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**The Transportation Sector Model
of the National Energy Modeling System**

Model Documentation Report

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Update Information

This is the 10th edition of the *Model Documentation Report: Transportation Sector Demand Model of the National Energy Modeling System (NEMS)*. It reflects changes made to the module over the past year for the *Annual Energy Outlook 2005*. These changes include:

- Update historical fuel economy data and calibrate Fuel Economy Model for Corporate Average Fuel Economy (CAFE) compliance.
- Update cost and efficiency values for advanced subsystem technologies.
- Estimate new light-duty vehicle (LDV) travel demand equation using new population and income data.
- Collect data to update passenger aircraft sales and stocks, that includes the characteristics of 1) advanced technologies currently considered for use in aircraft, and 2) the use of cargo aircraft.
- Develop new algorithm that examines the demand and supply of passenger aircraft.
- Revise Seat Miles Demanded algorithms, by gathering data, performing regressions, and obtaining new coefficients.

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1. INTRODUCTION

Statement of Purpose

This report documents the objectives, analytical approach and development of the NEMS Transportation Model. 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 the NEMS Transportation Model for model analysts, users, and the public. Second, this report meets the legal requirements of the Energy Information Administration (EIA) to provide adequate documentation in support of its statistical and forecast reports (*Public Law 93-275, § 57(b)(1)*). Third, it permits continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements.

1A. Model Summary

The NEMS Transportation Model comprises a series of semi-independent models that 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 motor gasoline, distillate, jet fuel, and alternative fuels (such as compressed natural gas [CNG]) that are not commonly associated with transportation. The current NEMS forecast horizon extends to the year 2025 and uses 1995 as the start year. Forecasts are generated through separate consideration of energy consumption within the various modes of transport, including: private and fleet light-duty vehicles; aircraft; marine, rail, and truck freight; and various modes with minor overall impacts, such as mass transit and recreational boating. This approach is useful in assessing the impacts of policy initiatives, legislative mandates that affect individual modes of travel, and technological developments.

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

1B. Model Structure

The NEMS Transportation Model consists of six modules developed to represent a variety of travel modes that are very different in design and utilization, save for their intended purpose of conveying passengers and/or freight. The six modules include: 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 submodule, 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 that is designed to estimate criteria emissions from the transportation sector. The components of the six active modules are briefly described in turn below.

1B-1. LDV Module

The LDV Module is the most extensive of the modules in the Transportation Model, owing to the overwhelming choice of technology and make and models in car 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 submodules.

Manufacturers Technology Choice Module (MTCM)

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

Regional Sales Module

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

Consumer Vehicle Choice Module (CVCM)

The CVCM uses estimates of new car fuel efficiency, obtained from the MTCM, 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 module is useful both to assess the penetration of alternative fuel vehicles and to allow analysis of policies that might impact this penetration.

LDV Stock Accounting Module

The LDV Stock Accounting Module 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) Module

The VMT Module is the travel demand component of the LDV Stock Module that 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 LDV Fleet Module generates estimates of the stock of cars and light trucks used in business, government, and utility fleets. The module also estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined vintages.

1B-2. Air Travel Module

The air travel component of the NEMS Transportation Model comprises two separate submodules: the Air Travel Demand Module and the Aircraft Fleet Efficiency Module. These modules 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 Module

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

Aircraft Fleet Efficiency Module (AFEM)

The AFEM is a structured accounting mechanism that, subject to user-specified parameters, provides estimates of the number of narrow- and wide-body aircraft, and regional jets required to meet the demand generated in the preceding module. This module also estimates aircraft fleet efficiency using a weighted average of the characteristics of surviving aircraft and those acquired to meet demand.

1B-3. Freight Transport Module

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

1B-4. Miscellaneous Energy Use Module

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

1C. Model Archival Citation

Archived as part of the NEMS production runs for the *Annual Energy Outlook 2005 (AEO2005)*.

1D. Report Organization

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

2. MODEL PURPOSE AND SCOPE

2A. Objectives

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

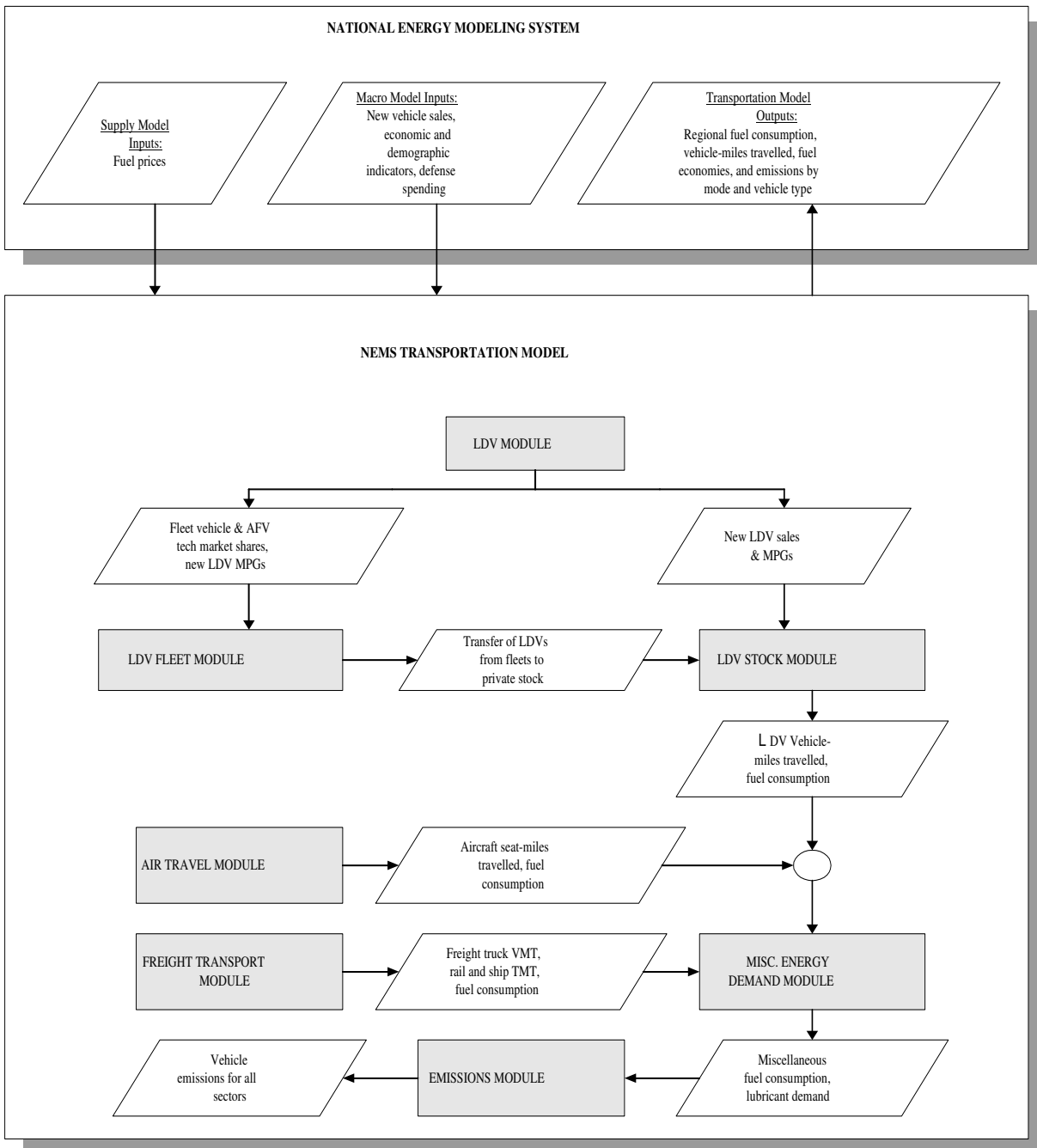
2B. Model Overview

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

The first module executed is the LDV Module, which addresses the characteristics of new cars and light trucks. This module comprises a series of submodules that 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 module that 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 module to determine the size and characteristics of the

Figure 1. NEMS and the NEMS Transportation Sector Model



Note: the emissions module is currently inactive.

aircraft fleet required to meet that demand. The output of this module also includes an estimate of the demand for jet fuel and aviation gasoline, which is subsequently passed to the Miscellaneous Energy Use Module. The Freight Transport Module uses NEMS forecasts of real fuel prices, trade indices, and selected industries' output to estimate travel demand and energy consumption in each of three primary freight modes: truck, rail, and marine. Travel and fuel demand estimates are subsequently passed to the Miscellaneous Energy Use Module.

