMRANGE)

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

$$FE_{YEAR} = FE_{YEAR} * (1 + ADJFE_{YEAR}) \qquad \textbf{(62)}$$

and

$$RANGE_{Year,FuelType} = TANKSIZE * FE_{Year} * (1 + AFVADJRN_{FuelType}) \qquad \textbf{(63)}$$

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.

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 CAFÉ 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 base year (CLYEAR) market share. The market share increment (or decrement) is determined by one of the following equations (depending on vehicle class):

All Vehicle Classes Except Luxury Cars:[5]

$$DIFF\$LN_{CLYEAR} = A * \ln\left(\frac{YEAR}{CLYEAR}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{CLYEAR}}\right) + C * \ln\left(\frac{INCOME_{YEAR} - \$13{,}000}{INCOME_{CLYEAR} - \$13{,}000}\right) + D * \ln\left(\frac{PRICE_{YEAR}}{PRICE_{CLYEAR}}\right) \qquad \textbf{(64)}$$

where:

DIFF$LN = the log market share increment from the year CLYEAR.

Luxury Cars

The calculated increment is added to the base year market share to obtain a current year value. After market shares are derived for all vehicle classes, the results are normalized so that market shares sum to 100% within each CAFÉ group.

$$DIFF\$LN_{CLYEAR} = A * \ln\left(\frac{YEAR}{CLYEAR}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{CLYEAR}}\right) + C * \ln\left(\frac{INCOME_{YEAR}}{INCOME_{CLYEAR}}\right) + D * \ln\left(\frac{PRICE_{YEAR}}{PRICE_{CLYEAR}}\right) \qquad \textbf{(65)}$$

The regression results are shown in Table 3-3 and represent the coefficients and elasticities contained in equations 64 and 65.

---

[5] Note: Market shares for Mini and Sub-Compact cars are solved jointly using equation 63. The resulting combined market share is allocated between the two classes based on the original 1999 allocation. Special treatment of these two classes was made necessary by the small sample size in the analysis data sets.

Table 3-3. Regression Results From LDV Market Share Model

Group	F Val	R^2	Intercept	MDLY	LPGAS	LYD	LNPLT
Mini and Subcompact	14.359	0.891	-5.428	0.056 (1.761)	1.33 (1.828)	-0.169 (-1.524)	1.136 (2.288)
Sports	11.193	0.808	-2.475	-0.049 (-1.903)	0.26 (.466)	.0068 (.059)	
Compact	5.533	0.76	-5.021	0.111 (2.117)	1.332 (1.35)	0.107 (.52)	0.383 (.825)
Intermediate	3.084	0.536	-1.01	-0.051 (-1.742)	-0.213 (-.335)	-0.0017 (-.013)	
Large	16.880	0.864	-3.312	-0.119 (-4.754)	0.042 (.077)	0.231 (2.018)	
Luxury	18.458	0.939	-3.1	0.126 (2.336)	1.166 (2.704)	0.169 (1.441)	-0.435 (-.699)
Mini Truck	1.378	0.341	2.268	-0.018 (-.168)	-3.648 (-1.6)	-0.968 (-2.027)	
Compact Pickup	19.183	0.916	-8.749	-0.042 (-1.238)	-0.811 (-1.48)	0.174 (1.247)	1.91 (5.122)
Compact Van	804.167	0.998	-9.3	0.01 (.352)	0.832 (1.727)	0.307 (3.045)	1.466 (16.421)
Compact Utility	274.104	0.994	-7.36	-0.042 (-1.447)	-0.2 (-.396)	0.366 (2.933)	0.763 (8.474)
Standard Size Trucks	1.582	0.475	-2.779	-0.056 (-1.523)	0.252 (.307)	0.144 (.846)	

Class Market Shares

Solve for the log-share ratio:

$$RATIO\$LN = DIFF\$LN + \ln\left(\frac{CLASS\$SHARE_{1990}}{1 - CLASS\$SHARE_{1990}}\right) \qquad \textbf{(66)}$$

where:

RATIO$LN = Log of the market share ratio of the considered vehicle class

Solve for the class market share:

$$CMKS = \frac{e^{(RATIO\$LN)}}{1 + e^{(RATIO\$LN)}} \tag{67}$$

where:

CMKS = Class market share, subsequently reassigned to the appropriate vehicle class and group, $CLASS\$SHARE_{icl,igp}$

Normalize so that shares total 100% within each CAFÉ group:

$$CLASS\$SHARE_{icl,igp,YEAR} = \frac{CLASS\$SHARE_{icl,igp,YEAR}}{\sum_{icl=1}^{7} CLASS\$SHARE_{icl,igp,YEAR}} \tag{68}$$

CALCULATE CORPORATE AVERAGE FUEL ECONOMY (CAFÉ)

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 CAFÉ calculation proceeds as follows:

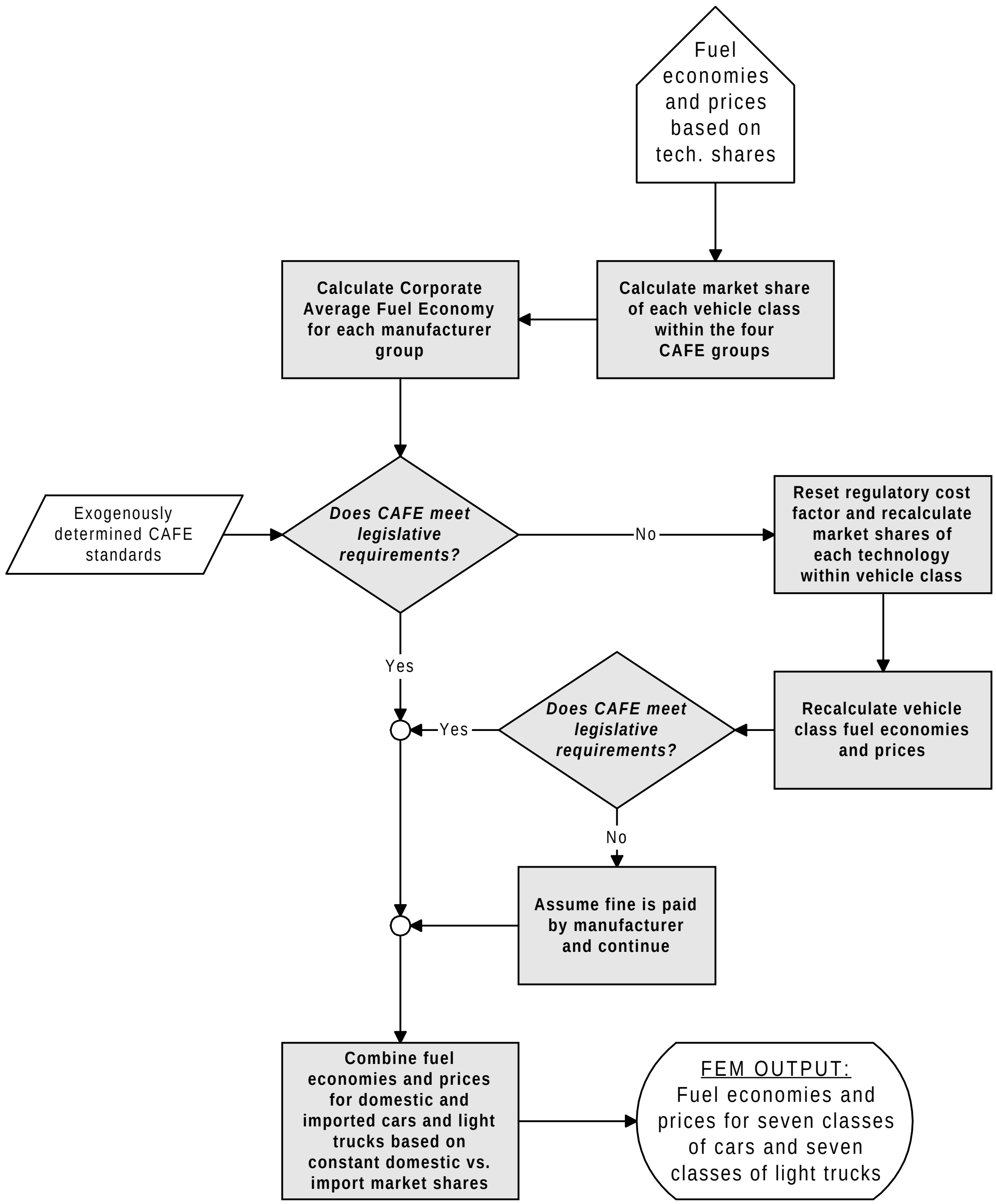
$$CAFE_{i,k,YEAR} = \frac{\sum_{i=1}^{7} CLASS\$SHARE_{i,k,YEAR}}{\sum_{i=1}^{7} \frac{CLASS\$SHARE_{i,k,YEAR}}{FE_{i,k,YEAR}}} \tag{69}$$

where:

i = Vehicle Class
k = CAFÉ Group

This CAFÉ estimate is then compared with the legislative standard for the manufacturer group and year. If the forecast CAFÉ is less than the standard, a second iteration of the model is performed after resetting the regulatory cost (REGCOST). If the recalculated CAFÉ is still below the standard, no further iteration occurs, as the manufacturer is then assumed to pay the fine, see Figure 3A-7.

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



<u>COMBINE RESULTS OF DOMESTIC AND IMPORTED VEHICLES</u>

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 characteristic is determined by weighting each vehicle 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 NHTSA estimates of the domestic and imported market shares:[6]

$$\begin{aligned} MPG_{i,class} = {} & (FEMMPG_{dom,class} * PERGRP_{dom,class}) \\ & + (FEMMPG_{imp,class} * PERGRP_{imp,class}) \end{aligned} \quad \textbf{(70)}$$

$$\begin{aligned} HPW_{i,class} = {} & (FEMHP_{dom,class} * PERGRP_{dom,class}) \\ & + (FEMHP_{imp,class} * PERGRP_{imp,class}) \end{aligned} \quad \textbf{(71)}$$

$$\begin{aligned} PRI_{i,class} = {} & (FEMPRI_{dom,class} * PERGRP_{dom,class}) \\ & + (FEMPRI_{imp,class} * PERGRP_{imp,class}) \end{aligned} \quad \textbf{(72)}$$

$$\begin{aligned} RNG_{i,class} = {} & (FEMRNG_{dom,class} * PERGRP_{dom,class}) \\ & + (FEMRNG_{imp,class} * PERGRP_{imp,class}) \end{aligned} \quad \textbf{(73)}$$

$$\begin{aligned} WGT_{i,class} = {} & (FEMWGT_{dom,class} * PERGRP_{dom,class}) \\ & + (FEMWGT_{imp,class} * PERGRP_{imp,class}) \end{aligned} \quad \textbf{(74)}$$

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

[6] 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.

Note that the vehicle characteristics from the FEM subroutine (FEMMPG, FEMHP, FEMPRI, FEMRNG, and FEMWGT) have been converted to six size classes considered by the remainder of the Transportation Model. All mini-compact cars are imported, and all standard pickups, standard vans, and standard utility vehicles 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

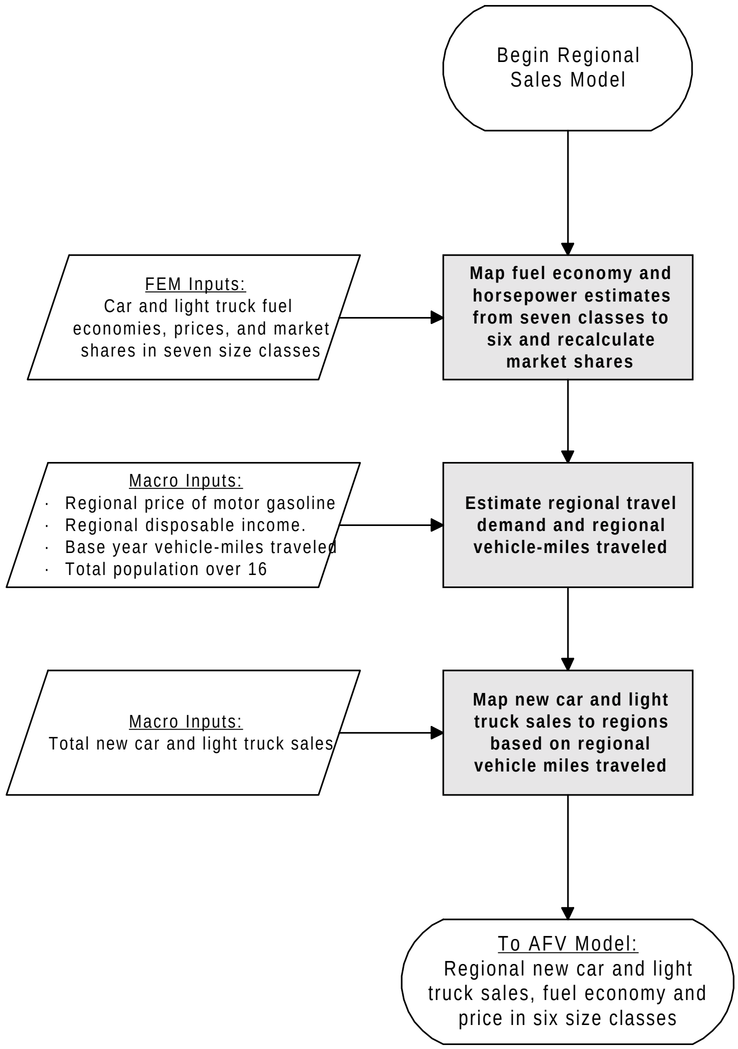
The Regional Sales Model is a simple accounting mechanism which uses exogenous estimates of new car and light truck sales, and the results of the Fuel Economy Model to produce estimates of regional sales and characteristics of light duty vehicles, which are subsequently passed to the Light Duty Stock 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% of all vehicles sold by the year 2003 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 is used to compress the seven vehicle size classes generated by the Fuel Economy Model into six size classes used in subsequent calculations and the second generates regional shares of fuel consumption, driving demand, and sales of vehicles by size class.

The Regional Sales Model flowchart is presented in Figure 3A-2 below.

Figure 3A-6. Regional Sales Model



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 seven size classes and CAFÉ groups described in the Fuel Economy Model (FEM). The fraction of car and truck sales attributed to fleets is assumed to remain constant 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 Macro Module. This is required due to the fact that definitions used in the Transportation Module differ from those used in the Macro Module. The trucks enumerated by the Macro Module's definition of "light trucks" includes those of less than 14,000 pounds GVW, and are not identified by axle configuration. 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 Light Commercial Truck 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 attentions toward minivans and sport utility vehicles in recent years.

Determine the number of Light Truck sales which are classified as LDT's:

$$T\_LDT\_MAC_N = MC\_SQDTRUCKS_N * LT10K * \left[(LT2A4 * LT2A4LDV) + (LTOSU * LTOSULDV) \right] \quad \textbf{(75)}$$

where:

T_LDT_MAC = Total LDT's (under 8,500 pounds), as estimated by the Macro Module
MC_SQDTRUCKS = Total Light Truck sales (under 14,000 lbs.), from the Macro Module
LT10K = Fraction of these trucks under 10,000 lbs.
LT2A4 = Fraction of light trucks with a 2-axle, 4-tire configuration
LT2A4LDV = Fraction of these trucks less than 8,500 lbs.
LTOSU = Fraction of light trucks with other axle configurations
LTOSULDV = Fraction of these trucks less than 8,500 lbs.
N = Year

Calculate total LDV sales:

$$T\_LDV\_MAC_N = MC\_SQTRCARS_N + T\_LDT\_MAC_N \quad \textbf{(76)}$$

where:

T_LDV_MAC = Total car and adjusted light truck sales
MC_SQTRCARS = Total car sales, from the Macro Module

Allocate LDV sales between cars and light trucks:

$$TMC\_SQTRCARS_N = T\_LDV\_MAC_N * (1 - CARLTSHR)$$

$$and \qquad \textbf{(77)}$$

$$TMC\_SQDTRUCKS_N = T\_LDV\_MAC_N * CARLTSHR$$

where:

TMC_SQTCARS = Total sales of new cars
TMC_SQTRUCKS = Total sales of new light trucks
CARLTSHR = Allocation factor representing LDT fraction of LDV sales

Calculate non-fleet, non-commercial sales of cars (*igp=1,2*) and light trucks (*igp=3,4*) in FEM 7size classes:

$$NVS7SC_{igp,icl,N} = CLASS\$SHARE_{icl,igp,YEAR} * TMC\_SQTRCARS_N * \left(1 - FLTCRAT_{1990}\right) * SALESHR_{igp,N}$$

$$and \qquad \textbf{(78)}$$

$$NVS7SC_{igp,icl,N} = CLASS\$SHARE_{icl,igp,YEAR} * TMC\_SQDTRUCKS_N * \left(1 - (FLTTRAT_{1990})\right) * SALESHR_{igp,N}$$

where:

TMC_SQTCARS = Total new car sales
TMC_SQTTRUCKS = Total now light truck sales
CLASS$SHARE = The market share for each automobile class, from FEM
FLTCRAT = Fraction of new cars purchased by fleets
FLTTRAT = Fraction of new light trucks purchased by fleets
SALESHR = Fraction of vehicle sales which are domestic/imported

Sales within the seven size classes (class) are then distributed among six size classes (sc), combining the domestic and import groups (igp), as follows:

$$NCSTSC_{sc} = \sum_{igp=1}^{2} \sum_{class=1}^{7} \left(NCS7SC_{igp,class} \right) * MAP76_{class,sc,igp}$$

$$and \qquad \textbf{(79)}$$

$$NLTSTSC_{sc} = \sum_{igp=3}^{4} \sum_{class=1}^{7} \left(NTS7SC_{igp,class} \right) * MAP76_{class,sc,igp}$$

where:

MAP76 = Weighting coefficients associated with cars and trucks, respectively

The non-fleet market shares for cars and light trucks are then calculated by size class:

$$PASSHRR_{sc} = \frac{NCSTSC_{sc}}{\sum_{sc=1}^{6} NCSTSC_{sc}}$$

$$and \qquad \textbf{(80)}$$

$$LTSHRR_{SC} = \frac{NLTSTSC_{SC}}{\sum_{SC=1}^{6} NLTSTSC_{SC}}$$

The average horsepower of cars and light trucks is then calculated:

$$AHPCAR_{sc} = \sum_{sc=1}^{6} HPW_{car,sc} * PASSHRR_{sc}$$

$$and \qquad \textbf{(81)}$$

$$AHPTRUCK_{sc} = \sum_{sc=1}^{6} HPW_{trk,sc} * LTSHRR_{sc}$$

Determine Regional Values of Fuel Demand and Vehicle Sales

Regional demand shares for each of eleven fuels 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:

$$SEDSHR_{FUEL,REG,T} = \frac{SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)}{\sum_{REG=1}^{9} SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)} \quad \textbf{(82)}$$

where:

SEDSHR = Regional share of the consumption of a given fuel in period *T*
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 is used here for the 1990 computation of VMT16R and VMTEER.