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

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

2C. Input and Output

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

A large number of data inputs exogenous to NEMS are supplied to the Transportation Model 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.

The Light Duty Vehicle Module requires the largest number of exogenous inputs. In the MTCM, these inputs include the characteristics of the automotive technologies considered, such as their effects on vehicle horsepower, weight, fuel efficiency, and price. Vehicle characteristics in the CVCM are similarly obtained, with vehicle price, range, emissions levels, and relative

efficiency being read in from an external data file.

Table 1. Inputs to the Transportation Model from Other NEMS Models

NEMS Macro Model: Economic and Demographic Indicators	NEMS Supply Models: Prices		
	Natural Gas Transmission and Distribution	Petroleum Marketing	Electricity Market
<ul style="list-style-type: none"> ● Merchandise Exports ● Gross Domestic Product (GDP) ● GDP Deflator ● Disposable Income ● U.S. Population ● U.S. Population over 16 ● Industrial Output by SIC Code ● Defense Spending 	<ul style="list-style-type: none"> ● CNG 	<ul style="list-style-type: none"> ● Motor Gasoline ● Distillate ● Residual Fuel Oil ● Methanol ● Ethanol ● LPG ● Jet Fuel ● Aviation Gasoline 	<ul style="list-style-type: none"> ● Electricity

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 that determine the average number of available seat-miles each plane will supply in a year. The Freight Module receives exogenous estimates of freight intensity, modal shares, and characteristics of the considered technologies.

Each submodule performs calculations at a level of disaggregation commensurate with the nature of the mode of transport, the quality of the input data and the level of detail required in the output. For example, the MTCM and the CVCMM Modules address twelve size classes (six for both car and light truck). The Transportation Model maps the output of each submodule into variables of the appropriate dimension for use in subsequent steps.

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. Within NEMS, the Transportation Model 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 submodules in the Transportation

Model on these economic and price inputs is made clear in the detailed model specifications in the following section.

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 complete presentation of the Transportation Model, these modules and key submodules are discussed separately in the following.

This section describes the general theoretical approach taken in the model, the assumptions that were incorporated, and the methodology employed. The key computations and equations in 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 the Transportation Model, 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 the 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 MTCM, the Regional Sales Module, and the CVCM. Due to the differing methodological approaches and data requirements, each section is presented individually.

3A-1. Manufacturers Technology Choice Module¹

The MTCM is a subcomponent of the LDV segment of the NEMS Transportation Model. MTCM produces estimates of new light duty vehicle fuel efficiency that are then used as inputs to other components of the Transportation Model.

The MTCM 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 module addresses the commercial viability of up to sixty-three separate technologies within each of twelve vehicle market classes (six car and six light truck), four CAFE groups, and fifteen fuel types. The six car market classes include five classes based on passenger plus cargo volume; including Minicompact (volume < 85 cubic ft), Subcompact (volume between 85 and 99 cubic ft), Compact (volume between 100 and 109 cubic ft), Midsize (volume between 110 and 119 cubic ft), Large (volume > 120 cubic ft), and Two-seaters (all cars with two seats). Station wagons fall into the same class as the sedan of the same make. For instance, the Ford Taurus station wagon is in the large car class, similar to the Ford Taurus sedan. The six classes of light truck are based mainly on utility and inertia weight and include compact and standard vans, pickups, and utility vehicles. The four groups for which CAFE standards are set are: Domestic Cars, Import Cars, Domestic Trucks, and Import Trucks.

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

- 1) Technological characteristics of a vehicle
- 2) Level of acceleration performance of a vehicle
- 3) Mix of vehicle classes sold
- 4) Vehicle safety and emission standards.

To forecast technological change, the entire fleet of new cars and light duty trucks are disaggregated into twelve market classes that are relatively homogenous in terms of consumer perceived attributes such as size, price and utility. Technological improvements to each of these market classes are then forecast based on the availability of new technologies to improve fuel economy as well as their cost effectiveness under two user-specified alternative scenarios. The central assumptions involved in this technological forecast are as follows:

¹ U.S. Department of Energy, Energy Information Administration, Updates to the MTCM, provided by Energy and Environmental Analysis, 2001.

1. All manufacturers can obtain the same benefits from a given technology, provided they have adequate lead time (i.e., no technology is proprietary to a given manufacturer in the long term).
2. Manufacturers will generally adopt technological improvements that are perceived as cost-effective to the consumer, even without any regulatory pressure. However, the term cost-effective 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 module are able to specify one of two scenarios under which these forecasts are made. The first, identified as the "Standard Technology Scenario", permits the consideration of sixty-three automotive technologies whose availability and cost-effectiveness are either well documented or conservatively estimated. The second, identified as the "High Technology Scenario", modifies selected characteristics of the original matrix to render a more optimistic assessment of the cost and availability of technological improvements. Based on the technological improvements adopted, a fuel economy forecast is developed for each of the market classes.

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

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

The module also allows specification of CAFE standards by year, and of different standards for domestic and import vehicles, as well as the penalty (in dollars) per car per mile per gallon below

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

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 module 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 module allows companies to choose non-compliance as a cost-minimizing strategy, as may occur if penalties are set at unrealistic levels relative to the difficulty of achieving the CAFE standards.

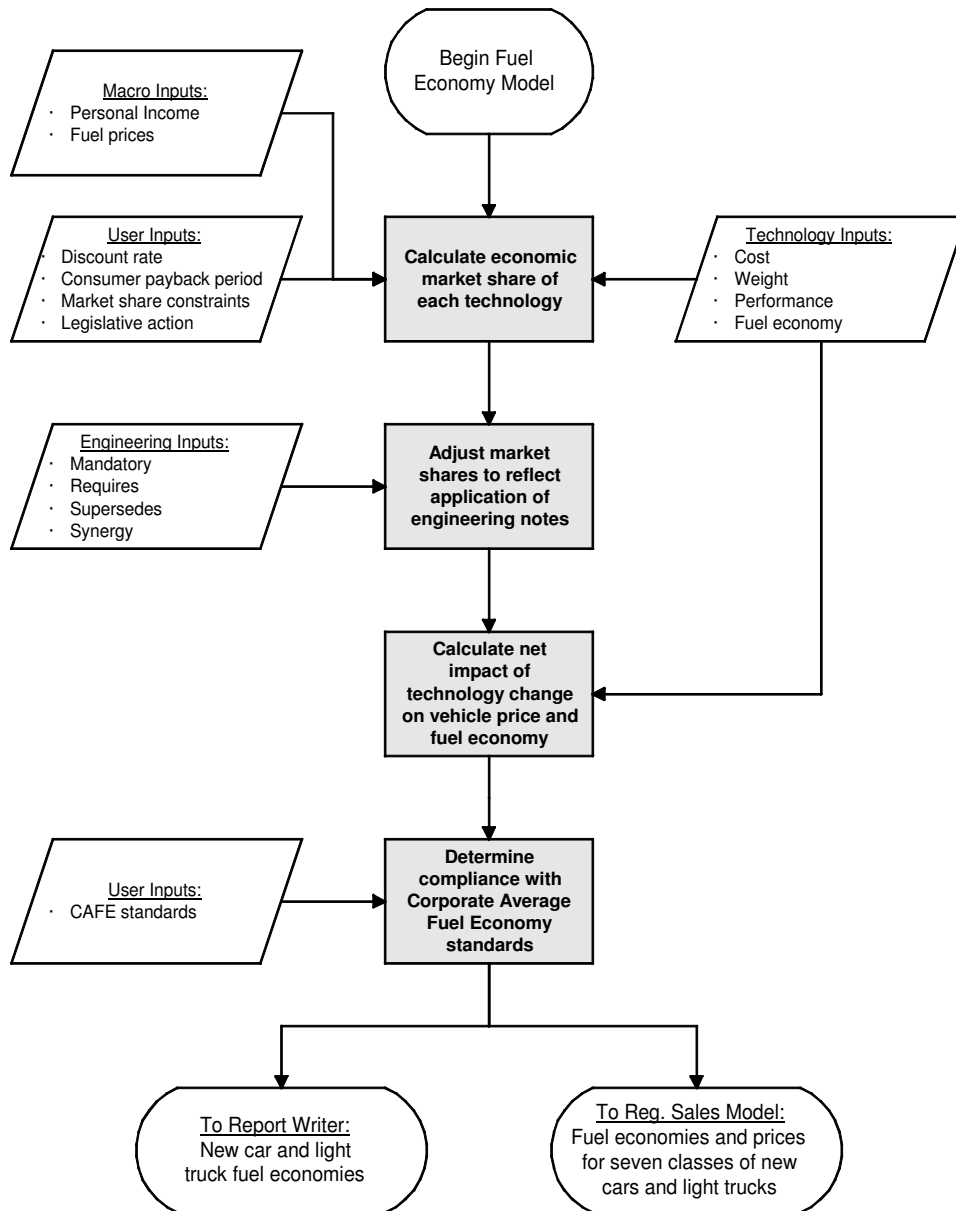
Finally, the module also accounts for all known safety and emission standard changes during the forecast period. These are generally limited to the 1995 to 2008 timeframe, however. Emission standards and safety standards increase vehicle weight, and in some cases decrease engine efficiency. The module accounts for the Tier II emission standards as well as the California Low Emission Vehicle (LEV) program, and the LEV program will be adopted in those states that have similar programs, namely Maine, Massachusetts, Vermont, New York, and California. Safety standards include fuel economy penalties for air bags, side intrusion and roof crush (rollover) strength requirements that are mandatory over the next ten years.