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:

$$COSTMIR_{REG,T} = 0.1251 * \left(\frac{TPMGTR_{REG,T}}{MPGFLT_{T-1}} \right) \quad \textbf{(83)}$$

where:

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

Calculate regional income:

$$INCOMER_{REG,T} = \left(\frac{TMC\_YD_{REG,T}}{TMC\_POPAFO_{REG,T}} \right) \quad \textbf{(84)}$$

where:

INCOMER = Regional per capita disposable income

TMC_YD = Total disposable income in region *REG*
TMC_POPAFO = Total population in region *REG*

Estimate regional driving demand:[7]

$$VMT16R_{REG,T} = \rho\, VMT16R_{REG,T-1} + \beta_0 (1 - \rho) + \beta_1 \left(COSTMIR_{REG,T} - \rho\, COSTMIR_{REG,T-1}\right)$$
$$+\beta_2 \left(INCOMER_{REG,T} - \rho\, INCOMER_{REG,T-1}\right) + \beta_3 \left(PRFEM_T - \rho\, PRFEM_{T-1}\right) \quad \textbf{(85)}$$

and:

$$VMTEER_{REG,T} = VMT16R_{REG,T} * TMC\_POP16_{REG,T} * DAF_T \quad \textbf{(86)}$$

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*
TMC_POP16 = Total regional population over the age of 16
DAF = A demographic adjustment factor, to reflect different age groups' driving patterns

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,T} = \frac{VMTEER_{REG,T}}{\sum_{REG=1}^{9} VMTEER_{REG,T}} \quad \textbf{(87)}$$

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

$$NCS_{REG,SC,T} = NCSTSC_{SC,T} * RSHR_{REG,T} \quad \textbf{(88)}$$

and:

$$NLTS_{REG,SC,T} = NLTSTSC_{SC,T} * RSHR_{REG,T} \quad \textbf{(89)}$$

where:

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

---

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

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 1990-2020. 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:

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

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. The scope of the AFV module covers a 30 year time period with 9 regional target groups, twelve EPA size classes. 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 thirteen 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 alcohol, and gaseous, 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, and flex-fuel methanol and ethanol. Hybrid electric vehicles contain both gasoline and diesel hybrids. Dedicated ethanol and methanol, and dedicated compressed natural gas (CNG) and LPG comprise the dedicated alcohol and gaseous 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 decision of 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:

$$PSPR_{i,it,osc} = PRI_{i,it,osc} * TMC\_PGDP \tag{90}$$

where:

i = Index referring to vehicle type (car or light truck)
it= Index referring to fuel type (1-16)
osc= Index referring to vehicle size class (1-6)
PRI = Aggregate vehicle price
TMC_PGDP = Implicit GDP price deflator from Macro Module, used to convert $90 to nominal

Calculate fuel costs:

$$FLCOST_{i,it,osc,ir} = \frac{FPRICE_{it,ir} * TMC\_PGDP}{MPG_{i,it,osc}} \tag{91}$$

where:

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

Calculate Fuel Availability (TALT2) Subroutine Methodology

The variable fuel availability attempts to capture the dynamics associated with increasing numbers of refueling stations. The assumed premise is that the number of refueling stations is proportional to the number of vehicle that support it. 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 per vehicle stock. Fuel availability is used in the AFV Logit Model as an input into the decision process of 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 fuel type that might be using the fuel

$$PREDSTK_{ifl,\ year} = LDVSTK_{ifl,\ year-1} + W * LDVSTK_{ifl=\ flex\ :\ bi-fuel,\ year-1} \quad \textbf{(92)}$$

where:

PREDSTK = Predicted vehicle stock used to calculate needed refueling stations
LDVSTK = Vehicle stock
W = weight given to assumed proportion of flex or bi-fuel vehicle stock that refuel with alternative fuel
ifl= fuel type; 1...8

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

$$ALTSTAT_{ifl,\ year} = ALTSTAT_{ifl,\ year-1} + \frac{PREDSTK_{ifl,\ year} - PREDSTK_{ifl,\ year-1}}{STARAT_{ifl}} \quad \textbf{(93)}$$

where:

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

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

$$FUELVSAL_{ir,\ ifl,\ year} = NCSTECH_{ir,is,it,year-1} + NLTECH_{ir,is,it,year-1}$$

$$AFVSHREG_{ir,\ ifl,year} = \frac{FUELVSAL_{ir,\ ifl,year}}{\sum FUELVSAL_{ir,\ ifl,year}} \quad \textbf{(94)}$$

$$ALTSTA_{ir,\ ifl,year} = ALTSTAT_{ifl,year} * AFVSHREG_{ir,\ ifl,year}$$

where:

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

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

$$FAVAIL_{ifl,year,ir} = \frac{ALTSTA_{ir,\ ifl,year}}{ALTSTA_{ir,gasoline,year}} \tag{95}$$

Calculate acceleration (0-60 mph) in seconds:

$$ACCL_{i,it,osc} = e^{(-0.00275)} * \left(\frac{HPW_{i,it,osc}}{WGT_{i,it,osc}} \right)^{-0.776} \tag{96}$$

Calculate maintenance and battery costs in nominal dollars:

$$MAINT_{1,it,osc,ir} = \frac{MAINTCAR_{it,ir} * TMC\_PGDP}{1.326}$$

$$and \tag{97}$$

$$MAINT_{2,it,osc,ir} = \frac{MAINTTRK_{it,ir} * TMC\_PGDP}{1.326}$$

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

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:

$$X3132 = X31_{iv,is} * \frac{X23_{iv,is}}{X22_{iv,is}}$$

$$BETAFA = X31_{iv,is} * \frac{BETAFA2_{iv,is}}{X22_{iv,is}} \tag{98}$$

where:

X3132 = Coefficient for vehicle range; (X3132 = Flex methanol, X3142 = Flex ethanol, X3152 = CNG Bi-fuel, and X3162 = LPG Bi-fuel)
X31 = Coefficient for multi-fuel generalized cost by *iv* vehicle type and *is* size 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.

$$UISUM_{ifuel,year,ir} = X31_{iv,is} * FLCOST_{iv,it,is,ir,year} + X3132 * (1/VRNG_{iv,it,is,year}) + BETAFA * e^{(BETAFA22_{iv,is} * FAVL_{it,ir,year})} \quad \textbf{(99)}$$

where:

UISUM = Utility Value function for vehicle attributes at multi-fuel level for *ifuel* fuel type, *ir* region
FLCOST = Fuel cost of driving per mile for AFV technology, *it*, in cents per mile
VRNG = Vehicle range in miles
FAVL = Fuel availability indexed relative to gasoline

3) Utility values are exponentiated and summed.

$$ESUM = e^{UISUM_{ir,\ ifuel,year}}$$

$$ETOT = \sum ESUM \quad \textbf{(100)}$$

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.

$$GENCOST = \frac{1}{X31_{iv,is}} * \log(ETOT) \quad \textbf{(101)}$$

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, and flex-fuel methanol and ethanol), 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

$$\begin{aligned} UISUM_{jt} = & X21_{iv,is} * PSPR_{iv,it,is,yrs} + X22_{iv,is} * GENCOST \\ & + X24_{iv,is} * BRCOST25_{iv,it,is,yrs} + X25_{iv,is} * ACCL_{iv,it,is,yrs} \\ & + X26_{iv,is} * HFUEL_{iv,it,is,yrs} + X27_{iv,is} * MAINT_{iv,it,is,yrs} \\ & + X28_{iv,is} * LUGG_{iv,it,is,yrs} + X29_{iv,is} * \log(MMAVAIL_{iv,is,iy,yrs}) \\ & + X210_{iv,it} \end{aligned} \qquad \textbf{(102)}$$

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 = Vehicle price at the second level in dollars
X22 = Fuel cost per mile at the second level in cents per mile
X24 = Battery replacement cost at the second level
X25 = Vehicle acceleration time from 0 to 60 miles per hour in seconds
X26 = Electric vehicle home refueling capability
X27 = Maintenance cost in dollars
X28 = Luggage space indexed to gasoline vehicle
X29 = Vehicle make and model diversity availability relative to gasoline
X210 = 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

$$UISUM_{jt} = X21_{iv,is} * PSPR_{iv,it,is,yrs} + X22_{iv,is} * FLCOST + X23_{iv,is} * (\frac{1}{VRNG_{iv,it,is,yrs}})$$
$$+ X24_{iv,is} * BRCOST25_{iv,it,is,yrs} + X25_{iv,is} * ACCL_{iv,it,is,yrs}$$
$$+ X26_{iv,is} * HFUEL_{iv,it,is,yrs} + X27_{iv,is} * MAINT_{iv,it,is,yrs} \qquad \textbf{(103)}$$
$$+ X28_{iv,is} * LUGG_{iv,it,is,yrs} + X29_{iv,is} * \log(MMAVAIL_{iv,is,iy,n})$$
$$+ X210_{iv,it} + BETAFA2_{iv,is} * e^{(BETAFA22_{iv,is} * FAVL_{it,ir,yrs})}$$

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

$$ESUM_{jt} = e^{UISUM_{jt}}$$
$$ETOT_{jg} = \sum ESUM_{it} \qquad \textbf{(104)}$$
$$XSHARE_{jg,jt} = \frac{ESUM_{jt}}{ETOT_{jg}}$$

Level One

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

$$GCOST_{jg} = \frac{1}{X21_{iv,is}} * \log(ETOT_{jg}) \qquad \textbf{(105)}$$

where:

GCOST = Generalized cost function of the jg group

Calculate the utility value based on the generalized cost function

$$UISUM_{jg} = X11_{iv,is} * GCOST_{jg} \qquad \textbf{(106)}$$

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.

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

$$ETOT(1) = \sum ESUM_{jg}$$

$$YSHARE_{jg} = \frac{ESUM_{jg}}{ETOT(1)} \qquad \textbf{(107)}$$

$$APSHR44_{iv,is,ir,it} = \frac{XSHARE_{jg,jt}}{YSHAREjg}$$

APSHR44 is found in equation (127), the vehicle sales equation in the LDV Fleet module.

3B. LDV Fleet Module

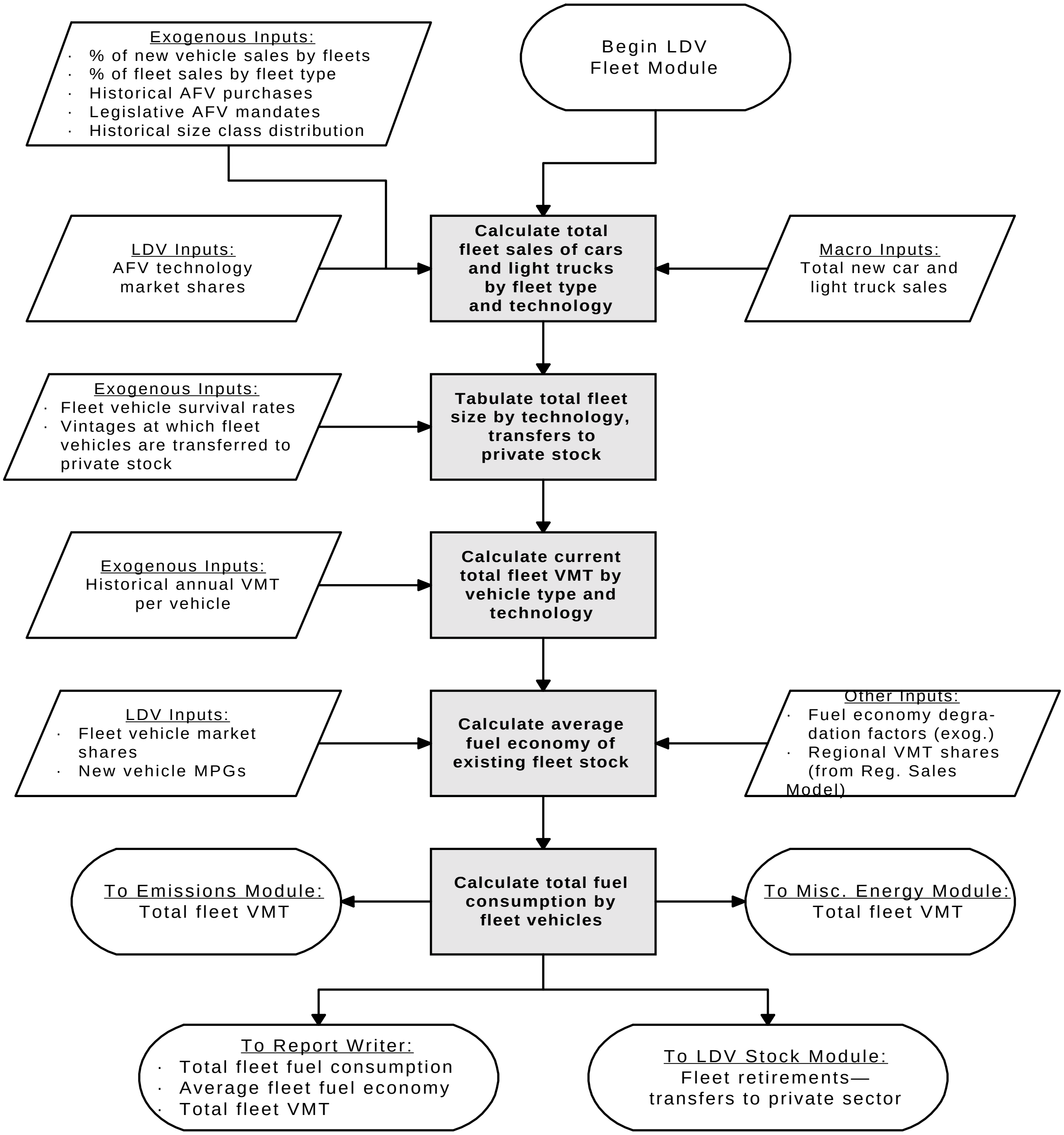
The Light Duty Vehicle Fleet Module generates estimates of the stock of cars and trucks used in business, government, and utility fleets, and subsequently estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined vintages. The LDV Fleet Module has also been amended to include a characterization of Light Commercial Trucks (LCT's), 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.

In a departure from the conventions of other modules, this model uses the same variable names for cars and light trucks; they 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 3C-1. Additional flowcharts outlining major LDV Fleet calculations in more detail are presented at the end of 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:

$$FLTSAL_{IT=1,ITY,T} = FLTCRAT * SQTRCARS_T * FLTCSHR_{ITY}$$

and **(108)**

$$FLTSAL_{IT=2,ITY,T} = FLTTRAT * SQDTRUCKSL_T * FLTTSHR_{ITY}$$

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
SQTRCARS = Total automobile sales in a given year
SQDTRUCKSL = Total 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
IT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = 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 do not extend to privately owned or leased fleet vehicles. This separation is based on an extrapolation of historical trends in business fleets, using an assumed upper limit.

$$BFLTFRAC_T = BFLTFRACMIN + (BFLTFRACMAX - BFLTFRACMIN) * e^{(K_2 \cdot (T+1989-1971))} \quad \textbf{(109)}$$

and:

$$BUSCOV_T = FLTSAL_{IT=1,ITY=1,T} * BFLTFRAC_T \quad \textbf{(110)}$$

where:

BUSCOV = Business fleet acquisitions covered by EPACT provisions
BFLTFRAC = Fraction of business fleet purchases covered by EPACT provisions in year T

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

$$FLTPCT_{VT=1,ITY=1,3,IFS=3} = k_3 \left[\frac{1}{Ln(50)} \right] \quad \textbf{(111)}$$

For light trucks:

$$FLTPCT_{VT=2,ITY=1,3,IFS=3} = (50)^{k_{2,ITY}} \qquad \textbf{(112)}$$

where:

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

Calculate the number of fleet vehicles covered by the provisions of EPACT, taking into consideration the geographic and central-refueling constraints. These constraints are constant, and are tabulated below.

For cars:

$$FLTSALX_{IT=1,ITY=1,T} = BUSCOV_T * FLTPCT_{IT,ITY,T} * CTLREFUEL_{ITY} * MSA_{ITY} * FLT20_{ITY}$$
$$and \qquad \textbf{(113)}$$
$$FLTSALX_{IT=1,ITY\neq 1,T} = FLTSAL_{IT,ITY,T} * CTLREFUEL_{ITY} * MSA_{ITY} * FLT20_{ITY}$$

For light trucks:

$$FLTSALX_{IT=2,ITY=1,3,T} = FLTSAL_{IT,ITY,T} * FLTPCT_{IT,ITY,T} * CTLREFUEL_{ITY} * MSA_{ITY} * FLT20_{ITY}$$
$$and \qquad \textbf{(114)}$$
$$FLTSALX_{IT=2,ITY=2,T} = FLTSAL_{IT,ITY,T} * CTLREFUEL_{ITY} * MSA_{ITY} * FLT20_{ITY}$$

where:

FLTSALX = The number of vehicles of each vehicle and fleet type subject to EPACT requirements.
CTLREFUEL = The percentage of fleet vehicles which are capable of being centrally refueled.
MSA = The percentage of fleets which have 20 or more vehicles located within urban areas.
FLT20 = The percentage of fleet vehicles actually located within urban areas.

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

The number of alternative-fuel vehicles sold for each fleet and vehicle type under EPACT mandates is then estimated:

$$FLTALTE_{IT,ITY,T} = FLTSALX_{IT,ITY,T} * EPACT3_{ITY,T} \qquad \textbf{(115)}$$

where:

FLTALTE = AFV sales to fleets under EPACT mandates
EPACT3 = Sales-weighted aggregation of EPACT purchase requirements, reflecting impacts on three fleet types.

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

$$FLTALTH_{IT,ITY,T} = FLTSAL_{IT,ITY,T} * FLTAPSHR1_{ITY} \qquad \textbf{(116)}$$

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 :

$$FLTALT_{IT,ITY,T} = MAX\left[FLTALTE_{IT,ITY,T} \ , \ FLTALTH_{IT,ITY,T}\right] \qquad \textbf{(117)}$$

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:

$$FLTCONV_{IT,ITY,T} = FLTSAL_{IT,ITY,T} - FLTALT_{IT,ITY,T} \quad \textbf{(118)}$$

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:

$$FLTSLSCA_{IT,ITY,IS,T} = FLTALT_{IT,ITY,T} * FLTSSHR_{IVT,ITY,IS}$$

and: **(119)**

$$FLTSLSCC_{IVT,ITY,IS,T} = FLTCONV_{IT,ITY,T} * FLTSSHR_{IT,ITY,IS}$$

where:

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

A new variable is then established, disaggregating AFV sales by engine technology:

$$FLTECHSAL_{IT,ITY=1,IS,ITECH} = FLTSLSCA_{IT,ITY=1,IS} * APSHRFLTB_{IT,ITECH,ITY=1}$$

$$FLTECHSAL_{IT,ITY\neq 1,IS,ITECH} = FLTSLSCA_{IT,ITY\neq 1,IS} * FLTECHSHR_{ITECH,ITY} \quad \textbf{(120)}$$

and:

$$FLTECHSAL_{IT,ITY,IS,ITECH=6} = FLTSLSCC_{IT,ITY,IS}$$

where:

FLTECHSAL = Fleet sales by size, technology, and fleet type
APSHRFLTB = Alternative technology shares for the business fleet
FLTECHSHR = Alternative technology shares for the government and utility fleets
ITECH = Index of engine technologies: 1-5 = alternative fuels (neat), 6 = gasoline

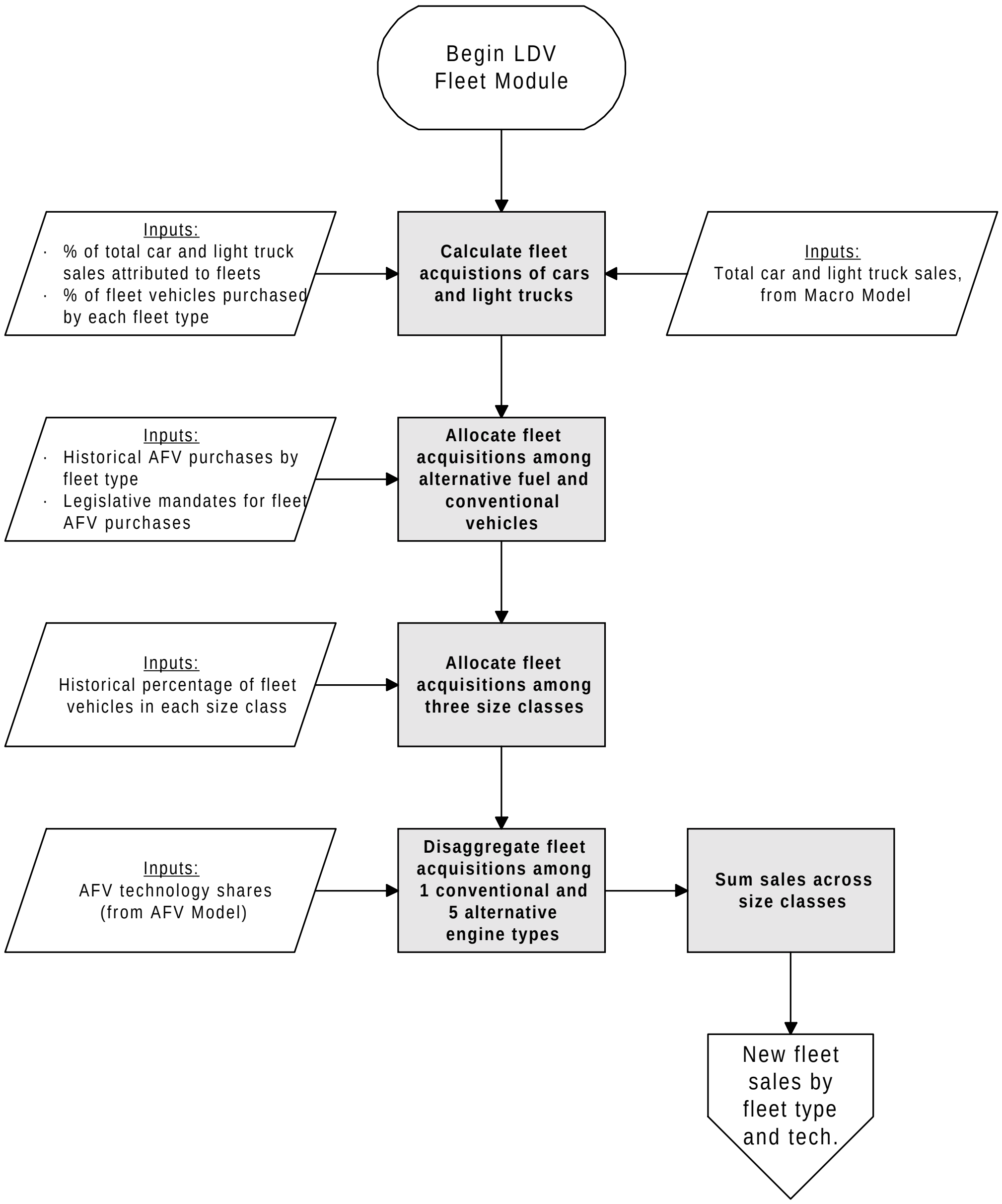
Sales are then summed across size classes:

$$FLTECH_{IT,ITY,ITECH} = \sum_{IS=1}^{6} FLTECHSAL_{IT,ITY,IS,ITECH} \quad \textbf{(121)}$$

where:

FLTECH = Vehicle purchases by fleet type and technology

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



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. This is done by applying the appropriate survival factors to the current vintages and inserting FLTECH into the most recent vintage:

$$FLTSTKVN_{IT,ITY,ITECH,IVINT,T} = FLTSTKVN_{IT,ITY,ITECH,IVINT-1,T-1} * SURVFLTT_{VT,IVINT-1}$$
$$and:$$
$$FLTSTKVN_{IT,ITY,ITECH,IVINT=1,T} = FLTECH_{IT,ITY,ITECH,T} \quad \textbf{(122)}$$

where:

FLTSTKVN = Fleet stock by fleet type, technology, and vintage
SURVFLTT = Survival rate of a given vintage
IVINT = 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:

$$OLDFSTK_{IT,ITY,ITECH,IVINT,T} = FLTSTKVN_{IVT,ITY,ITECH,IVINT,T} \quad \textbf{(123)}$$

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 (ITY)	Transfer Vintage (IVINT)
Automobile (VT = 1)	Business (ITY = 1)	5 Years
Automobile	Government (ITY = 2)	6
Automobile	Utility (ITY = 3)	7
Light Truck (VT = 2)	Business	6
Light Truck	Government	7
Light Truck	Utility	6

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{IT,ITY,ITECH,T} = \sum_{IVIN=1}^{6} FLTSTKVN_{IVT,ITY,ITECH,IVIN,T} \quad \textbf{(124)}$$

where:

TFLTECHSTK = Total stock within each technology and fleet type

$$TOTFLTSTK_T = \sum_{VT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} TFLTECHSTK_{VT,ITY,ITECH,T} \qquad \textbf{(125)}$$

Calculate the grand total of surviving vehicles:

where:

TOTFLTSTK = Total of all surviving fleet vehicles

The percentage of total fleet stock represented by each of the vehicle types and technologies is determined as follows:

$$VFSTKPF_{IT,ITY,ITECH,T} = \frac{TFLTECHSTK_{IT,ITY,ITECH,T}}{\sum_{IT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} TFLTECHSTK_{IT,ITY,ITECH,T}} \qquad \textbf{(126)}$$

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.