The forecasts are calculated at the most disaggregate level of manufacturer type (domestic/import), vehicle type (car/light truck) and market class. Car and light trucks are each separated into six market classes. Each market class represents an aggregation of vehicle models that are similar in size and price, and are perceived by consumers to offer similar attributes. The car classes are similar to the U.S. Environmental Protection Agency (EPA) size classes, and are based on passenger and trunk volume. Truck classification is essentially identical to the EPA classification. This leads to a total of 24 possible classes (6 size classes x 2 vehicle types x 2 manufacturer types), but some have no vehicles, e.g., there are no domestic minicompact cars. These classes are individually forecast to 2025.

MODEL STRUCTURE

The MTCM forecasts fuel economy by vehicle class. See Figure 2 for flow chart of Manufacturers Technology Choice Module. MTCM begins with a baseline, describing the fuel economy, weight, horsepower and price for each vehicle class in 2000. In each forecast period, the module identifies technologies that are available in the current year. Each available technology is subjected to a cost effectiveness test that balances the cost of the technology against the potential fuel savings and the value of any increase in performance provided by the technology. The cost effectiveness is used to generate an economic market share for the technology.

Figure 2. Manufacturers Technology Choice Module



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

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

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

ESTABLISH ALTERNATIVE FUEL VEHICLE CHARACTERISTICS RELATIVE TO CONVENTIONAL GASOLINE

The initialization subroutine, AFVADJ, calculates the price, weight, fuel economy and horsepower for the alternative fuel vehicles for all historic years through the MTCM base year. Most of these are set relative to the gasoline vehicle values as shown in the following equations. All of the incremental adjustments used for alternative fuels have been exogenously determined

and are included in the data input file, trninput.wk1. In the equations that follow, FuelType represents the sixteen alternative fuel vehicle types. These are gasoline, turbo direct-injection diesel, flex-fuel methanol and ethanol, dedicated methanol and ethanol, dedicated CNG and LPG, CNG and LPG bi-fuel, dedicated electric, diesel/electric and gasoline/electric hybrid, methanol fuel cell, hydrogen fuel cell, and gasoline fuel cell.

- 1) Calculate CVCM historic year values for car prices at different production levels.
 - a) Mini, Sub-Compact, Compact, and Two-Seaters at 2,500 units/year:

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

where,

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

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

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

where,

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

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

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

where,

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

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

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

where,

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

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

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

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

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

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

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

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

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

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

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

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

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

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

where,

AFVADJPR = Incremental price adjustment for a EV/Hybrid vehicles
 WEIGHT_{Year, Gasoline} = Weight of a gasoline vehicle in the current year
 WEIGHT_{Midsize, Domestic, Year, Gasoline} = Weight of a midsize, domestic gasoline vehicle in the current year

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

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

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

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

a) Fuel Economy Calculation:

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

where,

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

b) Weight Calculation:

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

where,

AFVADJWT = Input Weight adjustment, relative to gasoline vehicles.

c) Horsepower Calculation:

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

where,

AFVADJHP = Input Horsepower adjustment, relative to gasoline vehicles.

CALCULATE TECHNOLOGY MARKET SHARES

MTCM first determines the cost effective market shares of technologies for each vehicle class and then calculates the resulting fuel economy, weight, horsepower, and price through the subroutine FEMCALC. In each forecast period this function is called three times. During the first pass, technology market shares are calculated for all vehicle classes. In the second pass, the

technology market shares are recalculated for vehicles in groups failing to meet the CAFE standards. During this pass, the cost effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFE.³ If a vehicle group continues to fail to meet CAFE standards after the second pass, no further adjustments to technology market shares are made. Rather, in the third pass, it is assumed that the manufacturers focus solely on CAFE compliance at the expense of increased performance.

For each vehicle class, FEMCALC follows these steps:

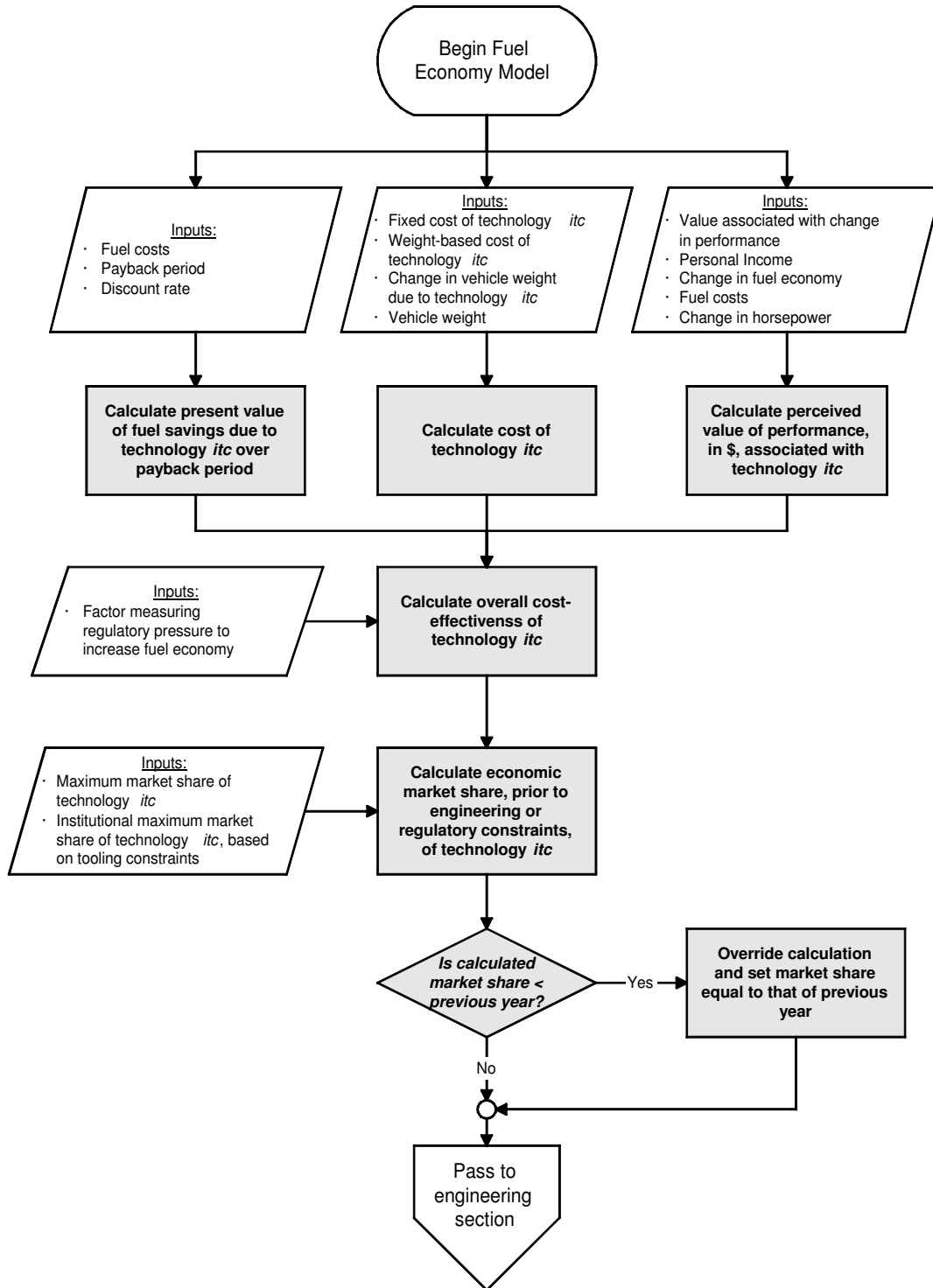
- A. Calculate the economic market share for each technology
- B. Apply the engineering notes to control market penetration
 - Adjust the economic market shares through application of the following three types of engineering notes: mandatory notes, supersedes notes, and requires notes.
 - Adjust the fuel economy impact through application of the synergy engineering notes
- C. Calculate the net impact of the change in technology market share on fuel economy, weight and price
- D. Estimate EV and Fuel Cell Characteristics
- E. Adjust horsepower based on the new fuel economy and weight
- F. Readjust fuel economy based on the new horsepower, and price based on the change in horsepower