Calculate regional vehicle sales, by technology and size class:

$$VSALES_{1,is,ir,it} = APSHR44_{1,is,ir,it} * NCS_{ir,is}$$

$$and \qquad \textbf{(127)}$$

$$VSALES_{2,is,ir,it} = APSHR44_{2,is,ir,it} * NLTS_{ir,is}$$

where:

NCS = Regional new car sales within corresponding size classes
NLTS = Regional new light truck sales within corresponding size classes

Calculate total regional sales of electric and electric hybrid vehicles:

$$ELECVSAL_{ir} = \sum_{is=1}^{6} \sum_{it=7}^{10} VSALES_{i,is,ir,it} \quad \textbf{(128)}$$

where:

ELECVSAL = Regional electric vehicle sales

Calculate total vehicle sales across all technologies:

$$VSALEST_{is,ir} = \sum_{it=1}^{16} VSALES_{i,is,ir,it} \quad \textbf{(129)}$$

where:

VSALEST = Total regional vehicle sales, by size class

Calculate mandated sales of ZEV's by participating state:

$$ZEVST_{st} = \left(TMC\_SQTRCARS * STATESHR_{st,vt=1} + TMC\_SQDTRUCKSL * STATESHR_{st,vt=2}\right) * ZEV \quad \textbf{(130)}$$

where:

ZEVST = State-mandated minimum sales of ZEV's
TMC_SQTRCARS = Total car sales, from the MACRO module
TMC_SQDTRUCKSL = Total light truck sales, from the MACRO module
STATESHR = Share of national vehicle sales attributed to a given state
ZEV = State-mandated minimum sales share of ZEV's
ST = Index of participating state: CA, MA, NY, ME, and VT
VT = Index of vehicle type: 1 = cars, 2 = light trucks

Sum all of the credits used based on the sales that the advanced technology vehicle (ATV) module calculated from the logit model equations:

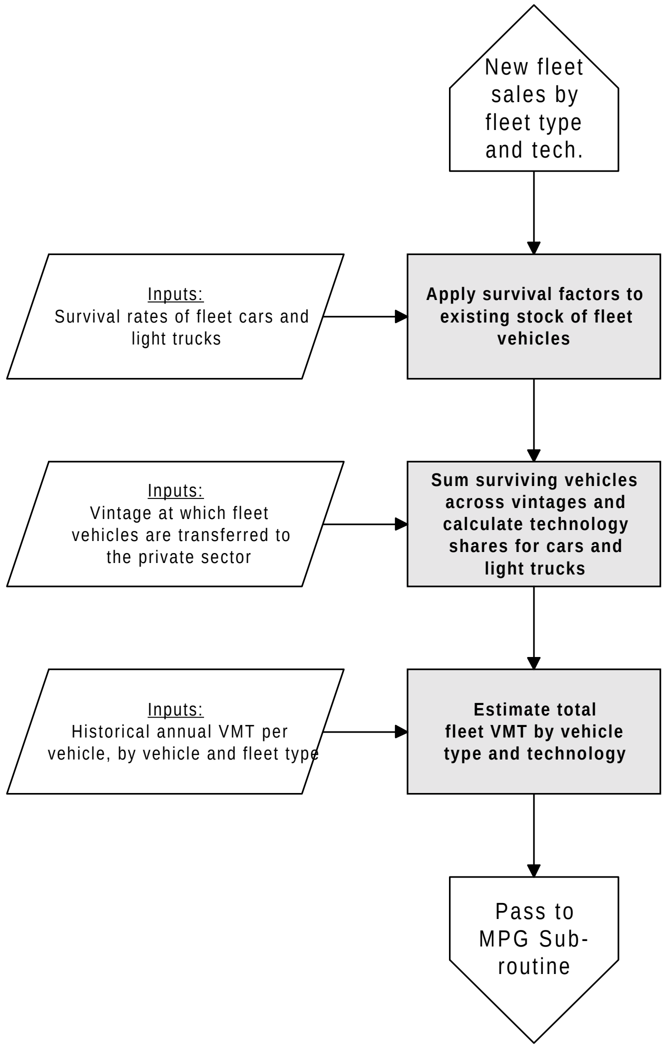
$$TOTCRED_{ir} = VSALES\_EVGH_{i,ir} + VSALES\_EVDH_{i,ir} + VSALES\_FCM_{i,ir} + VSALES\_FCG_{i,ir} \quad \textbf{(131)}$$

where:

VSALES_FCM = fuel cell methanol vehicles sales
VSALES_FCG = fuel cell gasoline vehicle sales
VSALES_EVGH = gasoline hybrid vehicle sales
VSALES_EVDH = diesel hybrid vehicle sales
TOTCRED = total available ZEV credit sales from either hybrid or fuel cell vehicles

If the total sales of hybrids and fuel cell vehicles (excluding hydrogen fuel cells), TOTCRED, is less

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



than the total maximum allowable Low Emission Vehicle Program (LEVP) credits, then

$$AVSALES_{i,is,ir,it} = AVSALES_{i,is,ir,it} * [\frac{(ZEVSALES_{ir} * .6)}{TOTCRED_{ir} - VSALES\text{-}EVGH_{i,ir}}] \quad \textbf{(132)}$$

where:

AVSALES = final total vehicle sales by engine technology; for hybrids and fuel cells excluding hydrogen
ZEVSALES = total ZEV sales that are mandated in census division IR
.6 = refers to 60 percent of total ZEV's that are the maximum allowable LEVP credits

first subtract the gasoline hybrid sales from the total maximum allowable LEVP credits. Next, the remaining allowable credit sales are met by scaling up the other technologies available for the credit (diesel hybrid, fuel cell gasoline, and fuel cell methanol).

Calculate the total sales of ZEV's from the ATV module that consumers chose based on the logit model.

$$TZEVSAL_{ir} = VSALES\_FCH_{i,ir} + VSALES\_EV_{i,ir} \quad \textbf{(133)}$$

where:

TZEVSAL = total ZEV sales of hydrogen fuel cell and dedicated electric vehicles

If the total sales of electric dedicated and hydrogen fuel cell vehicles is less than the remaining 40 percent of the original ZEV sales mandate,

$$AVSALES_{i,is,ir,it} = AVSALES_{i,is,ir,it} * \frac{(ZEVSALES_{ir} * .4)}{TZEVSAL_{ir}} \quad \textbf{(134)}$$

where:

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

All of the additional sales of vehicles resulting from scaling up the hybrid and fuel cell vehicle sales are subtracted from the gasoline vehicles:

$$AVSALES_{i,is,ir,it} = AVSALES_{i,is,ir,it} - DEL\_TECH_{i,is,ir,it} \quad \textbf{(135)}$$

where:

DEL_TECH = sum of all the additional vehicle sales from scaling up hybrid and fuel cell vehicle sales to meet the credits or the ZEV mandates

Sum adjusted vehicle sales across technologies:

$$AVSALEST_{is,ir} = \sum_{it=1}^{16} AVSALES_{is,ir,it} \quad \textbf{(136)}$$

where:

AVSALEST = Total regional adjusted vehicle sales by size class

Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{is,ir,it} = \frac{AVSALES_{is,ir,it}}{AVSALEST_{is,ir}} \quad \textbf{(137)}$$

where:

APSHR55 = Absolute regional market shares of adjusted vehicle sales

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

$$NCSTECH_{ir,is,it} = NCS_{ir,is} * APSHR55_{1,is,ir,it}$$

and **(138)**

$$NLTECH_{ir,is,it} = NLTS_{ir,is} * APSHR55_{2,is,ir,it}$$

where:

NCSTECH = Regional new car sales by technology, within six size classes
NLTECH = Regional light truck sales by technology, with six size classes

Calculate Fleet VMT

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

$$FLTVMT_T = \sum_{IT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \left(TFLTECHSTK_{IT,ITY,ITECH,T} * FLTVMTYR_{IT,ITY,T} \right) \quad \textbf{(139)}$$

where:

FLTVMT = Total VMT driven by fleet vehicles
FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type

Total VMT is then disaggregated by vehicle type and technology:

$$FLTVMTECH_{IT,ITY,ITECH,T} = FLTVMT_T * VFSTKPF_{IVT,ITY,ITECH,T} \quad \textbf{(140)}$$

where:

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

Calculate Fleet Stock MPG

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

$$FLTMPG_{i,ity,it} = \left[\sum_{is=1}^{6} \frac{FLTECHSAL_{i,ity,is,it}}{MPG_{i,its,is}} \right]^{-1} \qquad \textbf{(141)}$$

where:

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

ITS = Index which matches technologies in the AFV model to corresponding *IT*

ITY = Fleet types referring to business, government, or utility

For conventional technologies, when *IT=6* refers to gasoline ICE's, the calculation is similar. The new fleet vehicle fuel economy is calculated as follows:

$$FLTMPG_{i,ity,it=6} = \left[\sum_{is=1}^{6} \frac{FLTECHSAL_{i,ity,is,it=6}}{MPG_{i,its=16,is}} \right]^{-1} \qquad \textbf{(142)}$$

Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{i} = \left[\frac{\sum_{is=1}^{6} \sum_{it=1}^{6} \frac{FLTECH_{i,ity,it}}{FLTMPG_{i,ity,it}}}{\sum_{is=1}^{6} \sum_{it=1}^{6} FLTECH_{i,ity,it}} \right]^{-1} \qquad \textbf{(143)}$$

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 ivint=1:

$$CMPGFSTK_{ity,it,ivint,n} = FLTMPG_{1,ity,it,n}$$

and **(144)**

$$TMPGFSTK_{ity,it,ivint,n} = FLTMPG_{2,ity,it,,n}$$

where:

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

For ivint=2,7:

$$CMPGFSTK_{ity,it,ivint,n} = CMPGFSTK_{ity,it,ivint-1,n-1}$$

and **(145)**

$$TMPGFSTK_{ity,it,ivint,n} = TMPGFSTK_{ity,it,ivint-1,n-1}$$

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

$$MPGFLTSTK_{1,ity,it} = \left[\sum_{ivint=1}^{maxvint} \frac{\left(\dfrac{FLTSKTVN_{1,ity,it,ivint}}{CMPGFSTK_{ity,it,ivint} * CDFRFG} \right)}{\left(FLTSTKVN_{1,ity,it,ivint} \right)} \right]^{-1}$$

and **(146)**

$$MPGFLTSTK_{2,ity,it} = \left[\sum_{ivint=1}^{maxvint} \frac{\left(\dfrac{FLTSKTVN_{2,ity,it,ivint}}{TMPGFSTK_{ity,it,ivint} * LTDFRFG} \right)}{\left(FLTSTKVN_{2,ity,it,ivint} \right)} \right]^{-1}$$

where:

MPGFLTSTK = Fleet MPG by vehicle and fleet type, and technology, across vintages
MAXVINT = Maximum *IVIN* index associated with a given vehicle and fleet type

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

$$FLTTOTMPG_i = \left[\sum_{ity=1}^{3} \sum_{it=1}^{6} \frac{TFLTECHSTK_{i,ity,it}}{MPGFLTSTK_{i,ity,it}} \right]^{-1} \quad \textbf{(147)}$$

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:

$$FLTLDVC_{i,ity,it} = \frac{FLTVMTECH_{i,ity,it}}{MPGFLTSTK_{i,ity,it}} \quad \textbf{(148)}$$

where:

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

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

$$FLTFCLDVBTU_{i,it} = \sum_{ity=1}^{3} FLTLDVC_{i,ity,it} * QBTU_{it} \quad \textbf{(149)}$$

where:

FLTFCLDVBTU = Fuel consumption, in Btu, by vehicle type and technology
QBTU = Energy content, in Btu/Gal, of the fuel associated with each technology

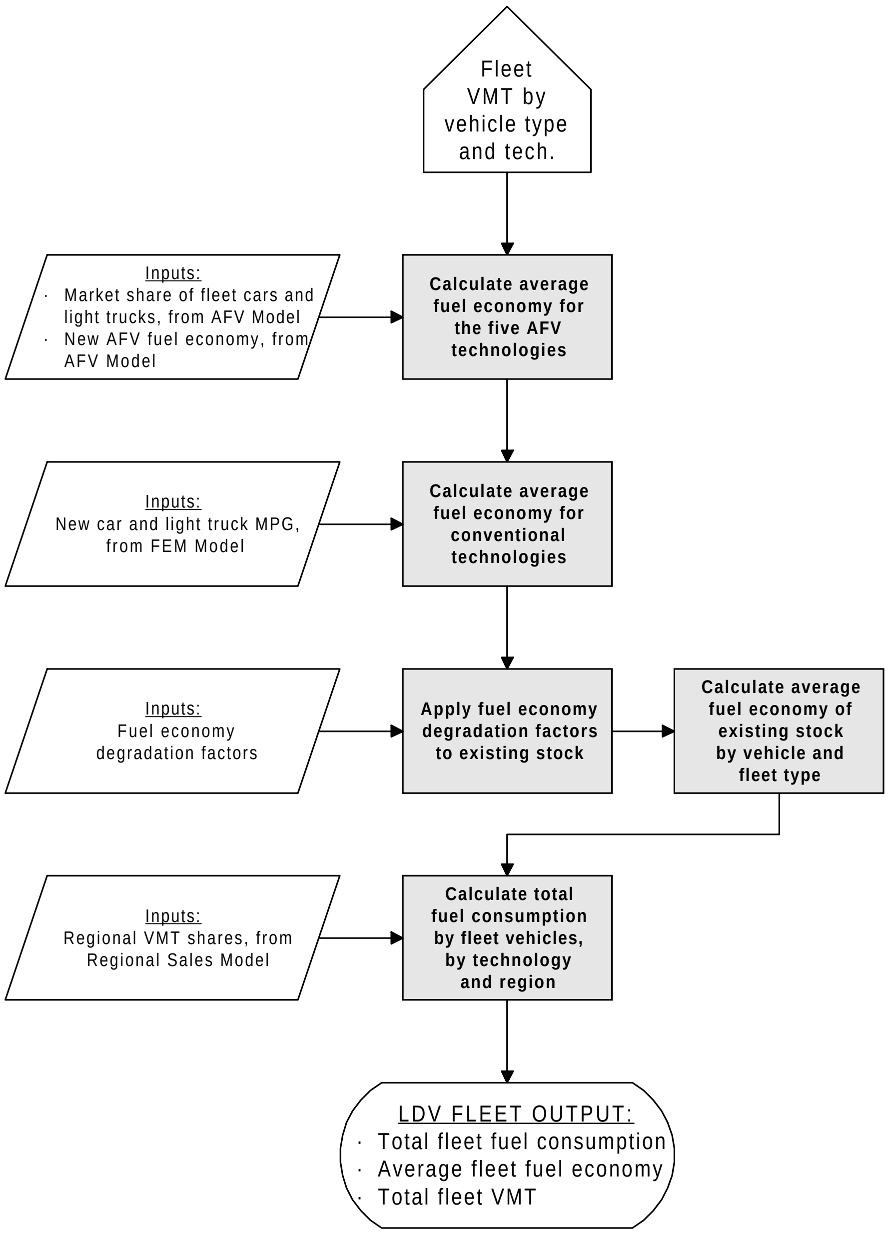
Consumption by trucks and cars are added, and total consumption is subsequently divided among regions:

$$FLTFCLDVBUTR_{ir,it} = \sum_{i=1}^{2} FLTFCLDVBTU_{i,it} * RSHR_{ir} \quad \textbf{(150)}$$

where:

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology
RSHR = Regional VMT shares, from the Regional Sales Model
IR = Index of regions

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



3B-2. Light Commercial Truck Module

The primary thrust of this model is to provide a stratification mechanism to allocate the stock and new sales of LCT's among the various major-use groups considered in this model. This involves using the distribution of trucks reported in the 1992 Truck Inventory and Use Survey (TIUS) to estimate the fraction of trucks that fall into the 8.5 to 10 thousand pound weight category, and subsequently distribute them according to the principal products carried. Trucks are classified by body-type (pickup and other single-unit trucks) and axle configuration (2-axle, 4-tire and other). Historical stock numbers are derived from FHWA's Highway Statistics, and new sales are obtained from the macroeconomic model. In addition to providing a distribution of trucks according to major use, TIUS provides sufficient data to estimate average annual miles and fuel economy within each strata. Flow charts describing the stratification scheme for existing truck stock and new purchases are provided below (Figure 3B-5 and Figure 3B-6).

Figure 3B-5. Distribution of FHWA Single-Unit Truck Stocks

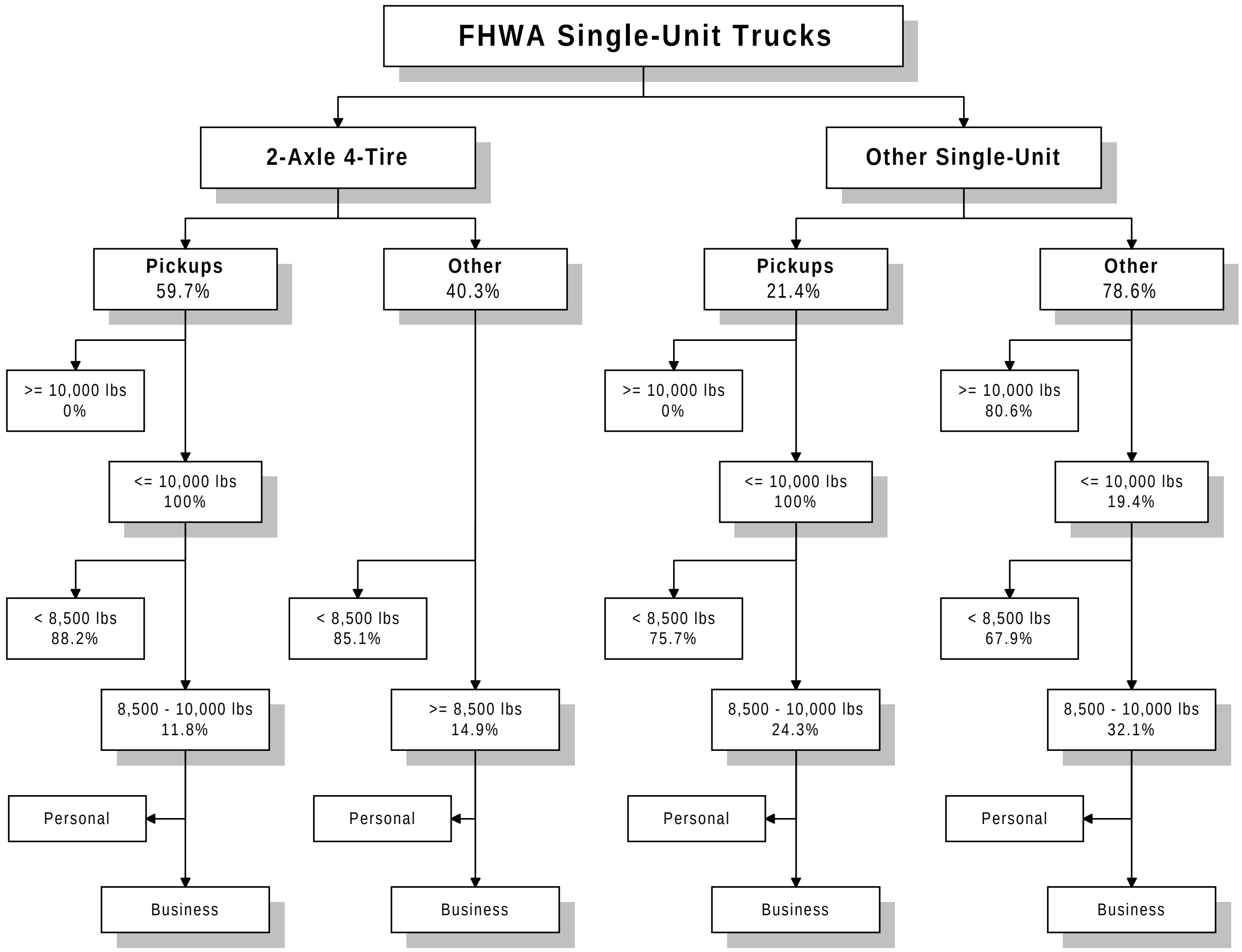
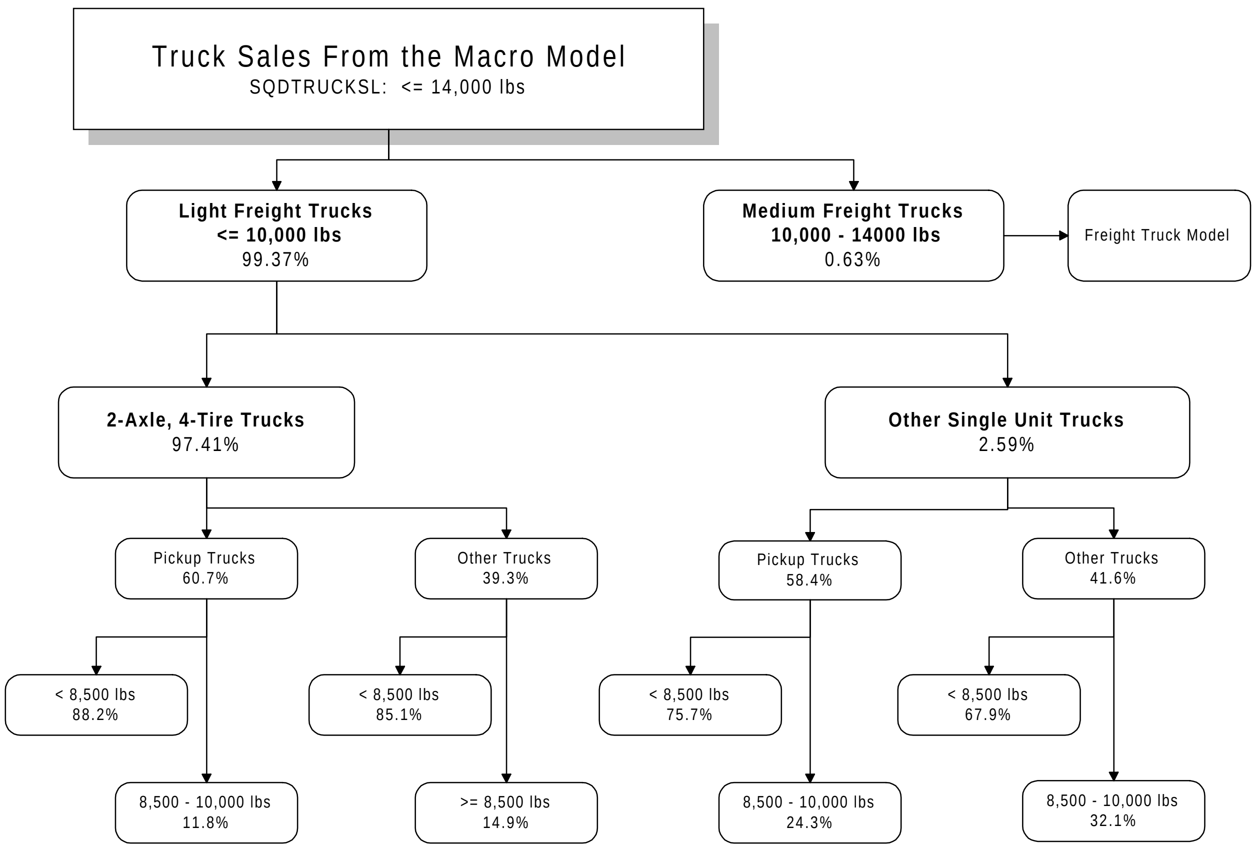