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

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 3. These are addressed in turn below.

³ See the variable REGCOST in Equation 20.

Figure 3. MTCM: Economic Market Share Calculation



CALCULATE ECONOMIC MARKET SHARE

Fuel Savings Value

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

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

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

$$\begin{aligned} FIVEYR_FUELCOST_1 &= \frac{1}{5} * \sum_{i=Year-8}^{Year-4} FUELCOST_i \\ FIVEYR_FUELCOST_2 &= \frac{1}{5} * \sum_{i=Year-7}^{Year-3} FUELCOST_i \\ PSLOPE &= MAX(0, FIVEYR_FUELCOST_1 - FIVEYR_FUELCOST_2) \end{aligned} \tag{14}$$

where,

FUELCOST = the price of fuel in the specified prior years

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

$$PRICE_EX_{Year=i} = PSLOPE * (i + 2) + FIVEYR_FUELCOST_1 \tag{15}$$

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

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{Year-1}} - \left(\frac{1}{1 + DEL_FE_{itc} * FE_{Year-1}} \right) \right) * PRICE_EX_i * (1 + DISCOUNT)^{-i} \quad (16)$$

where,

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

Technology Cost

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

$$TECHCOST_{itc} = DEL_COSTABS_{itc} + DEL_COSTWGT_{itc} (ABS(DEL_WGTABS_{itc}) + ABS(DEL_WGTWGT_{itc}) * WEIGHT_{Year-1, FuelType}) \quad (17)$$

where,

- TECHCOST = The cost per vehicle of technology *itc*.
- DEL_COSTABS = The absolute cost of technology *itc*.
- DEL_COSTWGT = The weight-based change in cost (\$/lb).
- DEL_WGTABS = The fractional change in absolute weight-based cost associated with technology *itc*.
- DEL_WGTWGT = The fractional change in relative weight-based cost associated with technology *itc*.
- WEIGHT = The original vehicle weight for different fuel type vehicles.

Learning Cost Adjustment

The technology cost is adjusted to include the multiplicative total of four individual cost curve adjustments (production volume, manufacturing advances, design advances, and scientific advances). The four influences introduced into the cost calculation are intended to represent potential cost changes due to production volume economies of scale and potential scientific,

manufacturing, and design advances. Manufacturing advances can generally be thought of as improvements to non-mature production techniques, such that unit production costs decline at a rate that exceeds that associated with economies of scale alone. Design advances reflect improvements in the cost effectiveness of production due to refinements in the fundamental design of a specific technology. Scientific advances can generally be thought of as fundamental changes in the understanding of specific technologies that lead to more cost effective approaches than currently available.

$$TECHCOST_{itc} = TECHCOST_{itc} * LEARN_COST_MULTIPLIER_1 * LEARN_COST_MULTIPLIER_2 * LEARN_COST_MULTIPLIER_3 * LEARN_COST_MULTIPLIER_4 \quad (18)$$

where,

- LEARN_COST_MULTIPLIER₁ = Cost adjustment due to scientific advances.
- LEARN_COST_MULTIPLIER₂ = Cost adjustment due to manufacturing advances.
- LEARN_COST_MULTIPLIER₃ = Cost adjustment due to design advances.
- LEARN_COST_MULTIPLIER₄ = Cost adjustment due to production volume economies of scale.

Performance Value

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

$$VAL_PERF_{itc} = VALUEPERF * PERF_COEFF * \frac{INCOME_{Year}}{INCOME_{Year-1}} * (1 + DEL_FE_{itc}) * \frac{FUELCOST_{Year-1}}{FUELCOST_{Year}} * DEL_HP_{itc} \quad (19)$$

where,

- VAL_PERF = The dollar value of performance of technology itc
- VALUEPERF = The value associated with an incremental change in performance
- PERF_COEFF = The parameter used to constrain vehicle performance
- DEL_FE = The fractional change in fuel economy of technology itc
- DEL_HP = The fractional change in horsepower of technology itc
- FUELCOST = The actual price of fuel (in the given year)

Economic Market Share

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

$$COSTEF_FUEL_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + (REGCOST * FE_{Year-1} * DEL_FE_{itc})}{TECHCOST_{itc}} \quad (20)$$

$$COSTEF_PERF_{itc} = \frac{VAL_PERF_{itc} - TECHCOST_{itc}}{TECHCOST_{itc}} \quad (21)$$

$$MKT_FUEL_{itc} = \frac{1}{1 + e^{MKT_1COEFF * COSTEF_FUEL_{itc}}} \quad (22)$$

$$MKT_PERF_{itc} = \frac{1}{1 + e^{MKT_2COEFF * COSTEF_PERF_{itc}}} \quad (23)$$

where,

- COSTEF_FUEL = A unitless measure of cost effectiveness based on fuel savings
- COSTEF_PERF = A unitless measure of cost effectiveness based on performance
- REGCOST⁴ = A factor representing regulatory pressure to increase fuel economy, in \$ per MPG
- TECHCOST = The cost of the considered technology
- VAL_PERF = The performance value associated with technology *itc*
- MKT_FUEL = Market share based on fuel savings
- MKT_PERF = Market share based on performance
- MKT_1COEFF = -4 if COSTEF_FUEL < 0, and -2 otherwise
- MKT_2COEFF = -4 if COSTEF_PERF < 0, and -2 otherwise

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

$$ACTUAL_MKT_{itc,Year} = PMAX_{itc} * MAX(MKT_FUEL_{itc} * MKT_PERF_{itc}) \quad (24)$$

where,

- ACTUAL_MKT = The economic share, prior to consideration of engineering or regulatory constraints.
- PMAX = The institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in a separate

⁴ During pass 1 REGCOST has a value of 0. During passes 2 and 3 it is set to REG_COST, which is a user input. This penalty is discussed in the earlier section entitled Calculate Technology Market Shares.

subroutine. This subroutine (FUNCMAX) sets the current year maximum market share based on the previous year's share (see Table 2).

Table 2. Maximum Light Duty Vehicle Market Penetration Parameters (percent)

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

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

Market Share Overrides

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

$$ACTUAL_MKT_{it,Year} = MAX(ACTUAL_MKT_{it,Year-1}, ACTUAL_MKT_{it,Year}) \quad (25)$$

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

$$ACTUAL_MKT_{itc,Year} = MIN(1, MKT_MAX_{itc}, ACTUAL_MKT_{itc,Year}) \quad (26)$$

where,

MKT_MAX = The maximum market share for technology *itc*

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 4.