Figure 3B-6: Distribution of Light Truck Sales



LCT Model Equations

Calculate the light commercial trucks sales:

$$LT\_CLTT = MC\_SQDTRUCKSL * LT10K * 10^6 \quad \textbf{(151)}$$

where:

LT_CLTT_N = Sales of light trucks less than 10,000 pounds
$MC\_SQTRUCKSL_N$ = Total sales of light trucks, from the Macro Model
LT10K = Fraction of Light Duty Trucks with a gross vehicle weight of less than 10,000 pounds

Divide LCT sales between 2-axle, 4-tire and other single-unit (OSU) trucks:

$$CLTSAL2A4T = LT\_CLTT * LT2A4$$

$$and \quad \textbf{(152)}$$

$$CLTSALOSU = LT\_CLTT * LTOSU$$

where:

LT2A4 = Fraction of new light trucks of the 2-axle, 4 tire configuration
LTOSU = Fraction of new light trucks of other configuration

Divide sales of both truck types into pickup and non-pickup styles for trucks between 8,500 and 10,000 pounds:

$$CLTSAL2A4TS_{istyl} = CLTSAL2A4T * LT2A4CLT_{istyl}$$

$$and \quad \textbf{(153)}$$

$$CLTSALOSUS_{istyl} = CLTSALOSU * LTOSUCLT_{istyl}$$

where:

$LT2A4CLT_{istyl}$ = Fraction of 2-axle, 4-tire trucks between 8.5 and 10 thousand pounds, by style
$LTOSUCLT_{istyl}$ = Fraction of other single unit trucks between 8.5 and 10 thousand pounds, by style
istyl = Index of truck style: 1 = pickup, 2 = other

Allocate sales among the aggregate major-use groups:

$$CLTSAL_{is,istyl,isic} = CLTSAL2A4TS_{istyl} * CLTSICSHR_{is,istyl,isic} \qquad for\ \ is = 1$$

$$and \qquad \textbf{(154)}$$

$$CLTSAL_{is,istyl,isic} = CLTSALOSUS_{istyl} * CLTSICSHR_{is,istyl,isic} \qquad for\ \ is = 2$$

where:

CLTSICSHR = Share of LCT sales allocated to each major-use group, by truck type and style
is = Index of truck type: 1 = 2-axle, 4-tire; 2 = other single-unit truck
isic = Index of major use group: 1 = Agriculture; 2 = Mining; 3 = Construction; 4 = Trade; 5 = Utilities; 6 = Personal

Update LCT stocks to reflect survival curve and sales:

$$CLTSTK_{is,istyl,isic,n} = CLTSTK_{is,istyl,isic,n-1} * SURVCLT_{is} + CLTSAL_{is,istyl,isic,n} \qquad \textbf{(155)}$$

where:

CLTSTK = Light commercial truck stock
SURVCLT = Percentage of previous year's stock which gets carried over, by truck type

Estimate the VMT demand for LCT's, by sector:

$$CLTVMT_{is,istyl,isic,n} = CLTVMT_{is,istyl,isic,n-1} * \left[\frac{CLTSIC_{isic,n}}{CLTSIC_{isic,n-1}}\right] \qquad \textbf{(156)}$$

where:

$CLTSIC_{isic}$ = Aggregate measures of industrial output for sectors 1-5; level of personal travel demand for sector 6.

Estimate new LCT fuel economy, assuming that growth from baseline (1992) values parallels that of other light-duty trucks:

$$NCLTMPG_{is,istyl,isic,n} = NCLTMPG_{is,istyl,isic,n-1} * \left[\frac{MPGT_{n}}{MPGT_{n-1}}\right] \qquad \textbf{(157)}$$

where:

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

Incorporate new LCT estimates into existing stock:

$$CLTMPG_{is,istyl,isic,n} = \left[\frac{\left\{ \left(\frac{CLTSTK_{is,istyl,isic,n-1} * SURVCLT_{is}}{CLTMPG_{is,istyl,isic,n-1}} \right) + \left(\frac{CLTSAL_{is,istyl,isic,n-1}}{NCLTMPG_{is,istyl,isic,n-1}} \right) * LTDFRFG_{n} \right\}}{CLTSTK_{is,istyl,isic,n}} \right]^{-1} \quad \textbf{(158)}$$

where:

CLTMPG = Stock MPG of light commercial trucks, by truck type and style
LTDFRFG = Scaling factor, associated with the increased use of reformulated gasoline

Calculate aggregate sales-weighted new LCT MPG:

$$NCLTMPGT = \left[\sum_{is} \sum_{istyl} \sum_{isic} \left\{ \frac{\left(\frac{CLTSAL_{is,istyl,isic}}{\sum_{is} \sum_{istyl} \sum_{isic} CLTSAL_{is,istyl,isic}} \right)}{NCLTMPG_{is,istyl,isic}} \right\} \right]^{-1} \quad \textbf{(159)}$$

Calculate VMT-weighted stock average MPG for light commercial trucks:

$$CLTMPGT = \left[\sum_{is} \sum_{istyl} \sum_{isic} \left\{ \frac{\left(\frac{CLTVMT_{is,istyl,isic}}{\sum_{is} \sum_{istyl} \sum_{isic} CLTVMT_{is,istyl,isic} * 1e^{9}} \right)}{CLTMPG_{is,istyl,isic}} \right\} \right]^{-1} \quad \textbf{(160)}$$

Calculate fuel consumption in gallons and Btu's for each truck type, style, and major-use category:

$$CLTGAL_{is,istyl,isic} = \frac{CLTVMT_{is,istyl,isic}}{CLTMPG_{is,istyl,isic}}$$

$$and \quad \textbf{(161)}$$

$$CLTBTU_{is,istyl,isic} = CLTGAL_{is,istyl,isic} * \frac{5.253}{42}$$

Calculate total Btu consumption by light commercial trucks, by summing over the indices:

$$CLTBTUT = \sum_{is} \sum_{istyl} \sum_{isic} CLTBTU_{is,istyl,isic} \quad \textbf{(162)}$$

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.

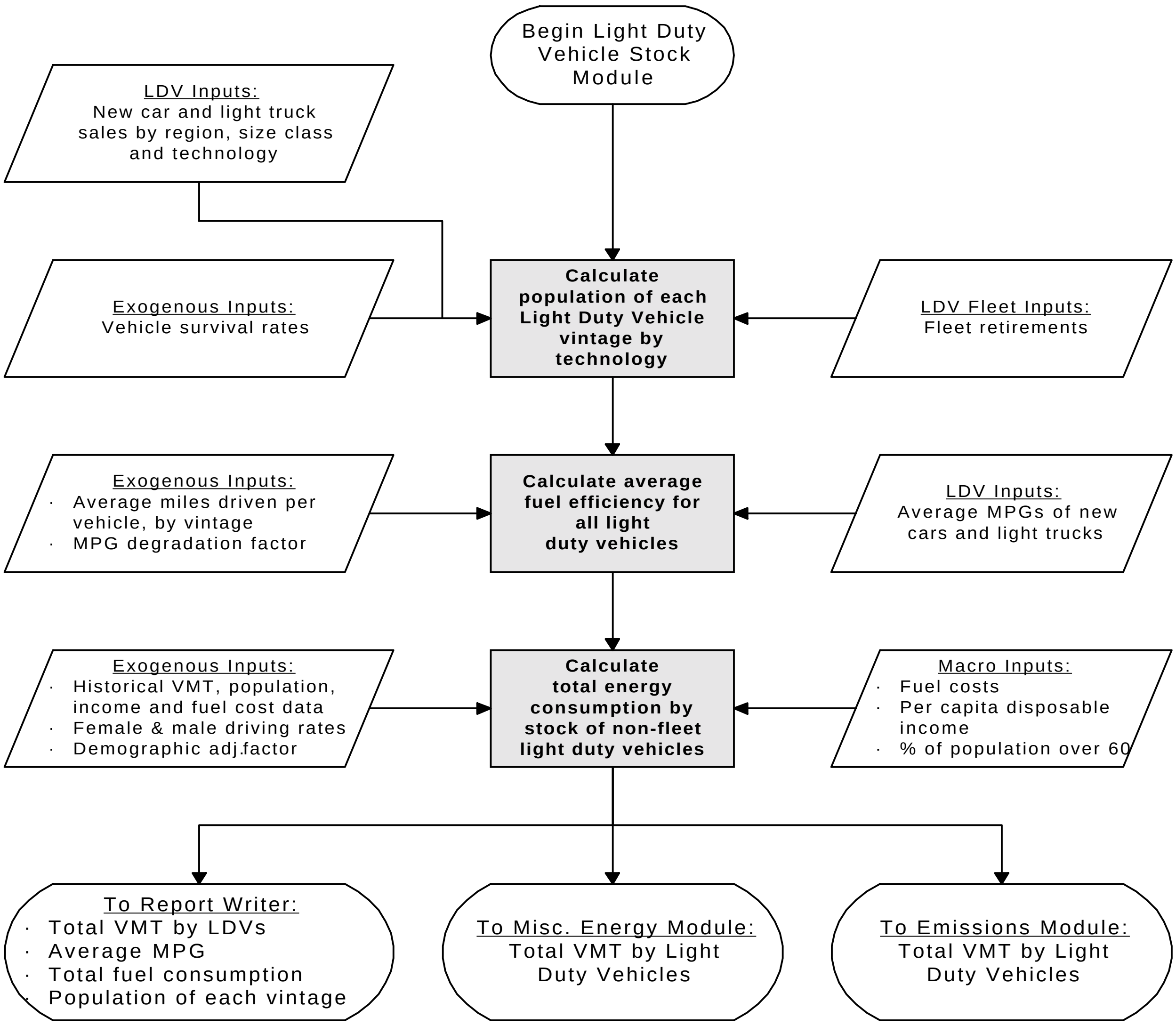
The Light Duty Vehicle Stock Module flowchart is presented in Figure 3C-1 below. More detailed diagrams of LDV Stock calculations are presented at the end of Section 3C.

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:

$$TECHNCS_{it} = \sum_{is=1}^{6} \sum_{ir=1}^{9} NCSTECH_{ir,is,it}$$

and **(163)**

$$TECHNLT_{it} = \sum_{is=1}^{6} \sum_{ir=1}^{9} NLTECH_{ir,is,it}$$

where:

TECHNCS = Total new car sales, by technology
TECHNLT = Total new light truck sales, by technology
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 *IVINT* = 2-19:

$$PASSTK_{it,ivint,n} = PASSTK_{it,ivint-1,n-1} * SSURVP_{ivint-1}$$

and **(164)**

$$LTSTK_{it,ivint,n} = LTSTK_{it,ivint-1,n-1} * SSURVLT_{ivint-1}$$

For *IVINT* = 20:

$$PASSTK_{it,ivint=20,n} = \left(PASSTK_{it,ivint=19,n-1} * SSURVP_{ivint=19}\right) + \left(PASSTK_{it,ivint=20,n-1} * SSURVP_{ivint=20}\right)$$

and **(165)**

$$LTSTK_{it,ivint=20,n} = \left(LTSTK_{it,ivint=19,n-1} * SSURVLT_{ivint=19}\right) + \left(LTSTK_{it,ivint=20,n-1} * SSURVLT_{ivint=20}\right)$$

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
IVINT = Index of vehicle vintage (1-20)

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 ORNL Transportation Energy Data Book, 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:

$$PASSTK_{it,ivint} = PASSTK_{it,ivint} + OLDFSTK_{car,ity,it,ivint}$$

and **(166)**

$$LTSTK_{it,ivint} = LTSTK_{it,ivint} + OLDFSTK_{truck,ity,it,ivint}$$

where:

OLTFSTK = Number of fleet vehicles rolled over into corresponding private categories
IVINT = Transition vintage: vintage at which vehicles of a given type are transferred
ITY = Type of fleet vehicle: Business, Government, or Utility

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

$$STKCAR = \sum_{ivint=1}^{20} \sum_{it=1}^{16} PASSTK_{it,ivint}$$

and **(167)**

$$STKTR = \sum_{ivint=1}^{20} \sum_{it=1}^{16} LTSTK_{it,ivint}$$

where:

STKCAR = Total stock of non-fleet automobiles
STKTR = Total stock of non-fleet light trucks

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

$$VSPLDV_{it} = \frac{\sum_{ivint=1}^{20} \left(PASSTK_{it,ivint} + LTSTK_{it,ivint} \right)}{STKCAR + STKTR} \quad \textbf{(168)}$$

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:

$$NVSALES_{i=1,is,it} = \sum_{ir=1}^{9} NCSTECH_{ir,is,it}$$

and **(169)**

$$NVSALES_{i=2,is,it} = \sum_{ir=1}^{9} NLTECH_{ir,is,it}$$

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

$$MPGC_{it} = \left[\frac{\sum_{is=1}^{6} \frac{NVSALES_{i=1,is,it}}{MPG_{i=1,it,is}}}{\sum_{is=1}^{6} NVSALES_{1,is,it}} \right]^{-1}$$

and **(170)**

$$MPGT_{it} = \left[\frac{\sum_{is=1}^{6} \frac{NVSALES_{i=2,is,it}}{MPG_{i=2,it,is}}}{\sum_{is=1}^{6} NVSALES_{i=2,is,it}} \right]^{-1}$$

where:

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

The overall fuel efficiency of cars and light trucks is then calculated across the twenty vintages addressed in the model.[8] 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

[8] Initial (1990) values for on-road car and light truck fleet MPG are obtained from the 1991 RTECS.

is done by summing the total number of miles driven across all vintages and technologies:[9]

$$TOTMICT = \sum_{it=1}^{16} \sum_{ivint=1}^{20} PASSTK_{it,ivint} * PVMT_{ivint}$$

and **(171)**

$$TOTMITT = \sum_{it=1}^{16} \sum_{ivint=1}^{20} LTSTK_{it,ivint} * LVMT_{ivint}$$

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

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:

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

and **(172)**

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

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:

[9] 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.

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

and **(173)**

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

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

$$MPGFLT = \frac{TOTMICT + TOTMITT}{CMPGT + TMPGT} \qquad \textbf{(174)}$$

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

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

and **(175)**

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

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.

Because personal automobile travel accounts for such a significant fraction of total energy consumption, it is important to ensure that the model which forecasts this travel demand be as accurate as possible. This accuracy is measured not so much by the predictive success of the model, but by the sensitivity of the model to the economic and policy levers which are of concern to the users, and by the ability of the model to respond to both short-term economic factors, and long-term demographic and structural trends. The model described in this section is an attempt to provide a more intuitive and inclusive approach to demographic influences in the estimation of travel demand.

Model Structure

The primary concern in forecasting VMT per licensed driver in the mid to long term is to address those effects that are liable to alter historical growth trends. The two factors considered to have the greatest potential affect on future VMT trends are the aging of the population and the growth of female driving rates relative to male driving rates. These are discussed in turn below.

<u>Population Aging</u>
VMT per licensed driver varies considerably by age group and sex. The mean VMT per driver by age group and sex is shown in Figure 3C-2. At the high end of this range are males 35 to 39 years of age, who on average drive close to 20 thousand miles per year. At the low end are females over seventy years of age who drive less than 4 thousand miles per year. Considering men and women together, the highest driving group is that of age 35-39, at 15,930 miles per year, while the lowest group is 70 and over, at 6,775 miles per year. This variation is significant because the average age of Americans is forecast to increase markedly in the coming decades.

The affect of the "aging of the population" on VMT cannot be assessed by analyzing historical data. As there has been little variation in the over 60 population share historically, it should not be particularly surprising that attempts to measure the "aging of the population" affect on VMT using econometric techniques have not been very satisfying. In spite of this, there is ample survey data indicating that drivers 60 and over drive substantially less than do younger. The most recent NPTS indicates that those over 60 drive only about half as much as do younger drivers. None of this would affect the accuracy of our aggregate VMT forecast if the proportion of the population 60 and over remained at 20 percent. The Census Department, however, accurately records the inevitable aging of the "baby boom" generation. In the early 2000's they project that the proportion of the population over 60 begins to rise sharply. By 2020, it reaches 30 percent, up from 21 percent in 2000.

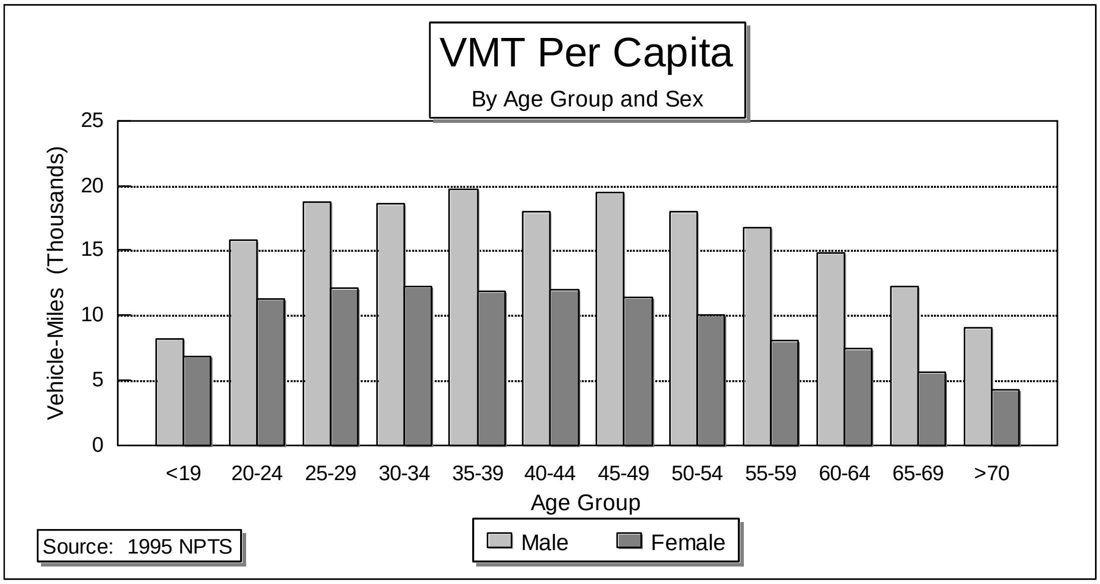


Figure 3C-2: VMT per Capita

The effect of the aging trend on travel could be substantial, but it is difficult to know the precise manner in which it will affect overall VMT. If one assumes that in 30 years, 65 year olds will drive about the same amount as current 65 year olds, then assessing the effect of population aging on VMT would be a matter of simple accounting. For example, total VMT in 2020 can be calculated simply by multiplying the number of drivers that will be in each age group in 2020 (Census forecast) by the current average VMT in each age group and then summing VMT across all age groups.

Unfortunately, one cannot be confident that the 65 year old of tomorrow will continue to behave as he or she does today. As individuals age, their levels of driving will probably continue to decline, particularly following retirement, as it has in the past. But it is unlikely to decline to the levels of current retirees, as those currently over 65 years old did not grow up in a society as dependant on the automobile as did the current 35 year olds. Additionally, retirees of the future may have substantially greater wealth, better health, and/or a greater desire for mobility than do current ones. Indeed, the 1995 NPTS estimates indicate that the estimated VMT per year for drivers greater than 70 years old has increased by nearly 75% over the 1983 estimate to 6,775 miles per person.

Growth in Female Driving Rates

Another 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. Evidence of this is provided in Figure 3C-3, which indicates that women between the ages of 20 and 45 dramatically increased their driving rates relative to their male counterparts. 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.

In earlier versions of the VMT model, an assumption was made that women would continue to drive less than men on a per capita basis. Historically, this has been true, as evidenced by the results of earlier NPTS reports. However, this historical discrepancy has been diminishing, and it is now thought more prudent to have this trend converge to parity with male driving rates. The rate of convergence is essentially arbitrary, and has been chosen to ensure that 80 percent of parity is achieved in 2010. This assumed trend is depicted below (Figure 3C-3), which asymptotically approaches 80 percent.

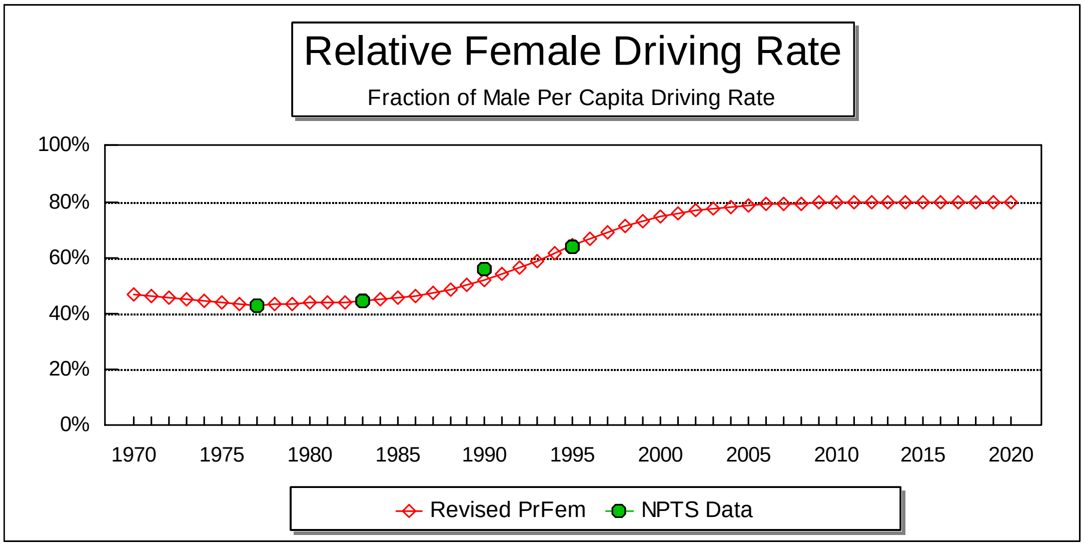


Figure 3C-3: Relative Female Driving Rate

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}) in 2010. Or, in equation form:

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

$$where: \qquad \textbf{(176)}$$

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

The user should be able to use the above formulation to implement other assumptions, should it become necessary.

Updating Data Inputs

Since the last revision of the VMT model, two more years of vehicle stock, VMT, and fuel consumption data have been made available from FHWA, and the income variable from the Macroeconomic Model has been revised. All macro inputs are now being 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:

$$VMTPD_T - \rho\, VMTPD_{T-1} = \alpha(1-\rho) + \sum_{N=1}^{3} \beta_N (X_{N,T} - \rho\, X_{N,T-1}) \qquad \textbf{(177)}$$

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. This assumption, however, has been only a first approximation, as FHWA does not classify these trucks by weight. In an attempt to further refine the model, a new category of truck has been defined: Light Commercial Trucks (LCT), 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 Macro Model. In order to avoid double-counting, the 2-axle, 4-tire strata of these LCT's, previously included in the LDV model, must be subtracted from the data inputs. Details of the stratification and estimation of LCT demand are provided in a subsequent section, which contains historical data estimates between 1990 and 1995. Estimates of LCT travel prior to 1990 are obtained by indexing the 1990 estimate to GDP growth trends from 1969 to 1990.

Several functional forms were tested in the development of this model, bringing to light the difficulty in constructing a model which incorporates both economic and demographic parameters which may be used for forecasting in the mid- to long-term. Problems with autocorrelation and multicollinearity motivated the implementation of a two stage approach in which the results of a linear econometric model are adjusted to reflect demographic constraints. The first stage provides a forecast of per driver VMT, based on historical data, which assumes that the age profile of the country remains constant. The second stage imposes a limiting factor which reflects the projected aging of the population and the reduced driving rates associated with older drivers.

In the first stage of this model, a generalized difference equation is used to estimate the unadjusted VMT per driver:

$$\begin{aligned} VMTPD_T = {} & \rho\, VMTPD_{T-1} + 3.593\,(1-\rho) - 0.088\,(CPM96_T - \rho\, CPM96_{T-1}) \\ & + 1.64 x 10^{-4}\,(YPC96_T - \rho\, YPC96_{T-1}) + 6.632\,(PrFem_T - \rho\, PrFem_{T-1}) \end{aligned} \qquad \textbf{(178)}$$

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 0.758.

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.

The unadjusted forecast is subsequently modified by a demographic adjustment factor (DAF), which is based on the age-specific driving rates reported in the 1995 NPTS. The DAF is based on the idea that the average VMTPD can be represented as a weighted average of the age-specific VMTPD's.

The DAF is an index which represents the effect of changes in the age distribution of the population over the forecast period. The DAF is a population-weighted index of the relative driving rates, expressed as follows:

$$DAF_T = \frac{\sum_A VMTPDI_{A,T} * POP_{A,T}}{\sum_A POP_{A,T}} \qquad \textbf{(179)}$$

where:

$POP_{A,T}$ = U.S. population by the 12 age groups, *A*, described above.

$VMTPDI_{A,T}$ represents the travel index illustrated in Figure 3C-4 and is defined as:

$$VMTPDI_{A,T} = \frac{VMTPD_{A,T}}{VMTPD_{MAX,T}} \qquad \textbf{(180)}$$

where:

$VMTPD_{A,T}$ = VMT per driver for a given age group for time *T*
$VMTPD_{MAX,T}$ = maximum VMT per driver for all age groups for time *T*

It has been suggested that this formulation underestimates the consequences of population aging, as drivers moving into the older age categories are likely to retain some of their earlier driving habits. In order to account for this shift, the VMTPDI is re-calculated to include a time dimension, under the

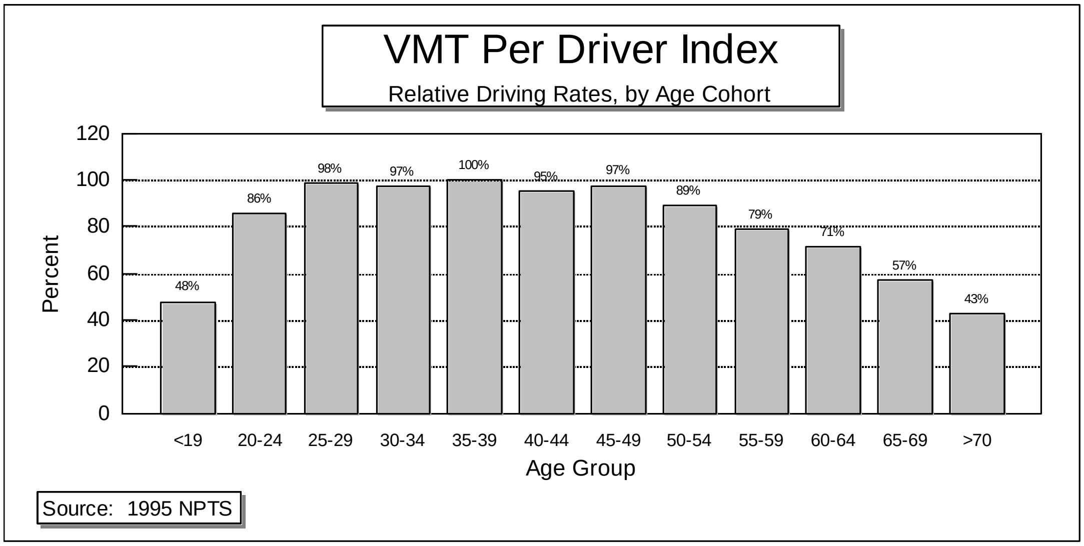


Figure 3C-4: Relative Driving Rate Index, by Cohort

assumption that the difference between each age cohort's VMTPDI and 1.0 will be reduced over the forecast period as follows: the VMTPDI for drivers in the 16-19 age group will reduce the gap by 15 percent; all age groups until the >70 group will converge 50 percent of the way to unity. Drivers older than 70 are further disaggregated into four groups: 70-74, 75-79, 80-84, and >=85. Their indices are tied to that of the next younger group as follows:

$$\begin{aligned} VMTPDI_{70,T} &= 0.9 * VMTPDI_{65,T} \\ VMTPDI_{75,T} &= 0.5 * VMTPDI_{70,T} \\ VMTPDI_{80,T} &= 0.5 * VMTPDI_{75,T} \\ VMTPDI_{85,T} &= 0.25 * VMTPDI_{80,T} \end{aligned} \quad \textbf{(181)}$$

These factors have been chosen to most closely approximate the historical values of the VMTPDI for the >=70 age group, when population weights are applied. For example, as was reported in the 1995 NPTS, VMT per driver in the youngest age cohort is 48 percent of the maximum VMT per driver in the overall distribution, this ratio grows to 56 percent by 2020.

The DAF resulting from this distribution changes over time based on two factors: the growth of the older population (serving to reduce the DAF), and the increases in the relative driving indices in the extremes of the distribution (serving to increase the DAF). In the early years of the revised formulation, the growth in the indices more than compensates for the population growth in the older cohorts, leading to a marked increase in the DAF. This levels off in the later years, falling as the effects of population aging become more pronounced.

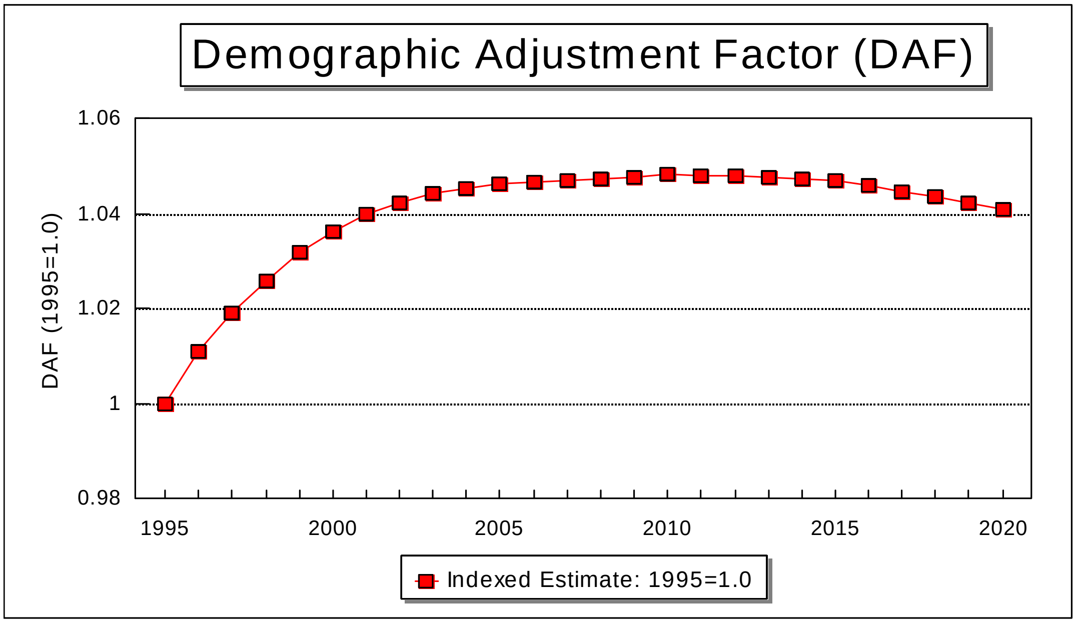


Figure 3C-5: Demographic Adjustment Factor

When applied to the VMT model, the DAF represented above (Figure 3C-5) is itself indexed to 1995, and is thus no longer bounded by 1.0.

The DAF is applied to historical VMTPD figures prior to the regression analysis described above. This permits a more consistent baseline comparison, by positing driving rates under a constant 1995 demographic distribution. The estimated results are subsequently re-transformed using the DAF, bringing them back in line with observed values.

$$VMTPD_T^{/} = VMTPD_T * \left[\frac{DAF_T}{DAF_{1995}} \right] \qquad \textbf{(182)}$$

Obtaining the VMTPD within each age cohort, then, is a matter of solving for VMTPDMAX, and applying the relative driving indices expressed in the VMTPDI. The results are presented in Figure 3C-6.

Using the parameters estimated above, and forecasts of relevant input variables, a base-case forecast of VMTPD is generated, and subsequently converted to total VMT by multiplying by the population at or above the driving age of 16 years. Total demand for light duty vehicle travel is finally allocated among the various conventional and alternative automobile technologies considered in NEMS, and consumption estimates are generated for each type of fuel.

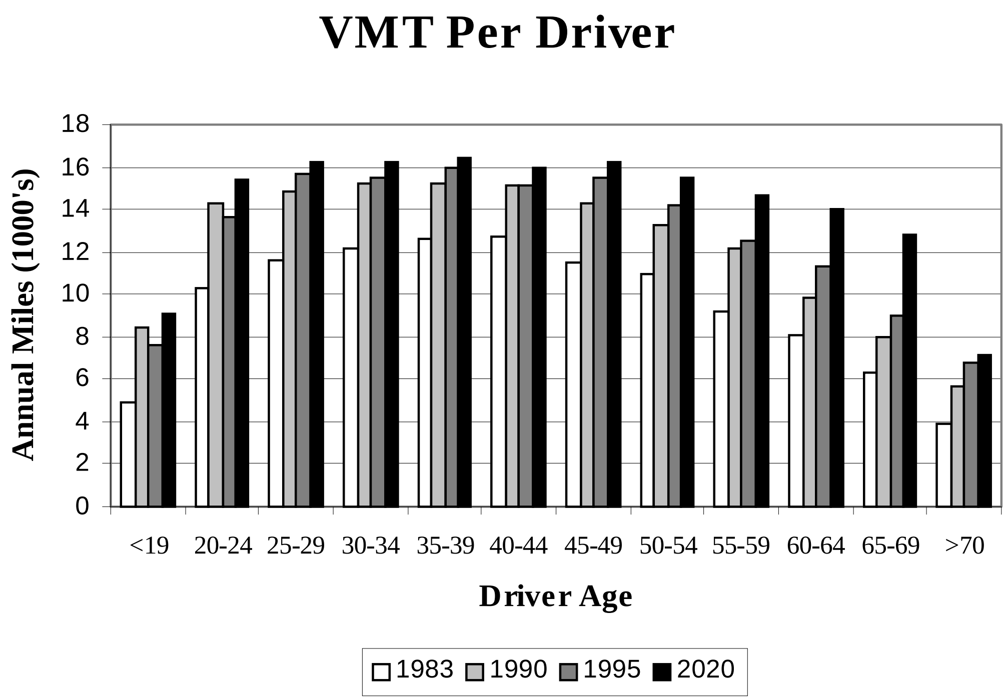


Figure 3C-6: VMT Per Driver, NPTS and AEO

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 in order to meet that demand.

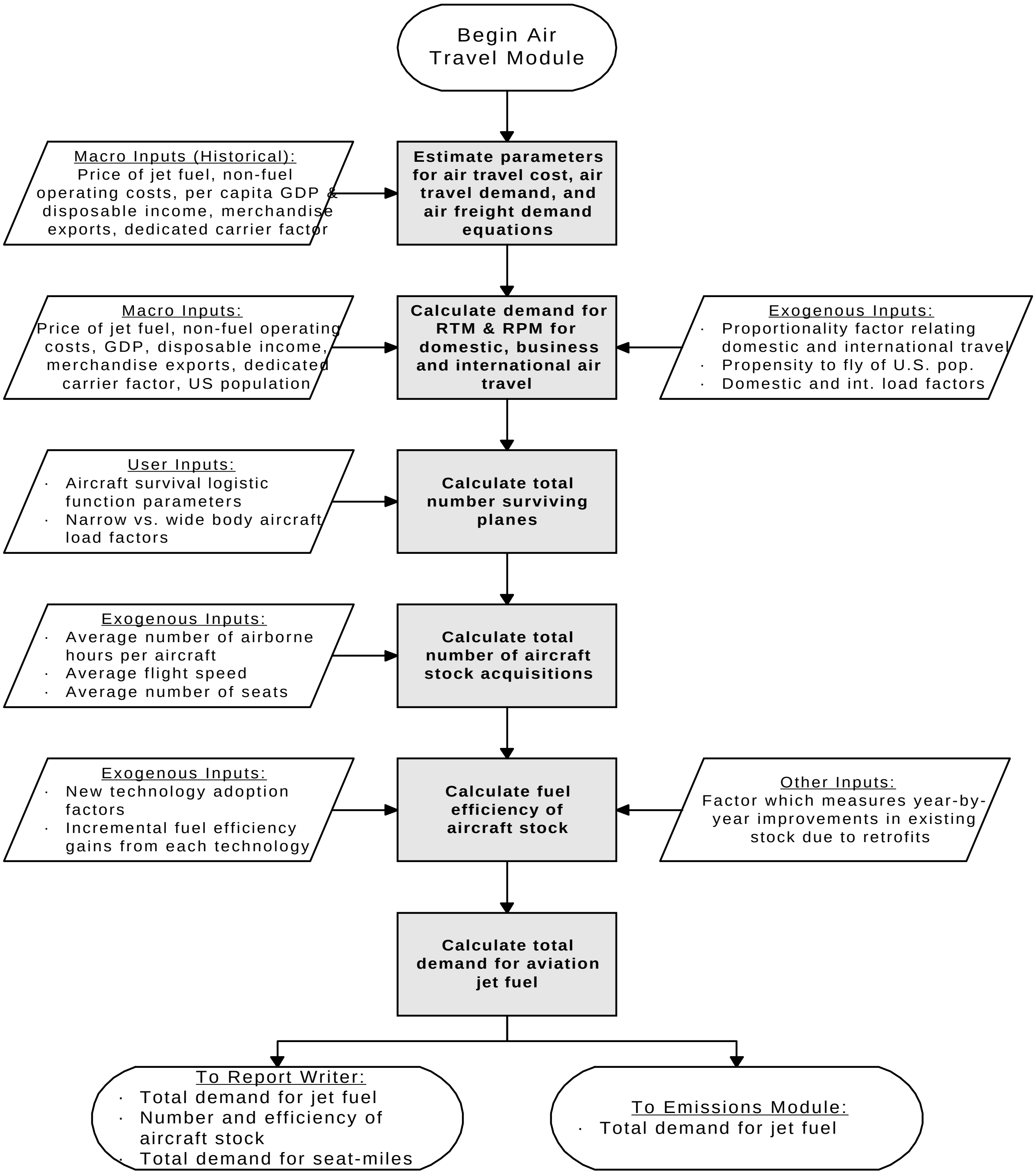
In order to increase the sensitivity of the forecast to economic and demographic parameters, a disaggregate model, incorporating separate treatment of business, personal, and international passenger travel has been implemented. Separate forecasts of domestic passenger and freight travel are generated, 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 further assumed that business and personal travel are motivated by different measures of economic conditions, and should be modeled separately. Finally, it is 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.

MODEL STRUCTURE

The Air Travel Demand Model, as implemented in NEMS, is a series of linear equations estimated over the period 1979-1990. 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:

$$YIELD = 10.52 + (.77 * PJFTR) \quad \textbf{(183)}$$

where:

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

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

Business:

$$RPMBPC = -152.82 + \left(32.00 * \frac{MC\_GDP96C}{TMC\_POPAFO}\right) - (2.858 * YIELD) \quad \textbf{(184)}$$

Personal:

$$RPMPPC = -27.71 + \left(56.00 * \frac{MC\_YD96C}{MC\_POPAFO}\right) - (23.68 * YIELD) \quad \textbf{(185)}$$

International:

$$RPMIPC = PCTINTT * (RPMBPC + RPMPPC) \quad \textbf{(186)}$$

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.

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

$$RTM = \left(-11{,}705 + (19.39 * MC\_EXDnN96C) + (2.78 * MC\_GDP96C)\right) - BELLYFRT \quad \textbf{(187)}$$

where:

MC_EXDnN96C = 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:

$$RPMP = RPMPPC * MC\_POPAFO * DI \tag{188}$$

$$RPMB = RPMBPC * MC\_POPAFO \tag{189}$$

$$RPMD = RPMB + RPMP \tag{190}$$

$$RPMI = RPMIPC * MC\_POPAFO \tag{191}$$

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 = Demographic index, reflecting the public's propensity to fly

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:

$$SMDEMD = \left(\frac{RPMD}{LFDOM}\right) + \left(\frac{RPMI}{LFINTER}\right) + (RTM * EQSM) \tag{192}$$

where:

SMDEMD = Total demand for available seat-miles
LFDOM = Load factor for domestic travel
LFINTER = Load factor for international travel
EQSM = Equivalent seat-miles conversion factor; used to transform freight RTM's

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 2020.

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 is directly estimated; jet fuel consumption is considered to be a fixed percentage of commercial aircraft demand, and aviation gasoline demand is projected using a time-dependent extrapolation. Military jet fuel use is estimated in another Module using forecasts of military budget trends.

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.[10] The development of the hub and spoke system has made airlines inclined to invest in smaller aircraft in recent years, but increasing airport congestion provides 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.

MODEL STRUCTURE

The model operates in two stages: the first is an estimation of the total fleet of each type of aircraft required to meet projected demand in any given year; the second is a determination of 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:

$$SMFRAC_{Narrow,T} = \left(\frac{ASMDEMD_{Narrow,T-1}}{SMDEMD_{T-1}} \right) * (1+\delta) \qquad \textbf{(193)}$$

[10] 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

where:

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

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:

$$ASMDEMD_{Narrow,T} = SMFRAC_{Narrow,T} \cdot SMDEMD_T$$

and **(194)**

$$ASMDEMD_{Wide,T} = (1 - SMFRAC_{Narrow,T}) \cdot SMDEMD_T$$

The survival rates of aircraft are subsequently estimated:

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

and **(195)**

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

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

$$SMSURV_{IT,T} = \sum_{IVINT=2}^{60} NPCHSE_{IT,IVINT-1,T-1} * SSURVPCT_{IVINT} * ASMP_{IT,T} \quad \textbf{(196)}$$

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)

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:

$$NPCHSE_{IT,IVINT=1,T} = \left[\frac{ASMDEMD_{IT,T} - SMSURV_{IT,T}}{ASMP_{IT,T}} \right] \quad \textbf{(197)}$$

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:

$$NPCHSE_{IT,IVINT,T} = NPCHSE_{IT,IVINT-1,T-1} * SSURVPCT_{IVINT} \quad ; \quad IVINT = 2 - 60 \quad \textbf{(198)}$$

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

$$NSURV_{IT,T} = \sum_{IVINT=1}^{60} NPCHSE_{IT,IVINT,T} \quad \textbf{(199)}$$

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:

$$STKOLD_{IT,T} = \frac{\left(NSURV_{IT,T} - NPCHSE_{IT,1,T}\right)}{NSURV_{IT,T}} \quad \textbf{(200)}$$

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:

$$TIMEFX_{IFX,T} = TIMEFX_{IFX,T-1} + \left(TIMECONST * TPN_{IFX} * TYRN_{IFX}\right) \quad \textbf{(201)}$$

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

$$COSTFX_{IFX,T} = 10 * \left(\frac{TPJFGAL_T - TRIGPRICE_{IFX}}{TPJFGAL_T}\right) * TPN_{IFX} * TYRN_{IFX} * TPZ_{IFX} \quad \textbf{(202)}$$

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:

$$TOTALFX_{IFX,T} = TIMEFX_{IFX,T} + COSTFX_{IFX,T} - BASECONST \quad \textbf{(203)}$$

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:

$$TECHPEN_{IFX,T} = \left[1 + e^{(-TOTALFX_{IFX,T})} \right]^{-1} \quad \textbf{(204)}$$

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

$$FRACIMP_{IT=1,T} = 1.0 + EFFIMP_{IFX=1} * \left(TECHPEN_{IFX=1,T} - TECHPEN_{IFX=2,T}\right) + \sum_{IFX=2}^{6} EFFIMP_{IFX} * TECHPEN_{IFX,T} \quad \textbf{(205)}$$

and

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

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:

$$NEWSMPG_{IT,T} = MAX \left[(FRACIMP_{IT,T} * SMPG_{IT,1}) \, , \, ((1.0 + \rho_{IT}) * SMPG_{IT,T-1} * STKIMP) \right] \quad \textbf{(206)}$$

where:

ρ = Average historic rate of growth of fuel efficiency
STKIMP = Stock efficiency improvement

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:

$$SMPG_{IT,T} = \left[\left(\frac{STKOLD_{IT,T}}{(1 + \rho_{IT}) * (SMPG_{IT,T-1})} \right) + \left(\frac{(1 - STKOLD_{IT,T})}{NEWSMPG_{IT,T}} \right) \right]^{-1} \quad \textbf{(207)}$$

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:

$$SMPGT_{T} = \left[\left(\frac{SMFRACN_{T}}{SMPG_{1,T}} \right) + \left(\frac{(1 - SMFRACN_{T})}{SMPG_{2,T}} \right) \right]^{-1} \quad \textbf{(208)}$$

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.