Mandatory Notes

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

$$ACTUAL_MKT_{itc,Year} = MAX(ACTUAL_MKT_{itc,Year}, MANDMKSH_{itc,Year}) \quad (27)$$

where,

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

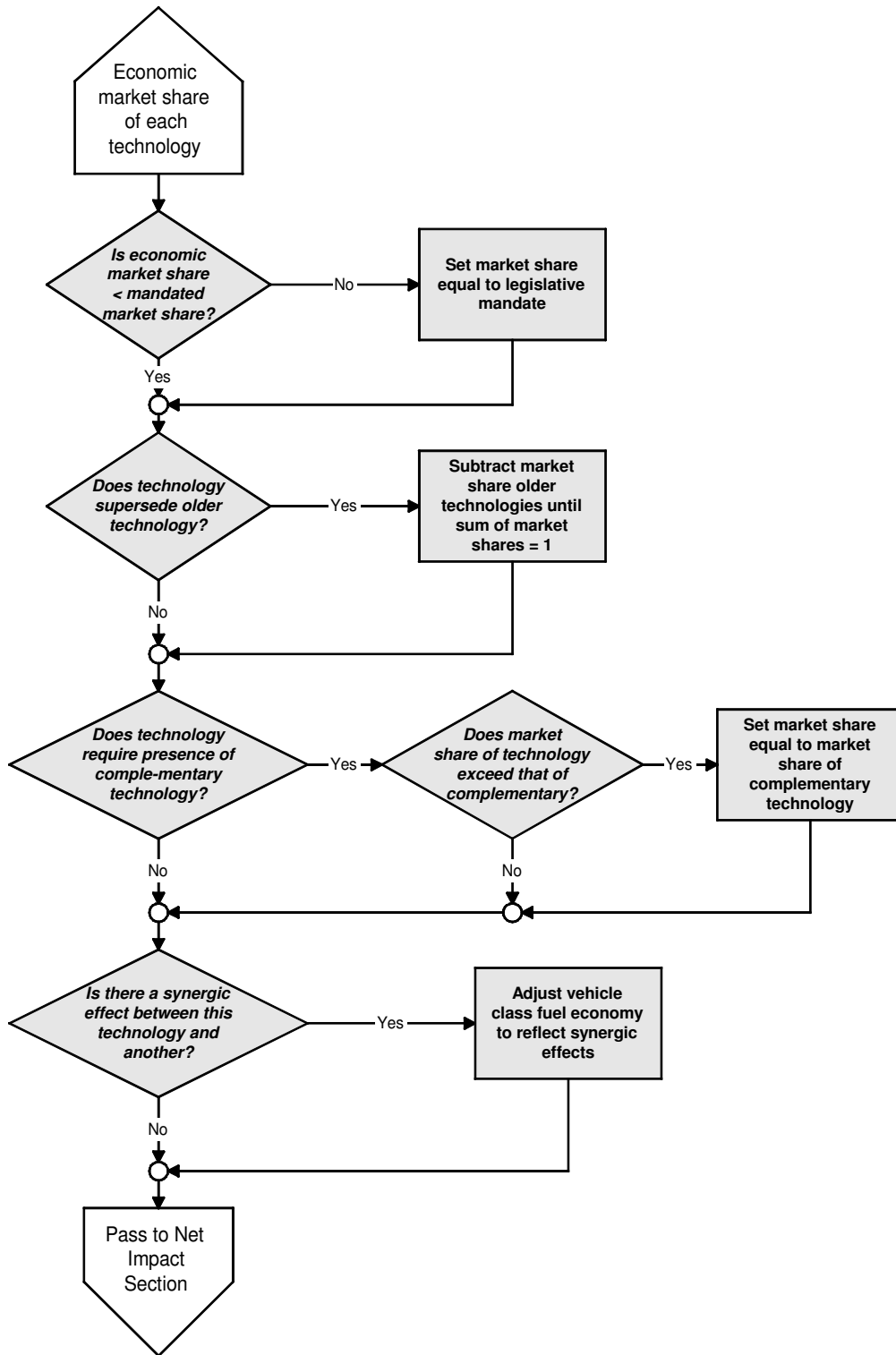
If the number of phase-in years is greater than 1, adopt a proportional share of the total mandatory share, MANDMKSH, each year. Since both the base and maximum market penetrations can vary by vehicle class, the actual market share logic must adopt annual shares in proportion to the allowable market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

$$ACTUAL_MKT_{itc,Year} = MAX \left(ACTUAL_MKT_{itc,Year}, MKT_PEN_{itc,BaseYear,FuelType} + PHASESHR_{Year} * (MKT_MAX_{itc} - MKT_PEN_{itc,BaseYear,FuelType}) \right) \quad (28)$$

where,

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

Figure 4. MTCM 2 Engineering Notes



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

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

Supersedes Notes

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

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

$$TOT_MKT_{itc,Year} = \sum_{ino=1}^{num_sup} ACTUAL_MKT_{ino,Year} \quad (30)$$

where,

- TOT_MKT = The total market share of the considered group of technologies
- ino = The index identifying the technologies in the superseding group related to technology *itc*
- num_sup = The number of technologies in the superseding group related to technology *itc*.

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

$$MAX_SHARE = MAX(MKT_MAX_{ino}) \quad (31)$$

where,

MAX_SHARE = The maximum allowable market share of the group, ino.

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

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

$$DEL_MKT_{itc} = TOT_MKT_{itc,Year} - MAX_SHARE \quad (32)$$

where,

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

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

$$ACTUAL_MKT_{itc,Year} = ACTUAL_MKT_{itc,Year} - DEL_MKT_{itc} \quad (33)$$

- 3) Adjust total market share to reflect this decrement

$$TOT_MKT_{itc,Year} = MAX_SHARE \quad (34)$$

Requires Notes

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

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

more than 1.0:

$$REQ_MKT = MIN \left(\sum_{req} ACTUAL_MKT_{req,Year-1}, 1.0 \right) \quad (35)$$

where,

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

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

$$ACTUAL_MKT_{itc,Year} = MIN(ACTUAL_MKT_{itc,Year}, REQ_MKT) \quad (36)$$

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

$$MKT_PEN_{itc,Year} = ACTUAL_MKT_{itc,Year} \quad (37)$$

Synergistic Notes

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

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

technologies on fuel economy, is negative so that the estimated synergy loss will also be negative and should be treated as an additive parameter.

$$SYNERGY_LOSS_{itc} = \sum_{syn} (MKT_PEN_{itc,Year} * MKT_PEN_{syn,Year} - MKT_PEN_{itc,Year-1} * MKT_PEN_{syn,Year-1}) * SYNDEL_{itc,syn} \quad (38)$$

where,

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

Syn = The set of technologies synergistic with technology *itc*.

SNR_DEL = The synergistic effect of related technologies on fuel economy.

CALCULATE NET IMPACT OF TECHNOLOGY CHANGE

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

$$DELTA_MKT_{itc} = MKT_PEN_{itc,Year} - MKT_PEN_{itc,Year-1} \quad (39)$$

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

Fuel Economy

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

$$FE_{year} = FE_{Year-1} + FE_{Year-1} * \left[\sum_{itc=1}^{NUMTECH} DELTA_MKT_{itc} * DEL_FE_{itc} * SYNERGY_LOSS_{itc} \right] \quad (40)$$

where,

NUMTECH = Number of newly adopted technologies

Vehicle Weight

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

$$WEIGHT_{Year, FuelType} = WEIGHT_{Year, FuelType} + DELTA_MKT_{itc} * (DEL_WGTECH_{itc} + WEIGHT_{Year, FuelType} * DEL_WGTWGT_{itc}) \quad (41)$$

where,

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

Vehicle Price

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

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

where,

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

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 Ni-MH batteries. The numerical constants in the equations represent the result of exogenous analysis and professional judgment on the part of the model developers.