<u>Estimating Fuel Consumption</u>

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:

$$JFGAL_{T} = \frac{SMDEMD_{T}}{SMPGT_{T}} * 1.04 \quad \textbf{(209)}$$

The demand for aviation gasoline is calculated as:

$$AGD_{IYEAR} = BASEAGD + GAMMA * e^{(-KAPPA * (IYEAR - 1979))} \quad \textbf{(210)}$$

where:

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

Convert the jet fuel demand in gallons to Btu:

$$JFBTU_T = JFGAL_T * \left(\frac{5.670 \ MMBtu/bbl}{42 \ gal/bbl} \right)$$

and **(211)**

$$AGDBTU_T = AGD_T * \left(\frac{5.048 \ MMBtu/bbl}{42 \ gal/bbl} \right)$$

Calculate the jet fuel and aviation gasoline demand by regions:

$$QJETR_{IR,T} = JFBTU_T * SEDSHR_{IF,IR,T}$$

and **(212)**

$$QAGR_{IR,T} = AGDBTU_T * SEDSHR_{IF,IR,T}$$

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:

$$XAIREFF_T = \frac{SMPGT_T}{SMPGT_{T=1}} \quad \textbf{(213)}$$

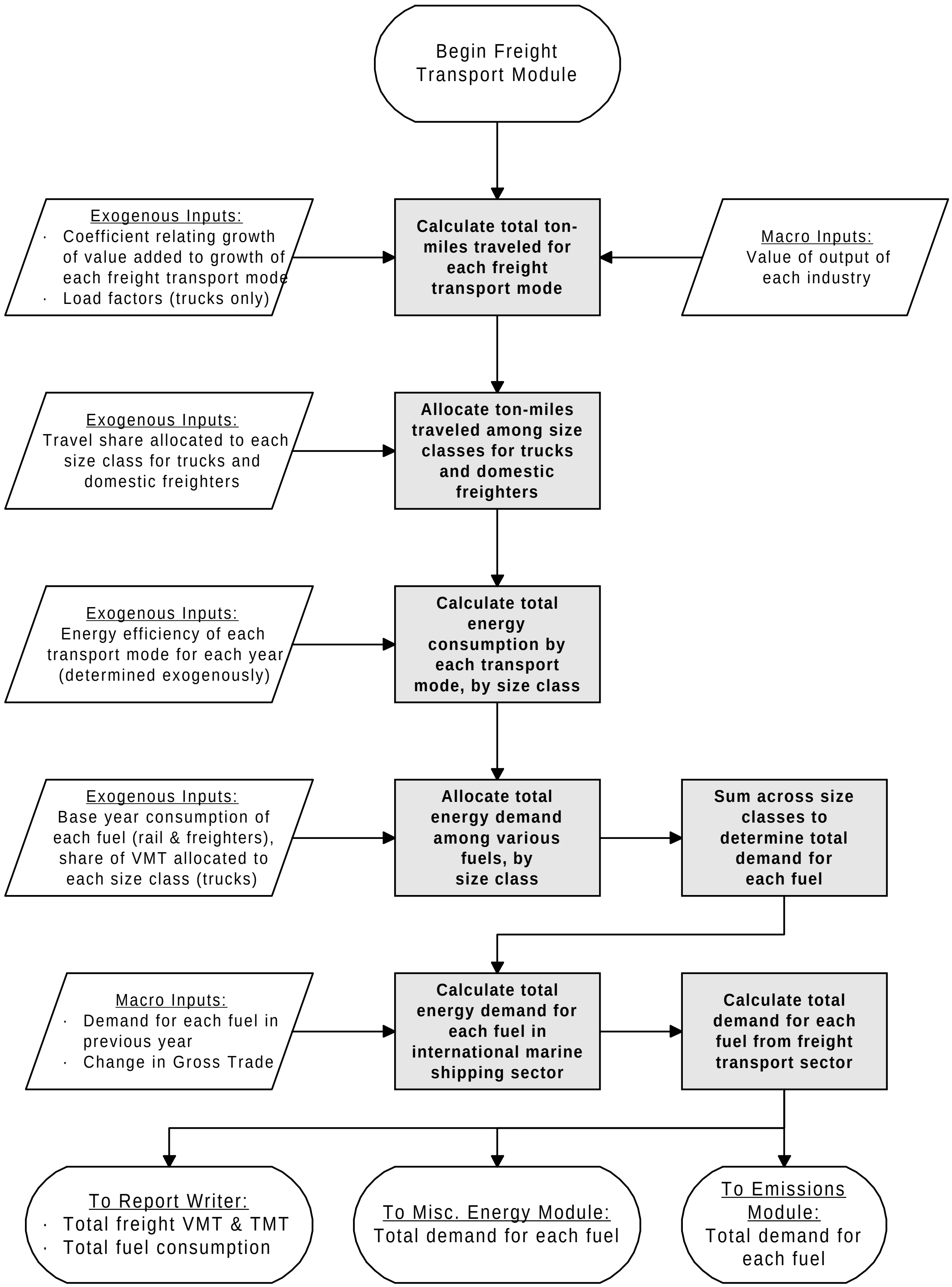
3E. Freight Transport Module

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 added. 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 added 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, purchases and retirements of freight trucks, important truck stock characteristics such as fuel technology market share and fuel economy, and fuel consumption.

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 added. 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. Eleven truck vintages, two 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 in order 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. Actual and perceived sectoral demand for freight travel in the form of vehicle-miles traveled (VMT) is then estimated and used to determine 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 medium 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 *Draft Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory[11] 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 *Draft Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory[12], and include advanced transmissions, lightweight materials, synthetic gear lube, advanced drag reduction, advanced tires, electronic engine controls, advanced engines, 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 separately for diesel, gasoline, LPG and CNG trucks.

Characterizations of existing and future fuel-saving technologies are documented[13]. Because future technologies are speculative, future technology characterizations can be modified by the user. However, existing characterizations are derived from historical data and should not be altered.

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

$$AVGPRC_{T,FUEL} = \frac{(PRICE_{T,FUEL} + PRICE_{T-1,FUEL} + PRICE_{T-2,FUEL})}{3} \qquad \textbf{(214)}$$

[11] *Draft 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.

[12] *Draft 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.

[13] *NEMS Transprtation Sector Model: Freight Truck Stock Adjustment Model Update,* Decision Analysis Corporation of Virginia, Task 95-101, Subtask 1-3, Appendix A, November 30, 1995.

where:

T = Index referring to model run year; where $T = 0,...,23$
$FUEL$ = Index referring to fuel type, where $FUEL$=1 refers to diesel, $FUEL$=2 refers to gasoline, $FUEL$=3 refers to LPG and $FUEL$=4 refers to CNG
AVGPRC = Average price of fuel $FUEL$ over three year period, in $ per MBtu
PRICE = Price of each fuel, in $ per MBtu

$$TGPRCXG_{T,SC,FUEL,TECH} = \frac{CAPCXG_{SC,FUEL,TECH}}{\sum_{IP=1}^{PAYBKXG_{SC,TECH}} MBTUTKXG_{SC} * MPGIPXG_{SC,FUEL,TECH} / ((1+(DISCRTXG*.01)^{IP})} \quad \textbf{(215)}$$

where:

$PAYBKXG$ = Payback period for a technology
TGPRCXG = Fuel price at which a technology 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
$TECH$ = 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. If the technology has not yet entered the market and the average price is greater than the technology's cost effective price, the technology enters the market during the current year:

$$\begin{gathered} For\ \ TECH = 3,...,16 \\ If \quad AVGPRC_{T,FUEL} \geq TGPRCX6_{SC,FUEL,TECH} \\ INITYR_{SC,FUEL,TECH} = T \end{gathered} \quad \textbf{(216)}$$

where:

$TECH$ = Index referring to fuel-saving technologies, where $TECH$ = 1,...,2 refers to currently available technologies and $TECH$ = 3...,16 refers to future technologies
SC = Index referring to truck size class, where SC = 2 refers to medium trucks and SC = 3 refers to heavy trucks
INITYR = Year in which technology $TECH$ enters market
LTGPRCX6 = Exogenously determined fuel price at which technology $TECH$ becomes economically viable

If a future technology enters market in the current year, coefficients for the logistic market penetration curve are determined:

$$COEFT_{SC,FUEL,TECH} = \frac{\ln(0.01)}{\left[\frac{CYCLE_{SC,FUEL,TECH}}{2}\right]}$$

and **(217)**

$$MIDYR_{SC,FUEL,TECH} = INITYR_{SC,FUEL,TECH} + \left[\frac{CYCLE_{SC,FUEL,TECH}}{2}\right]$$

where:

COEFT = Endogenously determined logistic market penetration curve parameter
CYCLE = Exogenously determined logistic market penetration curve parameter representing number of years until 99 percent of maximum market penetration
MIDYR = Endogenously determined logistic market penetration curve parameter

These coefficients are then used during the remainder of the forecast period to determine that technology's market share. 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:

$$PREFF_{T,SC,FUEL,TECH} = 1 + PRCVAR_{SC,FUEL,TECH} * \left[\frac{AVGPRC_{T,FUEL}}{TRIGPRC_{SC,FUEL,TECH}} - 1\right] \quad \textbf{(218)}$$

where:

PREFF = Effect of fuel price on market penetration rates for six fuel-saving technologies
PRCVAR = Exogenously determined fuel price sensitivity parameter for each technology, representing percent increase in technology market share if fuel price exceeds cost effective price by 100%

$$For\ TECH = 1,...,2$$

$$\begin{aligned} TECHSHR_{T,SC,FUEL,TECH} = \min \Big\{ & PREFF_{T,SC,FUEL,TECH} * \Big[BSHRT_{SC,TECH} \\ & + \left(ESHRT_{SC,FUEL,TECH} - BSHRT_{SC,TECH}\right) \\ & * \left(1 - e^{CONST_{SC,TECH} + COEFT_{SC,TECH} * T}\right)\Big], 1 \Big\} \end{aligned}$$

(219)

$$For\ TECH = 3,.....,16$$

$$TECHSHR_{T,SC,FUEL,TECH} = \min \left\{ PREFF_{T,SC,FUEL,TECH} * \frac{ESHRT_{SC,FUEL,TECH}}{1 + e^{COEFT_{SC,FUEL,TECH} * \left(T - MIDYR_{SC,FUEL,TECH}\right)}}, 1 \right\}$$

For each available technology, including existing technologies, the model determines its share of the available market in the current year:

where:

TECHSHR = Market share of fuel-saving technology *TECH* for size class *SC* and fuel type *FUEL*
CONST = Exogenously determined market penetration curve parameter for existing technologies
COEFT = Market penetration curve parameter; exogenous for existing technologies, endogenous for future technologies
BSHRT = Exogenously determined market penetration curve parameter representing market share of existing technology *TECH* in 1999
ESHRT = Exogenously determined market penetration curve parameter representing final market share of technology *TECH* if fuel price were always equal to the technology's cost effective price

If a 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:

$$TECHSHR_{T,SC,FUEL,TECH} = \left(1 - SPRSDEFF_{T,SC,FUEL,TECH}\right) * TECHSHR_{T,SC,FUEL,TECH} \quad \textbf{(220)}$$

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 price are tallied and combined to form a vector of "MPG Effects", which are used to augment the base fuel economy of new trucks of each size class and fuel type:

$$MPGEFF_{T,SC,FUEL} = \prod_{TECH=1}^{16} \left(1 + MPGINCR_{SC,FUEL,TECH} * TECHSHR_{T,SC,FUEL,TECH}\right) \quad \textbf{(221)}$$

where:

MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in year *T*
MPGINCR= Exogenous factor representing percent improvement in fuel economy due to each technology

Fuel economy of new medium and heavy trucks can finally be determined:

$$MPG_{T,SC,AGE=0,FUEL} = BASEMPG_{SC,FUEL} * MPGEFF_{T,SC,FUEL} \quad \textbf{(222)}$$

where:

BASEMPG = Fuel economy of new medium and heavy 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 per mile for trucks of each size class and fuel type:

$$FCOST_{T,SC,FUEL} = \frac{AVGPRC_{T,FUEL}}{MPG_{T,SC,FUEL}} * HTRATE \tag{223}$$

where:

FCOST = Fuel cost of driving a truck of fuel type *FUEL*, in dollars per mile
HTRATE = Heat rate of gasoline, in million Btu per gallon

The fuel cost of driving diesel trucks relative to AFVs is then calculated:

$$RCOST_{T,SC,FUEL} = 1 - \left[\frac{FCOST_{T,SC,FUEL}}{FCOST_{T,SC,FUEL=1}} - 1\right] * PRCDIFFVAR_{SC,FUEL} \tag{224}$$

where:

RCOST = Fuel cost per mile of diesel relative to LPG and CNG
PRCDIFFVAR = Exogenously determined parameter representing inherent variation in AFV market share due to difference in fuel prices

The market penetration curve parameters are determined during a user-specified trigger year:

$$COEFAFV_{SC,FUEL,FLT} = \frac{\ln(0.01)}{\left[\frac{CYCAFV_{SC,FUEL,FLT}}{2}\right]}$$

and **(225)**

$$MYRAFV_{SC,FUEL,FLT} = TRYRAFV_{SC,FUEL,FLT} + \frac{CYCAFV_{SC,FUEL,FLT}}{2}$$

where:

- *FLT* = Index referring to fleet type, where *FLT* = 1 refers to trucks in fleets of nine or less and *FLT* = 2 refers to trucks in fleets of ten or more
- COEFAFV = Endogenously determined logistic market penetration curve parameter
- CYCAFV = Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration
- MYRAFV = Logistic market penetration curve parameter representing "halfway point" to maximum market penetration
- TRYRAFV = Exogenously determined year in which each alternative fuel begins to increase in market share, due to EPACT or other factors

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

$$MPATH_{T,SC,FUEL,FLT} = RCOST_{T,SC,FUEL} * \left[BSHRF_{SC,FUEL,FLT} + \frac{ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT}}{1 + e^{COEFAFV_{SC,FUEL,FLT} \cdot (T - MYRAFV_{SC,FUEL,FLT})}} \right] \quad \textbf{(226)}$$

where:

- BSHRF = Base year (1997) market share of each fuel type
- ESHRF = Exogenously determined final market share of each fuel type

The share of diesel in conventional truck sales is forecast through a time-dependent exponential decay function based on historical data:

$$MPATH_{T,SC,FUEL=1,FLT} = BSHRF_{SC,FUEL,FLT} + \left[ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT} \right] * \left(1 - e^{CONSD_{SC,FLT} + COEFT_{SC,FLT} * T} \right) \quad \textbf{(227)}$$

where:

- CONSD = Exogenously determined market penetration curve parameter for diesel trucks
- COEFD = Exogenously determined market penetration curve parameter for diesel trucks

LPG and CNG trucks are already prominent in some sectors of the economy, most notably in the petroleum products sector. 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:

$$FSHR_{T,SEC,SC,FUEL=3,4,FLT} = \max \left[BSEC_{SEC,SC,FUEL,FLT} , MPATH_{T,SC,FUEL,FLT} \right] \quad \textbf{(228)}$$

where:

- BSEC = Exogenously determined base year (1997) share of alternative fuels in truck purchases

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:

$$FSHR_{T,SEC,SC,FUEL=1,FLT} = \left(1 - \sum_{FUEL=3}^{4} FSHR_{T,SEC,SC,FUEL,FLT} \right) * \left(\min \left[MPATH_{T,SC,FUEL,FLT} * BSECD_{SEC,SC,FLT} \, , \, 1 \right] \right) \quad \textbf{(229)}$$

where:

BSECD = Exogenously determined parameter representing tendency of each sector to purchase diesel trucks

The remainder of truck purchases are assumed to be gasoline:

$$FSHR_{T,SEC,SC,FUEL=2,FLT} = 1 - \sum_{FUEL=1,3,4} FSHR_{T,SEC,SC,FUEL,FLT} \quad \textbf{(230)}$$

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:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T-1,SEC,SC,AGE-1,FUEL,FLT} * \left(1 - SCRAP_{SC,AGE-1}\right) \quad \textbf{(231)}$$

where:

TRKSTK = Stock of trucks in year *T*
SCRAP = Exogenously determined factor which consists of the percentage of trucks of each age which are scrapped each year

A number of trucks are transferred in each year from fleets of ten or more to fleets of nine or less. Transfers of conventional trucks are based on exogenously determined transfer rates:

$$TRF1_{T,SEC,SC,AGE,FUEL} = TRFRATE_{SC,AGE} * TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} \quad \textbf{(232)}$$

where:

TRF1 = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks
TRFRATE = Exogenously determined parameter representing the percentage of trucks of each vintage to be transferred from fleets to non-fleets in each year

The transfer of alternative fuel trucks is somewhat more complicated. Alternative fuel trucks purchased by centrally refueled fleets might not be as easy to resell as conventional trucks, especially if LPG and CNG are not widely available at filling stations. For this reason, an additional routine is incorporated which, at the user's option, restricts the transfer of alternative fuel trucks from fleets to non-fleets. If this option is chosen, the share of LPG and CNG trucks in fleet transfers in each vintage cannot be greater than the share of each fuel in non-fleet purchases in each sector. In other words, if two percent of non-fleet trucks sold to Sector 3 in year *T* are fueled with LPG, no more than two percent of each vintage of fleet transfers can be LPG-fueled. Restricted AFV transfers are calculated as follows:

$$TRF2_{T,SEC,SC,AGE,FUEL=3,4} = FSHR_{T,SEC,SC,FUEL,FLT=1} * TRFRATE_{SC,AGE} * \sum_{FUEL=1}^{4} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} \quad \textbf{(233)}$$

where:

TRF2 = Number of trucks transferred from fleet to non-fleet populations, if the fuel mix of fleet transfers is exactly the same as the fuel mix of new non-fleet purchases

Actual fleet transfers are then defined as the unrestricted fleet transfers as calculated in *TRF1* for conventional trucks, and the minimum of unrestricted and restricted transfers for AFVs:

$$TRF_{T,SEC,SC,AGE,FUEL=1,2} = TRF1_{T,SEC,SC,AGE,FUEL,FLT}$$

$$and \quad \textbf{(234)}$$

$$TRF_{T,SEC,SC,AGE,FUEL=3,4} = \min\left[TRF1_{T,SEC,SC,AGE,FUEL}\ ,\ TRF2_{T,SEC,SC,AGE,FUEL}\right]$$

where:

TRF = Total number of trucks transferred from fleet to non-fleet populations

Fleet transfers do not automatically go to non-fleets in the same sector, but are allocated based on each sector's share of the total non-fleet truck population of each vintage of trucks:

$$TRFSHR_{T,SC,SEC} = \frac{\sum_{FUEL=1}^{4} \sum_{AGE=1}^{11} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}}{\sum_{FUEL=1}^{4} \sum_{AGE=1}^{11} \sum_{SEC=1}^{12} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}} \quad \textbf{(235)}$$

where:

TRFSHR = Share of fleet transfers which goes to each sector

The new existing population of trucks is simply the existing population (after scrappage) modified by fleet transfers:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} - TRF_{T,SEC,SC,AGE,FUEL}$$

and

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} + TRFSHR_{T,SEC,SC} * \sum_{SEC=1} TO12TRF_{T,SEC,SC,AGE,FUEL} \quad \textbf{(236)}$$

4. Calculate Purchases of New Trucks

Truck purchases are based on the operating characteristics of new and existing trucks, primarily the average annual vehicle mileage per truck, and on the demand for freight travel in the current year. Annual vehicle mileage determines the ability of the existing stock to meet the VMT demand. VMT per truck has increased steadily since the early 1970s, and is forecast as an index in which 1997 is equal to one. The index is defined as a time-dependent exponential decay function for each size class with exogenously determined parameters:

$$VMTTREND_{T,SC} = \frac{BSHRV_{SC} + \left(ESHRV_{SC} - BSHRV_{SC}\right) * \left(1 - e^{CONSV_{SC} + COEFV_{SC} \cdot T}\right)}{BSHRV_{SC} + \left(ESHRV_{SC} - BSHRV_{SC}\right) * \left(1 - e^{CONSV_{SC} + COEFV_{SC} \cdot 1992}\right)} \quad \textbf{(237)}$$

where:

VMTTREND = Index of average annual VMT per truck, where 1997 = 1
BSHRV = Exogenously determined VMT per vehicle increase factor representing minimum annual vehicle mileage
ESHRV = Exogenously determined VMT per vehicle increase factor representing maximum annual vehicle mileage
CONSV = Exogenously determined exponential VMT per vehicle increase factor
COEFV = Exogenously determined exponential VMT per vehicle increase factor

This index is multiplied by base year annual VMT to calculate VMT per truck in each year:

$$ANNVMT_{T,SEC,SC,AGE,FUEL} = ANNVMTBASE_{SEC,SC,AGE,FUEL} * VMTTREND_{T,SC} \quad \textbf{(238)}$$

where:

ANNVMT = Average annual VMT per vehicle by sector, size class, truck age and fuel type
ANNVMTBASE = Base year average annual VMT per vehicle by sector, size class, truck age and fuel type

Annual VMT per truck varies by sector, size class, truck age and fuel type, and is multiplied by the array of existing trucks to determine the VMT which can be provided by the current population of trucks in each sector:

$$VMTOLD_{T,SEC} = \sum_{FLT=1}^{2} \sum_{FUEL=1}^{16} \sum_{AGE=1}^{11} \sum_{SC=1}^{3} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} * ANNVMT_{SEC,SC,AGE,FUEL} \quad \textbf{(239)}$$

where:

VMTOLD = VMT which can be provided by existing stock of trucks in each sector, after scrappage

The next step is to calculate the demand for freight travel in each sector. Demand for freight travel is expressed in vehicle-miles traveled (assuming that load factors remain constant throughout the forecast period), and is calculated based on "freight adjustment coefficients", or FACs. FACs are intended to capture the relationship between growth in industrial output and demand for freight travel in each industrial sector. In keeping with the approach taken elsewhere in the NEMS Transportation Demand Sector Model, historical trends are moderated over time by means of a time-dependent exponential decay function. The current year FAC is calculated as follows:

$$COEFFAC = \ln\left[\frac{9}{T90 - T50}\right]$$

$$and$$

$$FACTR_{T,SEC} = FACBASE_{SEC} + \frac{1 - FACBASE_{SEC}}{1 + e^{COEFFAC * (T50 - T)}} \tag{240}$$

where:

COEFFAC = FAC decay parameter
T90 = User-specified year by which 90% of FAC decay is experienced
T50 = User-specified year by which 50% of FAC decay is experienced
FACTR = "Freight Adjustment Coefficient": factor relating growth in value added of sector *SEC* to growth in demand for freight truck VMT
FACBASE = Base year Freight Adjustment Coefficient

Freight adjustment coefficients, and the user-specified decay parameters, have a substantial impact on total truck VMT and hence on fuel consumption. The fifty and ninety percent years are currently set to 2002 and 2007, respectively; these can be easily modified by the user to reflect differing assumptions about the relationship between economic growth and truck VMT over time.

FACs are then used to calculate the actual VMT demand in each sector. The VMT demand in each year affects both the size of the truck stock and the number of miles driven by each truck in that year, and is calculated as follows:

$$For\ T = 0$$

$$VMTDMD_{T,SEC} = VMTDMDBASE_{SEC} * FACTR_{SEC} * \frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}}$$

$$For\ T = 1-22 \tag{241}$$

$$VMTDMD_{T,SEC} = VMTDMD_{T-1,SEC} * FACTR_{SEC} * \frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}}$$

where:

VMTDMD = Demand for freight travel by sector *SEC*, in year *T*
VMTDMDBASE = Demand for freight travel by sector *SEC*, in year 0
FACTR = "Freight Adjustment Coefficient": exogenously determined factor relating growth in value added of sector *SEC* to growth in demand for freight truck VMT

Truck purchases are based not on the actual VMT demand for a given year, for this cannot be known in advance by the decision-makers, but on the level of demand which is expected to occur at the time the trucks are delivered. Since industry practice is to order trucks six months in advance[14], the purchasing period for trucks delivered in year *T* extends from July 1 of year *T*-1 to June 30 of year *T*. Purchase orders are placed based on the expected freight shipping orders six months later. Expected shipping orders are based on two factors: the level of demand currently being experienced, or the perceived baseline demand, and the expected growth rate of VMT demand over the next six months.

The predicted growth in VMT demand can be defined as the growth experienced during the previous six months. On July 1 of year *T*-1, the predicted growth rate is simply the growth rate for year *T*-1, while on June 30 of year *T*, the predicted growth rate is the growth rate for year *T*. Assuming that truck ordering takes place continuously throughout the year, the predicted growth rate can be calculated as follows:

$$PVMTGROWTH_{T,SEC} = 0.5 * \left[\frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}} - 1 \right] + 0.5 * \left[\frac{OUTPUT_{T-1,SEC}}{OUTPUT_{T-2,SEC}} - 1 \right] \qquad \textbf{(242)}$$

where:

PVMTGROWTH = Growth rate with which perceived demand for freight travel in year *T* is forecast by freight companies

The perceived baseline demand is defined to be the level of VMT demand which has been experienced in the year prior to the purchasing period, and is estimated as follows:

$$For\ T = 0$$

$$PVMTBASE_{T,SC} = 0.5 * VMTDMDBASE_{SEC}$$

$$\textbf{(243)}$$

$$For\ T = 1-22$$

$$PVMTBASE_{T,SC} = 0.5 * VMTDMD_{T,SEC} + 0.25 * VMTDMD_{T-1,SEC}$$

where:

---

[14] Personal conversation with Donnie Hatcher of McClendon Trucking, Lafayette ,Alabama.

PVMTBASE = Baseline from which perceived demand for freight travel in year T is calculated.

Assuming that only the perceived baseline demand from previous needs to be "brought forward" into the current year, the VMT demand perceived by freight companies can be estimated as follows:

$$PVMTBASE_{T,SEC} = 0.5 * VMTDMT_{T-1,SEC} + 0.25 * VMTDMD_{T-2,SEC}$$

$$and$$

$$PVMTDMD_{T,SEC} = 0.25 * VMTDMD_{T,SEC} + PVMTBASE_{T,SEC} * \left(1 + PVMTGROWTH_{T,SEC}\right) * FACTR_{SEC} \quad \textbf{(244)}$$

where:

PVMTBASE = Baseline from which perceived demand for freight travel in year T is forecast by freight companies
PVMTDMD = Perceived demand for freight travel in year T

The difference between perceived VMT demand and VMT provided by the surviving stock of trucks constitutes the perceived unmet VMT demand, which is provided by purchasing new trucks:

$$PVMTUNMET_{T,SEC} = PVMTDMT_{T,SEC} - VMTOLD_{T,SEC} \quad \textbf{(245)}$$

where:

PVMTUNMET = Difference between perceived VMT demand and demand which can be met by existing stock of trucks

Unmet VMT demand is next allocated among size classes and fleet types by means of constant size class and fleet type allocation factors. Size class allocation factors determine truck purchases by size class, while fleet allocation factors represent the share of new trucks accounted for by fleets in each sector. The calculation is as follows:

$$PVMT_{T,SEC,SC,FLT=1} = MAX\left[PVMTUNMET_{T,SEC} * VMTSCFAC_{SEC,SC} * \left(1 - FLTSHR_{SEC,SC}\right), 0\right]$$

$$and \quad \textbf{(246)}$$

$$PVMT_{T,SEC,SC,FLT=2} = MAX\left[PVMTUNMET_{T,SEC} * VMTSCFAC_{SEC,SC} * FLTSHR_{SEC,SC}, 0\right]$$

where:

PVMT = Perceived demand for freight travel by new trucks of size class SC and fleet type FLT in sector SEC
VMTSCFAC = Exogenously determined parameter representing percentage of new truck sales which go to each size class SC in sector SEC
FLTSHR = Exogenous parameter representing percentage of new truck sales of each size class SC which go to fleets of ten or more in sector SEC

Market shares and VMT per vehicle for trucks of each fuel technology have been calculated above;

these are used to calculate a fuel technology-weighted average annual VMT per vehicle of the current year's class of new fleet and non-fleet trucks:

$$PVN_{T,SEC,SC,FLT} = \sum_{FUEL=1}^{4} FSHR_{T,SEC,SC,FUEL,FLT} * ANNVMT_{T,SEC,SC,AGE=0,FUEL} \quad \textbf{(247)}$$

where:

AGE = 0 refers to new trucks
PVN = Annual VMT per vehicle for new trucks in year T

Truck purchases are finally calculated as the perceived unmet VMT demand divided by VMT per truck, weighted by fuel type:

$$TRKSTK_{T,SEC,SC,AGE=0,FUEL,FLT} = \left[\frac{PVMT_{T,SEC,SC,FLT}}{PVN_{T,SEC,SC,FLT}}\right] * FSHR_{T,SEC,SC,FUEL,FLT} \quad \textbf{(248)}$$

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 in each NEMS Industrial Sector and divides by fuel economy to determine fuel consumption. Since truck purchases are based on the perceived unmet VMT, and not actual VMT demand, there may be excess VMT demand which is not currently being met by the existing or new trucks (there may also be a surplus of trucks in comparison to the actual VMT demand in a given year). Actual VMT demand must therefore be allocated among truck types:

$$VMT_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} * ANNVMT_{T,SEC,SC,AGE,FUEL} * \left[\frac{\sum_{SEC=1}^{12} VMTDMD_{T,SEC}}{\sum_{SEC=1}^{12} PVMTDMD_{T,SEC}}\right] \quad \textbf{(249)}$$

where:

VMT = Actual VMT by trucks of each type in year T

Freight truck fuel economy is dependent on the "fuel economy degradation factor", which converts EPA-rated fuel economy into on-road values, accounting for increased traffic congestion and other factors. This function is currently disabled, but can easily be utilized. The fuel economy degradation factor is calculated in the LDV Module and modified by the FTSAM based on the simplifying assumption that all of the fuel economy degradation occurs because of worsening driving conditions in congested urban areas. The light-duty vehicle degradation calculated in FEM is thus reduced to reflect the higher percentage of highway miles driven by freight trucks:

$$MPGDEGFAC_{T,SC} = \frac{1 - \left[\left(1 - MPGDEGFAC_{T,LDV}\right) * \frac{URBANSHR_{SC}}{URBSHRLDV}\right]}{1 - \left[\left(1 - MPGDEGFAC_{T=0,LDV}\right) * \frac{URBANSHR_{SC}}{URBSHRLDV}\right]} \quad \textbf{(250)}$$

where:

$MPGDEGFAC_{LDV}$ = Fuel economy degradation factor, from LDV Module
MPGDEGFAC = Fuel economy degradation factor for freight trucks
URBANSHR = % of miles driven in urban areas by trucks of each size class in base year (1997)
URBSHRLDV = % of miles driven in urban areas by LDVs in base year (1997)

EPA does not rate heavy-duty trucks for fuel economy. Because historical values for medium and heavy trucks reflect on-road fuel economies, the fuel economy degradation factor must be indexed so that the value in 1997 is equal to one.

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

$$FUEL_{T,SEC,SC,AGE,FUEL,FLT} = \frac{VMT_{T,SEC,SC,AGE,FUEL,FLT}}{MPG_{T,SEC,SC,AGE,FUEL} * MPGDEGFAC_{T,SC}} \quad \textbf{(251)}$$

where:

FUEL = Total freight truck fuel consumption by sector, size class and fuel type in year *T*, in gallons of gasoline equivalent
$MPGDEGFAC_{T,SC}$ = Fuel economy degradation factor, overwritten in the code by 0.99.

Converting from gasoline equivalent to trillion Btu is a trivial application of the heat rate of gasoline:

$$TRIL_{T,SEC,SC,FUEL,FLT} = \sum_{AGE=0}^{11} FUEL_{T,SEC,SC,AGE,FUEL,FLT} * HTRATE * 10^{-6} \quad \textbf{(252)}$$

where:

TRIL = Total fleet truck fuel consumption by sector, size class and fuel type in year *T*, in trillion Btu

6. Roll Truck Population and Fuel Economy

The final stage prepares the model for the next year by calculating new fuel economies of trucks which are ten years old or older:

$$MPG_{T+1,SC,SGE=10,FUEL} = \frac{\sum_{FLT=1}^{2}\sum_{AGE=10}^{11}\sum_{SEC=1}^{12} VMT_{T,SEC,SC,AGE,FUEL,FLT}}{\sum_{FLT=1}^{2}\sum_{AGE=10}^{11}\sum_{SEC=1}^{12} FUEL_{T,SEC,SC,AGE,FUEL,FLT}} \quad \textbf{(253)}$$

where:

- *AGE* = 10 refers to trucks in the tenth vintage, i.e., trucks which are ten years old during model run year *t*
- *AGE* = 11 refers to trucks in the eleventh vintage, i.e., trucks which are eleven years old or older during model run year *t*
- *T+1* = refers to the next model run year

The last two vintages of trucks are finally collapsed into one:

$$TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} + TRKSTK_{T,SEC,SC,AGE=11,FUEL,FLT} \quad \textbf{(254)}$$

This model is a disaggregate, policy-sensitive approach to the forecasting of freight truck energy demand. It represents a substantial improvement over the current model for a number of reasons, the foremost being that vehicle stock and purchases are considered for the first time. This allows the user to test policies which might affect the penetration of alternative fuels or future fuel-saving technologies into the heavy-duty vehicle market. Additional factors considered for the first time include the number and composition of trucks in fleets of ten or more, historical and future market trends of existing fuel-saving technologies, historical trends toward higher vehicle utilization rates, and the effect on truck fuel economy of worsening driving conditions.

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:

$$COALT_T = \sum_{IR=1}^{2} COALP_{T,IR} * t\ COALD(ST,IR) \qquad \textbf{(255)}$$

where: COALT = Total ton-miles traveled for coal in region IR (east/west) in year *T*
COALP = The production of coal in region IR in year T in tons
COALD =Distance coal has to travel in region IR in step year ST.

$$RTMT_T = \sum_{I=1}^{10} RTMT_{I,T_0} * FACR_I * \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_0}}\right] \qquad \textbf{(256)}$$

where:
RTMT = Total rail ton-miles traveled for industry *I* in year *T*
OUTPUT = Value of output of industry *I*, in base year dollars
FACR = Coefficient relating growth of value added with growth of rail transport

$$RTMT_{10,T} = (.1 * RTMT_{10,T}) + \left(.9 * RTMT_{10,T_0} * \frac{COALT_{I,T}}{COALT_{I,T_0}}\right) \qquad \textbf{(257)}$$

$$RTMT_T = \sum_{I=1}^{10} RTMT_{I,T} \qquad \textbf{(258)}$$

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

$$TQRAILT_T = FERAIL_T * RTMT_T \qquad \textbf{(259)}$$

where:
TQRAILT = Total energy consumption by freight trains
FERAIL = 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:

$$TQRAIL_{FUEL,T} = TQRAIL_{FUEL,T-1} * \left(\frac{TQRAILT_T}{TQRAILT_{T-1}} \right) \quad \textbf{(260)}$$

where:

$TQRAIL_{FUEL,T}$ = Total demand for each fuel by rail freight sector in year T

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:

$$TQRAILR_{TECH,R,T} = TQRAIL_{C,TECH,T} * SEDSHRDS_{C,TECH,T} \quad \textbf{(261)}$$

where:

$TQRAILR_{TECH,T}$ = Total regional fuel consumption for each technology

$SEDSHRDS_{TECH,T}$ = Regional share of rail freight fuel consumption, from SEDS

Calculate fractional change in rail travel and fuel efficiency:

$$XRAIL_T = \frac{RTMTT_T}{RTMTT_{T=1}}$$

and **(262)**

$$XRAILEFF_T = \frac{FERAIL_{T=1}}{FERAIL_T}$$

where:

XRAIL = Growth in rail travel from base year

XRAILEFF = Growth in rail efficiency from base year

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.

<u>Domestic Marine</u>

Once again, the estimation of total domestic waterborne travel demand is driven by forecasts of industrial output:

$$STMTT_T = \sum_{I=1}^{10} STMT_{I,T_D} * FACS_I * \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_D}}\right] \quad \textbf{(263)}$$

where:

STMT = Total ton-miles of waterborne freight for industry *I* in year *T*
OUTPUT = Value of output of industry *I*, in base year dollars
FACS = Coefficient relating growth of value added with growth of shipping transport
T_D = Year of most recent data update

This total is subsequently shared out among classes of domestic freighter:

$$STMT_{C,T} = TS_{C,T} * STMT_T \quad \textbf{(264)}$$

where:

TS = Travel share allocated to vessels in class *C*

Travel shares are considered constant, and allocated according to the most recent data:

$$TS_C = \frac{STMT_C}{STMT_{Total}} \quad \textbf{(265)}$$

At present, only one class of domestic waterborne transport is considered, but as further research is conducted, a greater level of detail may be justified.

Fuel use is subsequently estimated, using the average energy efficiency for each class of freighter (currently one class):

$$SFDT_T = FESHIP_T * STMT_T \quad \textbf{(266)}$$

where:

SFDT = Domestic ship energy demand

FESHIP = Average fuel efficiency

Estimated changes in energy intensity will be developed exogenously. The next step is to allocate total energy consumption among three fuel types (distillate fuel, residual fuel oil and gasoline):

$$SFD_{IF,T} = SFDT_{T} * SFSHARE_{IF,T} \tag{267}$$

where:

SFD = Domestic ship energy demand, by fuel
SFSHARE = Domestic shipping fuel allocation factor
IF = Index referring to shipping fuel type

The factor which allocates energy consumption among the three fuel types is based on 1998 data and is held constant throughout the run period[15].

$$TQSHIPR_{IF,REG,T} = SFD_{IF,T} * SEDSHR_{IF,REG,T} \tag{268}$$

Total energy demand is then regionalized:

where:

TQSHIPR = Total regional energy demand by domestic freighters
SEDSHR = Regional shares of fuel demand, from SEDS

Although only one class of vessel is considered at the present time, the model was designed to allow further stratification should more detailed data become available.

Calculate fractional change in domestic ship travel and fuel efficiency:

$$XSHIP_{T} = \frac{STMTT_{T}}{STMTT_{T=1}}$$

and **(269)**

$$XSHIPEFF_{T} = \frac{FESHIP_{T}}{FESHIP_{T=1}}$$

where:

XSHIP = Growth in ship travel from base year
XSHIPEFF = Growth in ship efficiency from base year

[15]Oak Rige National Laborartory, Center for Transportation Analysis, Transportation Energy Data Book Edition 20, October 2000, Oak Ridge, TN, Table 2.5.

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:

$$ISFDT_T = ISFDT_{T-1} + \left[\frac{GROSST_T}{GROSST_{T-1}} - 1 \right] * O.5 * ISFDT_{T-1} \qquad \textbf{(270)}$$

where:

ISFDT = Total international shipping energy demand in year *T*
GROSST = Value of Gross Trade (imports + exports), from Macro Model

Total energy demand is then allocated among the various fuels as above:

$$ISFD_{IF,T} = ISFDT_T * ISFSHARE_{IF,T} \qquad \textbf{(271)}$$

where:

ISFD = International freighter energy demand, by fuel
ISFSHARE = International shipping fuel allocation factor

Regional fuel consumption is then calculated:

$$TQISHIPR_{IF,IR,T} = ISFD_{IF,T} * SEDSHR_{IF,IR,T} \qquad \textbf{(272)}$$

where:

TQISHIPR = Total regional energy demand by international freighters
SEDSHR = Regional shares of fuel demand, from SEDS