1) Weight and cost of a lead acid battery

$$\begin{aligned} BATTERY1_WT &= 0.60 * WEIGHT_{Year,Gasoline} \\ &\text{and} \\ BATTERY1_COST &= BATTERY1_WT * 2.30 * 1.75 + 1500 \end{aligned} \tag{43}$$

where,

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

2) Weight and cost of a Ni-MH battery

$$\begin{aligned} BATTERY2_WT &= 0.203 * WEIGHT_{Year,Gasoline} \\ &\text{and} \\ BATTERY2_COST &= BATTERY2_WT * 8.20 * 1.75 + 1500 \end{aligned} \tag{44}$$

where,

0.203 = Fraction of vehicle weight accounted for by the battery system
BATTERY2_WT = Weight of a Ni-MH battery large enough to provide adequate range and performance
BATTERY2_COST = Cost of a Ni-MH battery

\$8.20 = Cost/pound of a Ni-MH battery
 1.75 = Cost multiplier to determine retail price
 \$1,500 = Fixed cost amortization per unit EV
 WEIGHT = Weight of a gasoline vehicle

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

3) Learning curve adjustment for battery costs

$$\begin{aligned}
 BATTERY1_COST &= BATTERY1_COST * LEADACID_COST_{Year} \\
 &\text{and} \\
 BATTERY2_COST &= BATTERY2_COST * NIMHY_COST_{Year}
 \end{aligned}
 \tag{45}$$

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 Ni-MH batteries:

4) Average price of an electric vehicle battery

$$\begin{aligned}
 BATTERY_{Year,ElectricVehicle} &= BATTERY1_COST * (1 - NIMHY_MKTSH_{Year}) \\
 &\quad + BATTERY2_COST * NIMHY_MKTSH_{Year}
 \end{aligned}
 \tag{46}$$

where,

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

Finally, Price, Weight and Fuel Economy are calculated:

5) Electric Vehicle Price

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

Since PRICEHI (high production Alternative Fuel Vehicle) 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

$$WEIGHT_{Year,ElectricVehicle} = \frac{BATTERY1_WT}{0.375} * (1 - NIMHY_MKTSH_{Year}) + \frac{BATTERY2_WT}{0.22} * NIMHY_MKTSH_{Year} \quad (48)$$

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

$$FE_{Year,ElectricVehicle} = \frac{0.8 * 2200}{0.16 * WEIGHT_{Year,ElectricVehicle}} \quad (49)$$

Hybrid Electric Vehicles (HEV)

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

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

Fuel Cell Vehicles

The subroutine FCCALC calculates fuel cell cost, vehicle price for low volume sales, at 2,500 units per year, and high volume sales, at 25,000 units per year, and fuel economy for methanol, hydrogen, and gasoline fuel cell vehicles, respectively. Note that although values for fuel cell vehicles are calculated for the early years, 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 fuel cell vehicles. In the following equations the FC subscript refers to methanol, hydrogen, and gasoline fuel cells.

1) Fuel Cell Cost

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

where,

FUELCELL = Cost of the fuel cell
 FUELCELL_COST = Exogenous input for the cost of the fuel cell in \$/kw
 WEIGHT = Weight of a gasoline vehicle

2) Battery Power required to initially power the vehicle

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

where,

BATTERY_POWER = Required battery power in Kw

3) Weight of Battery

$$BATTERY_WT = 2.2 * \frac{BATTERY_POWER}{0.5} \quad (53)$$

where,

2.2 = Base battery weight in lbs.
 BATTERY_WT = Weight of the battery

4) Cost of Battery

$$BATTERY_{Year,FC} = 2.30 * BATTERY_WT * LEADACID_COST_{Year} \quad (54)$$

where,

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

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

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

where,

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

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

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

7) Fuel Cell Fuel Economy (gasoline equivalent mpg)

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

where,

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

ADJUST HORSEPOWER

Calculating the net impact of changes in technology share on vehicle horsepower is a three-step process. See Figure 5.

Unadjusted Horsepower

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

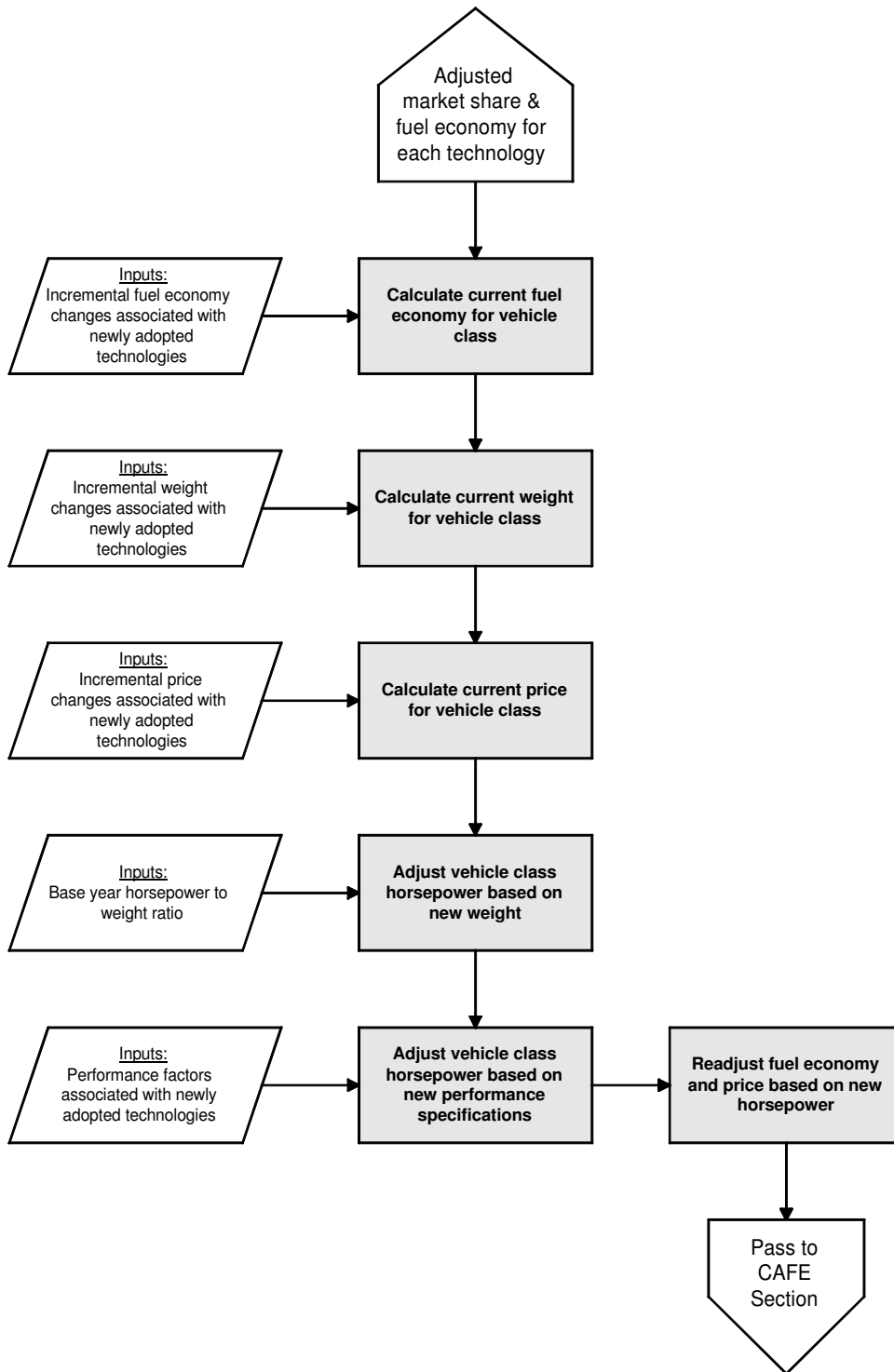
Assuming a constant horsepower/weight ratio for cars and light trucks:

$$HP_{Year,FuelType} = WEIGHT_{Year,FuelType} * \frac{HP_{Year-1,FuelType}}{WEIGHT_{Year-1,FuelType}} \quad (58)$$

where,

HP = Vehicle horsepower
 WEIGHT = Vehicle weight

Figure 5. MTCM: Weight and Horsepower Calculations



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

$$HP_{Year, FuelType} = 0.8 * WEIGHT_{Year, FuelType} * \frac{HP_{Year, Gasoline}}{WEIGHT_{Year, Gasoline}} \quad (59)$$