Figure 3E-2. Highway Freight Model

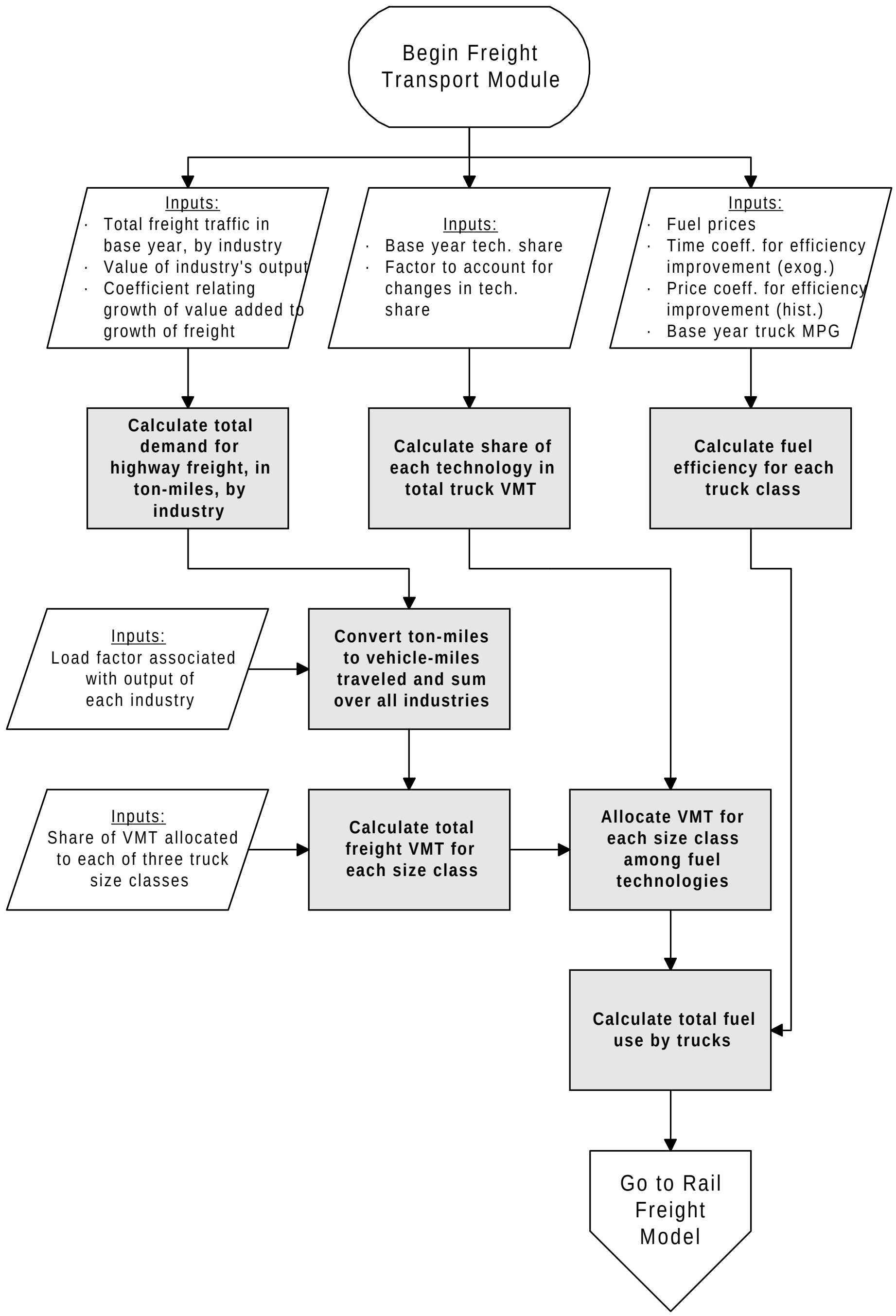


Figure 3E-3. Rail Freight Model

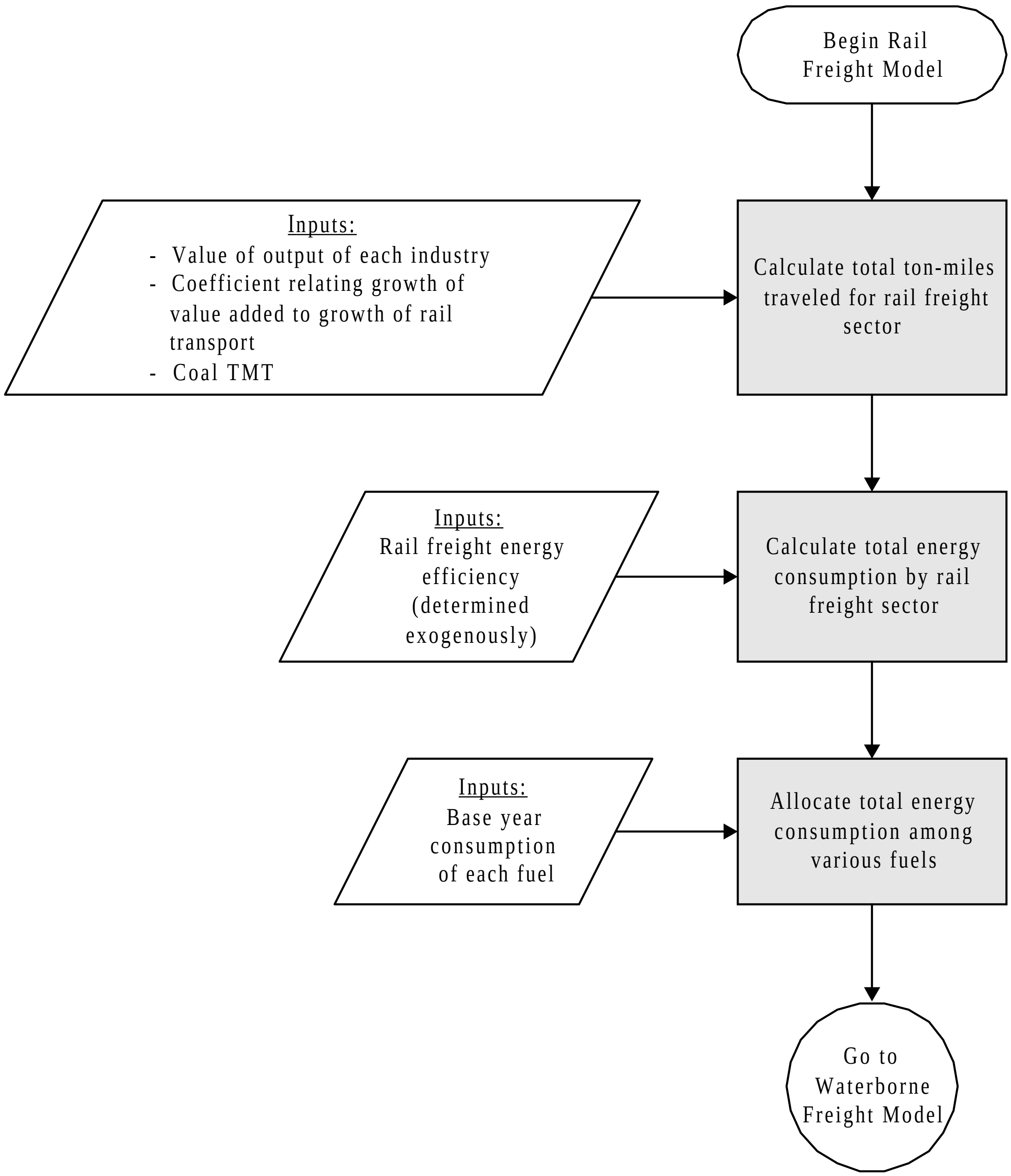
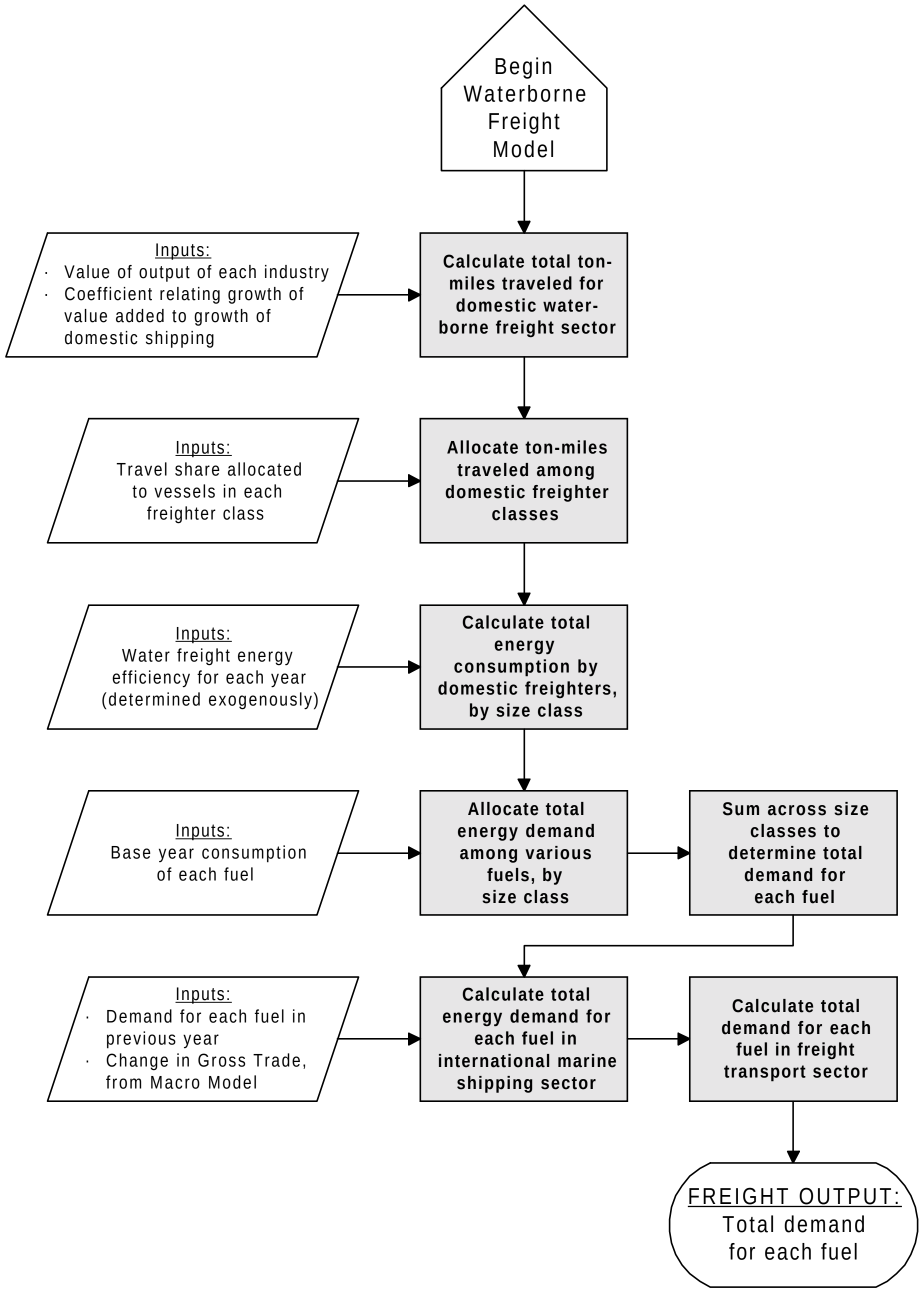


Figure 3E-4. Waterborne Freight Model



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.

MODEL STRUCTURE

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:

$$MILTARGR_T = \frac{TMC\_GFML_T}{TMC\_GFML_{T-1}} \quad \textbf{(273)}$$

where:

MILTARGR = The growth in the military budget from the previous year
TMC_GFML = Total defense budget in year T, from the macro economic segment of NEMS

Total consumption of each of four fuel types is then determined:

$$MFD_{IF,T} = MFD_{IF,T-1} * MILTARGR_T \quad \textbf{(274)}$$

where:

MFD = Total military consumption of the considered fuel in year T
IF = Index of fuel type: 1=Distillate, 2=Jet Fuel(Naptha), 3=Residual, 4=Jet Fuel(Kerosene)

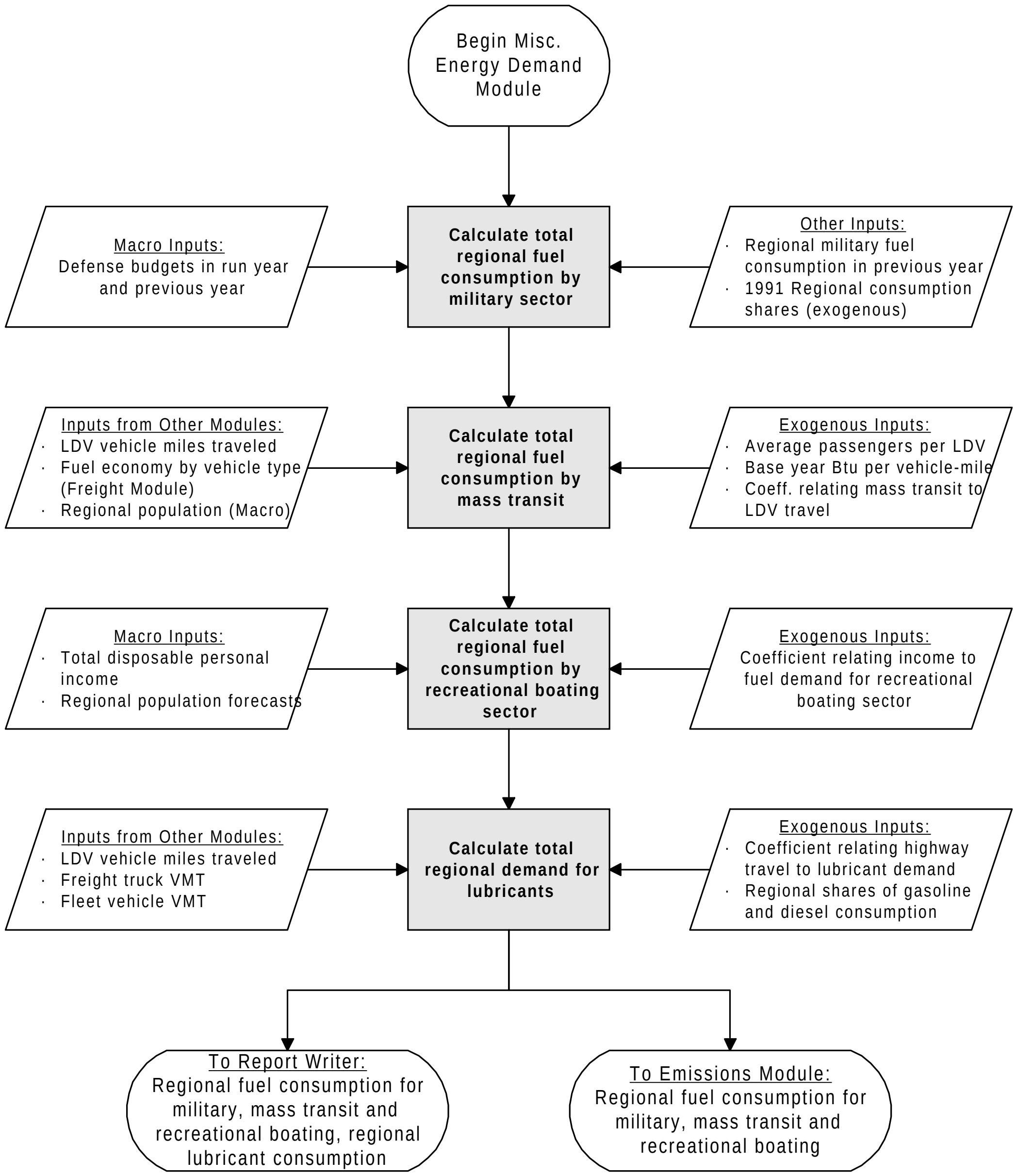
Consumption is finally distributed among the nine census regions:

$$QMILTR_{IF,REG,T} = MFD_{IF,T} * MILTRSHR_{IF,REG} \quad \textbf{(275)}$$

where:

QMILTR = Regional fuel consumption, by fuel type, in Btu
MILTRSHR = Regional consumption shares, from 1991 data, held constant

Figure 3F-1. Miscellaneous Energy Demand Module



Note: the emissions model is currently inactive

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:

$$TMOD_{1,T} = VMTEE_{T}$$

and:

$$TMOD_{IM,T} = TMOD_{IM,T-1} * \left[\frac{TMOD_{1,T}}{TMOD_{1,T-1}} \right]^{BETAMS} \tag{276}$$

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:

$$TMEFF_{IM,T} = \left[TMEFF_{IM,T-1} * \left(\frac{FMPG_{TYPE,T}}{FMPG_{TYPE,T-1}} \right) \right] \tag{277}$$

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:

$$QMODR_{IM,IR,T} = TMOD_{IM,T} * TMEFF_{IM,T} * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \tag{278}$$

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:

$$RECFD_T = RECFD_{T-1} * \left[\frac{TMC\_YD_T}{TMC\_YD_{T-1}}\right]^{BETAREC} \qquad \textbf{(279)}$$

where:

RECFD = National recreational boat gasoline consumption in year T
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:

$$QRECR_{IR,T} = RECFD_T * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}}\right] \qquad \textbf{(280)}$$

where:

QRECR = Regional fuel consumption by recreational boats in year T

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:

$$HYWAY_T = VMTEE_T + FTVMT_T + FLTVMT_T \qquad \textbf{(281)}$$

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:

$$LUBFD_T = LUBFD_{T-1} * \left[\frac{HYWAY_T}{HYWAY_{T-1}}\right]^{BETALUB} \qquad \textbf{(282)}$$

where:

LUBFD = Total demand for lubricants in year T
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:

$$QLUBR_{IR,T} = LUBFD_T * \left[\frac{\left(\left(VMTEE_T + FLTVMT_T\right) * SHRMG_{IR,T}\right) + \left(FTVMT_T * SHRDS_{IR,T}\right)}{HYWAY_T} \right] \quad \textbf{(283)}$$

where:

QLUBR = Regional demand for lubricants in year T, 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

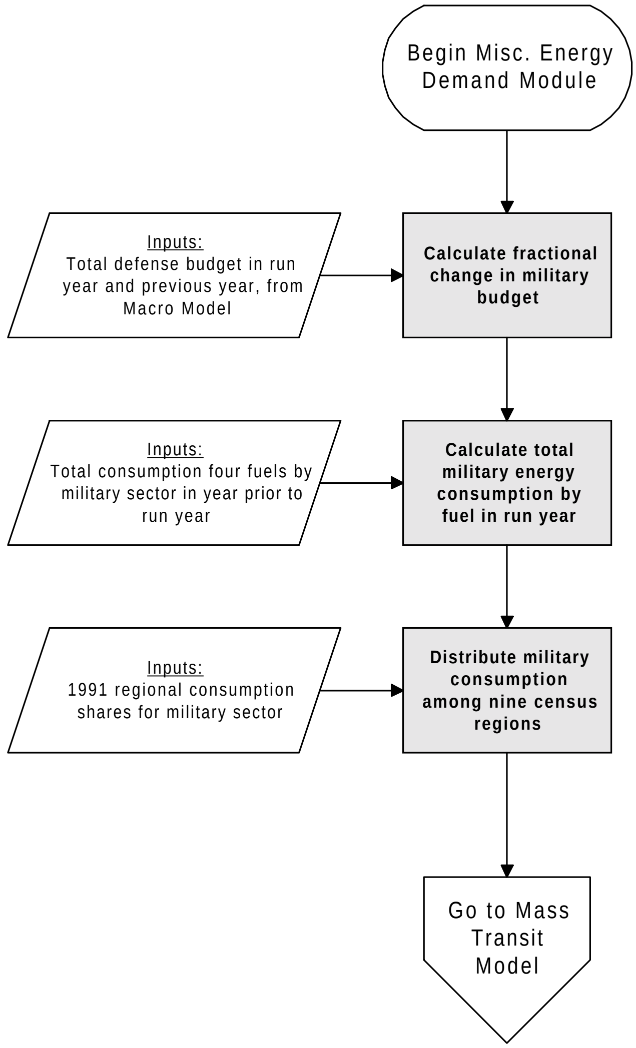


Figure 3F-3. Mass Transit Demand Model

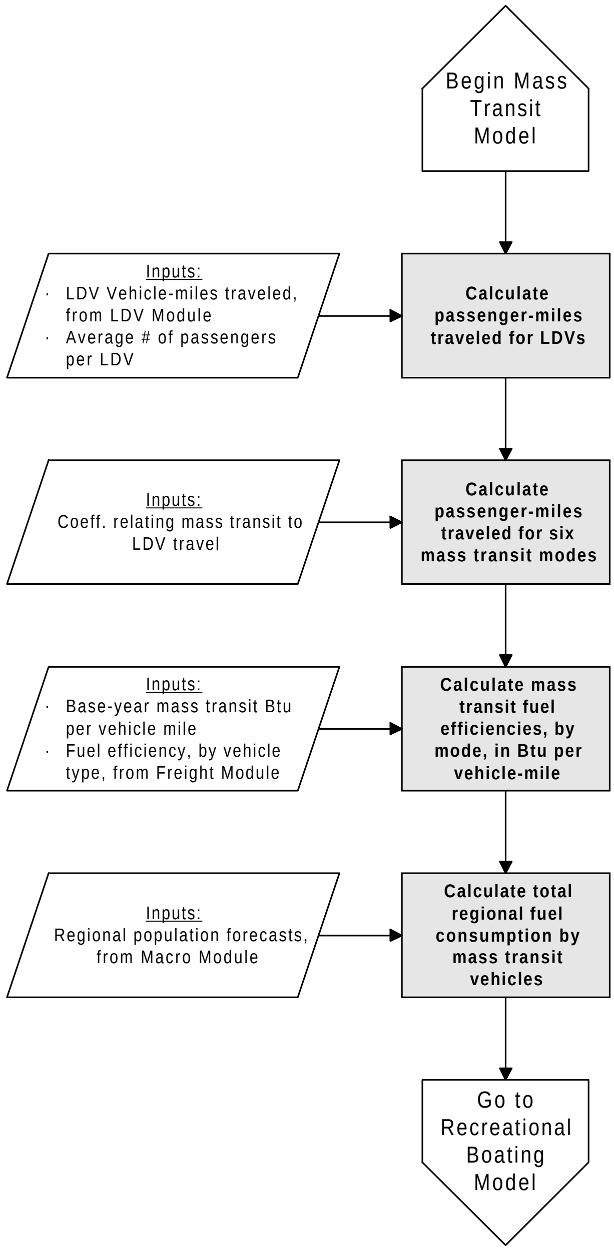


Figure 3F-4. Recreational Boating Demand Model

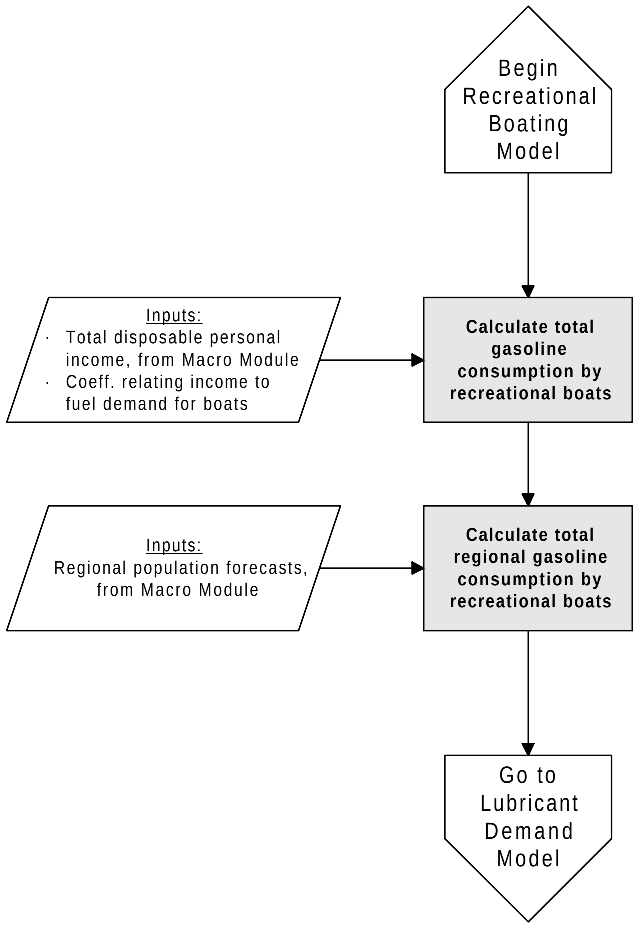


Figure 3F-5. Lubricant Demand Model