where,

FuelType = Dedicated Electric and Fuel Cell vehicles

Adjust Horsepower

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

Technology Adjustment

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

$$TECH_ADJHP_{year} = \sum_{itc=1}^{NUMTECH} (DELTA_MKT_{itc} * DEL_HP_{itc}) \quad (60)$$

where,

DEL_HP = the fractional change in horsepower by technology type

Consumer Preference Adjustment

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

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

where,

PERF_ADJHP = Performance Vehicle horsepower adjustment factor

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

$$DEMAND_USED = (PERFCAP - HP_WGT_{BaseYear}) * \left(\frac{USED CAP}{1 - USED CAP} \right) \quad (62)$$

where,

DEMAND_USED = Demand accrued between 1990 and 2000

PERFCAP = Performance cap

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

USED CAP = Input parameter

$$PERF_COEFF_{Year} = 1 - \left(\frac{HP_WGT_{Year} - HP_WGT_{BaseYear} + DEMAND_USED}{PERFCAP - HP_WGT_{BaseYear} + DEMAND_USED} \right) \quad (63)$$

where,

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

$$PERF_ADJHP_{Year} = PERF_ADJHP_{Year} * PERFFACT * PERF_COEFF_{Year} \quad (64)$$

where,

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

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

The total horsepower adjustment is now calculated:

$$TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year} \quad (65)$$

Maximum Limit on Total Horsepower Adjustment

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

$$\begin{aligned} HP_GIVEBACK_{Year} &= TTL_ADJHP_{Year} - 0.1 \\ PERF_ADJHP_{Year} &= PERF_ADJHP_{Year} - HP_GIVEBACK_{Year} \end{aligned} \quad (66)$$

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

$$TECH_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year} \quad (67)$$

Now, calculate the modified total horsepower adjustment:

$$TTL_ADJHP_{Year} = TECH_ADJHP_{Year} + PERF_ADJHP_{Year} \quad (68)$$

Maximum Limit on Horsepower to Weight Ratio

Also impose a maximum limit on the horsepower to weight ratio so that performance characteristics do not become unreasonable. If the horsepower to weight ratio is too high, first subtract any consumer preference for performance, PERF_ADJHP, since the fuel economy effect is not considered until later. If there is further need to lower the horsepower to weight ratio then

decrease any additional required horsepower demand from the technology-based part of the adjustment, TECH_ADJHP, and track this “giveback”, since HP_GIVEBACK must be converted back into fuel economy equivalent.

Horsepower to Weight Ratio Must Ensure Driveability

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

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

$$\begin{aligned}
 MIN_ADJHP_{Year} &= \left(\frac{HP_WGT_MIN_{BaseYear}}{HP_WGT_{Year}} - 1 \right) \\
 PERF_ADJHP_{Year} &= PERF_ADJHP_{Year} + MIN_ADJHP_{Year} - TTL_ADJHP_{Year} \\
 TTL_ADJHP_{Year} &= TECH_ADJHP_{Year} + PERF_ADJHP_{Year}
 \end{aligned}
 \tag{69}$$

Final Horsepower Adjustment for CAFE Compliance

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

$$\begin{aligned}
EXCESS_ADJHP_{Year} &= \min(TECH_ADJHP_{Year}, TTL_ADJHP_{Year} - MIN_ADJHP_{Year}) \\
TECH_ADJHP_{Year} &= TECH_ADJHP_{Year} - EXCESS_ADJHP_{Year} \\
TTL_ADJHP_{Year} &= TECH_ADJHP_{Year} + PERF_ADJHP_{Year}
\end{aligned}
\tag{70}$$

Compute the horsepower give back;

$$HP_GIVEBACK_{Year} = HP_GIVEBACK_{Year} + EXCESS_ADJHP_{Year} \tag{71}$$

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

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

READJUST FUEL ECONOMY AND PRICE

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

Fuel Economy Adjustment Factor

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

$$PERF_ADJHP_{Year} = PERF_ADJHP_{Year} - HP_GIVEBACK_{Year} \tag{73}$$

$$ADJFE_{Year} = -0.22 * PERF_ADJHP_{Year} - 0.56 * SIGN * PERF_ADJHP_{Year}^2 \tag{74}$$

where,

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

Adjusted Fuel Economy

The final vehicle fuel economy is then determined as follows:

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

Adjusted Vehicle Price

Vehicle price is finally estimated:

$$PRICE_{Year} = PRICE_{Year} + PERF_{Year} * ADJHP_{Year} * VALUEPERF_{Year} \quad (76)$$

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

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

Estimate Vehicle Range

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

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

where,

RANGE = Vehicle range
TANKSIZE = Tank size for a gasoline vehicle of the same size class
AFVADJRN = Range adjustment, relative to gasoline vehicle (exogenous, from Block Data)

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

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

each CAFE group.

CALCULATE CLASS MARKET SHARES

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

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

where,

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

Class Market Shares

Solve for the log-share ratio:

$$RATIO_LN = DIFFLN_{Year} + \ln\left(\frac{CLASS_SHARE_{class,group,CLYear}}{1 - CLASS_SHARE_{class,group,CLYear}}\right) \tag{79}$$

where,

RATIO_LN = Log of the market share ratio of the considered vehicle class
CLASS_SHARE = Class market share, assigned to the appropriate vehicle class and group
class = 6 Vehicle Classes
group = 4 CAFE Groups

Solve for the class market share:

$$CLASS_SHARE_{class,group,Year} = \frac{e^{RATIO_LN}}{1 + e^{RATIO_LN}} \tag{80}$$

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

$$CLASS_SHARE_{class,group,Year} = \frac{CLASS_SHARE_{class,group,Year}}{\sum_{class=1}^6 CLASS_SHARE_{class,group,Year}} \quad (81)$$

CALCULATE CAFE

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

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

For each vehicle group the CAFE calculation proceeds as follows:

$$CAFE_{group,Year} = \frac{\sum_{class=1}^6 CLASS_SHARE_{class,group,Year}}{\sum_{class=1}^6 \frac{CLASS_SHARE_{class,group,Year}}{FE_{class,group,Year}}} \quad (82)$$

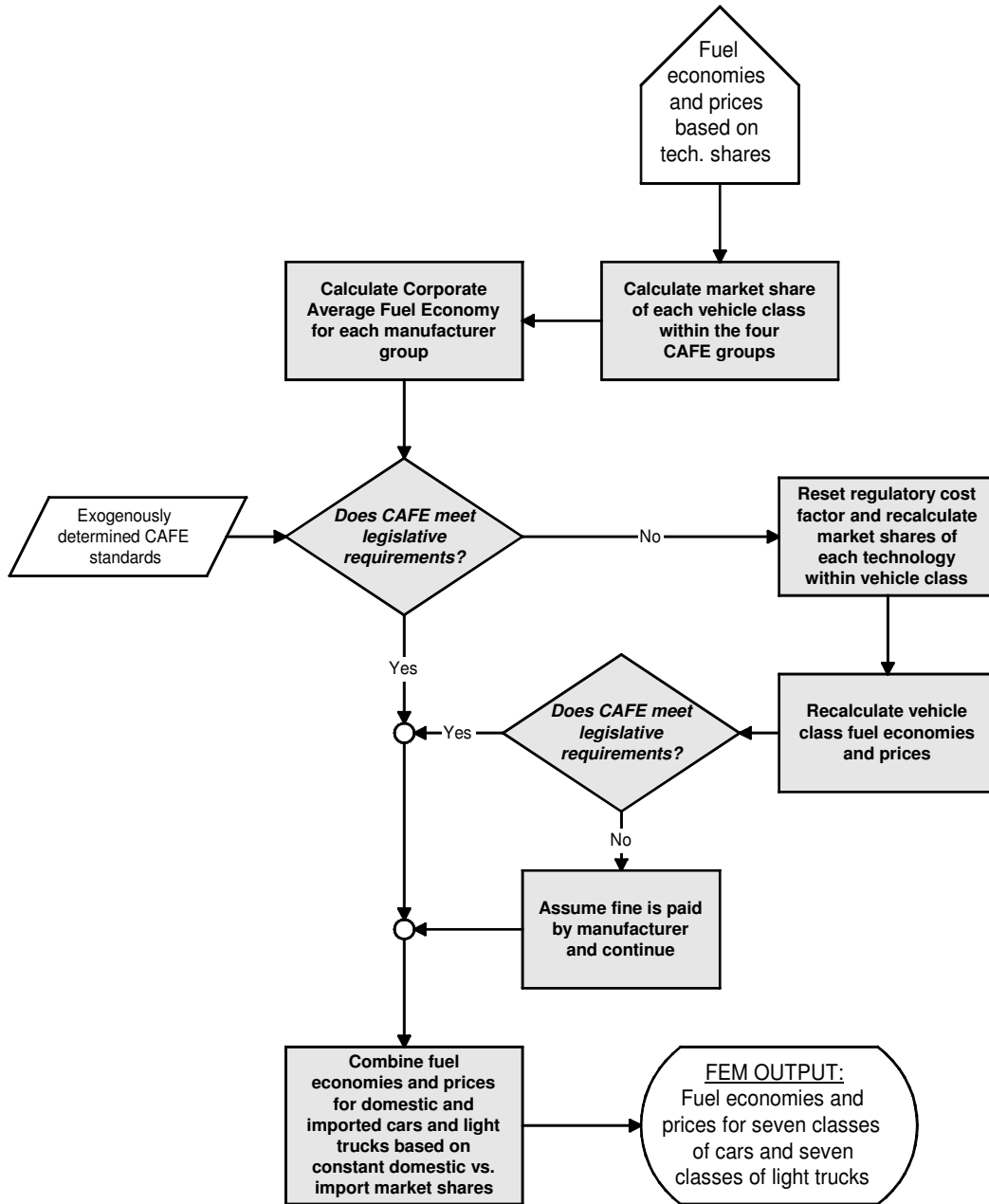
This CAFE estimate is then compared with the legislative standard for the manufacturer group and year. If the forecast CAFE is less than the standard, a second iteration of the module is performed after resetting the regulatory cost (REGCOST). If the recalculated CAFE is still below the standard, a third iteration occurs, and the manufacturer is then assumed to pay the fine, see Figure 6.

FORCED CAFE STANDARD

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

If the meeting of the CAFE standard switch is set, CAFEMEET=1, then the CAFETEST routine is called after completing the third pass of MTCM. New vehicle sales are re-computed for the

Figure 6. MTCM 4: CAFE Calculations



alternative fuel types, CAFETYP, in the following order: gas hybrids, diesels, and diesel hybrids. The order of vehicle types used in the calculations are: for cars, the standard types by size are used, and for light duty trucks, small SUV, small vans, small pickups, large SUV, large pickups, and large vans. For each vehicle group the CAFE calculation proceeds as follows.

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

$$DEL_SALES_{vt,class,CAFETYP} = DEL_APSHR * \sum_{FuelType=1}^{NUMFUELS} AVSALES_{vt,class,11,FuelType} \quad (83)$$

where,

$$\begin{aligned} DEL_APSHR &= 0.005 \\ AVSALES &= \text{Sales of new vehicles, as defined in (146)} \\ CAFETYP &= \text{Diesel hybrid, diesel, and gas hybrid} \end{aligned}$$

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

$$AVSALES_{vt,class,11,FuelType} = AVSALES_{vt,class,11,FuelType} + DEL_SALES_{vt,class,FuelType} \quad (84)$$

$$AVSALES_{vt,class,11,GAS} = AVSALES_{vt,class,11,GAS} - DEL_SALES_{vt,class,GAS} \quad (85)$$

where,

$$\text{FuelType} = \text{Gas hybrids, diesels, and diesel hybrids, in that order}$$

The new shares, APSHR55, are then re-calculated, as in (152). Total sales, AVSALEST, remain unchanged.

There are constraints to new vehicle sales. For each CAFETYP, sales stop after ten failures to meet the standard, or after 5 percent of total sales. Also, a maximum of 500,000 new sales are allowed for each CAFETYP.

If at any time gasoline sales become negative, sales of gasoline engines vehicles are increased

until sales reach zero, with a corresponding decrease in vehicle sales of diesel hybrids, diesels, and gas hybrids, respectively.

COMBINE RESULTS OF DOMESTIC AND IMPORTED VEHICLES

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

$$MPG_{vt,class} = \frac{1}{\frac{PERGRP_{dom,class}}{FE_{dom,class}} + \frac{PERGRP_{imp,class}}{FE_{imp,class}}} \quad (86)$$

$$HPW_{vt,class} = HP_{dom,class} * PERGRP_{dom,class} + HP_{imp,class} * PERGRP_{imp,class} \quad (87)$$

$$PRI_{vt,class} = PRICE_{dom,class} * PERGRP_{dom,class} + PRICE_{imp,class} * PERGRP_{imp,class} \quad (88)$$

$$VRNG_{vt,class} = RNG_{vt,class} = RANGE_{dom,class} * PERGRP_{dom,class} + RANGE_{imp,class} * PERGRP_{imp,class} \quad (89)$$

$$WGT_{vt,class} = WEIGHT_{dom,class} * PERGRP_{dom,class} + WEIGHT_{imp,class} * PERGRP_{imp,class} \quad (90)$$

where,

MPG = Vehicle fuel economy

HPW = Vehicle horsepower

PRI = Vehicle price

RNG = Vehicle range

WGT = Vehicle weight

PERGRP = Percent of vehicles import or domestic by size class

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

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

⁵ Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 24*, ORNL-6973, December 2004.

For Cars: Table 7.5, 2001 data. For Light Trucks: Table 7.6, 2001 data.

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

3A-2. Regional Sales Module

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

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

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

Redistribute MTCM Sale Shares Among Six Size Classes

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

It is first necessary to reallocate the estimates of car and light truck sales supplied by the Macroeconomic Module. This is required due to the fact that definitions used in the

Transportation Module differ from those used in the Macroeconomic Module. The trucks enumerated by the Macroeconomic Module's definition of light trucks include all trucks less than 14,000 pounds gross vehicle weight (GVW). In the Transportation Module these trucks are addressed in three separate sections: trucks under 8,500 pounds are included in the LDV Module; trucks between 8,500 and 10,000 pounds are modeled separately in the Class 2b Vehicle Module; and trucks over 10,000 pounds are included in the Highway Freight Module. Additionally, the LDV Module estimates the allocation of LDV sales between cars and light trucks, reflecting the changing purchase patterns of consumers who have been shifting their purchases toward minivans and sport utility vehicles in recent years.

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

$$CARSHARE_{Year} = e^{(\rho LOG(CARSHARE_{Year-1}) + \beta_0(1-\rho) + \beta_1[LOG(INCOME96_{Year}) - \rho LOG(INCOME96_{Year-1})])} * e^{(\beta_2[LOG(FUEL96_{Year}) - \rho LOG(FUEL96_{Year-1})] + \beta_3[DUMM_{Year} - \rho DUMM_{Year-1}])} \quad (91)$$

where,

INCOME96 = Per capita income in 1996 dollars

FUEL96 = Fuel price in 1996 \$ per gallon

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

p = Lag factor for the difference equation

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

$$NEWCARS_{Year} = (MC_SQTRCARS_{Year} + MC_VEHICLES_{1,Year} + MC_VEHICLES_{3,Year}) * CARSHARE_{Year} \quad (92)$$

and

$$NEWCLS12A_{Year} = (MC_SQTRCARS_{Year} + MC_VEHICLES_{1,Year} + MC_VEHICLES_{3,Year}) * (1 - CARSHARE_{Year})$$

where,

MPG NEWCARS = Total new car sales

NEWCLS12A = Total new light truck sales

MC_SQTRCARS = Total car sales, from the macroeconomic module

MC_VEHICLES_{1,Year} = Sales of light truck, 0 to 6,000 pounds GVW, from the macroeconomic module

MC_VEHICLES_{3,Year} = Sales of light trucks, 6,000 to 8,500 pounds GVW, from the macroeconomic module

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

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

$$\begin{aligned}
NVS7SC_{group=1-2,classYear} &= CLASS_SHARE_{class,group=1-2,Year} * NEWCARS_{Year} * (1 - FLTCRAT_{Year}) * SALES_{HR}_{group=1-2,Year} \\
&\text{and} \\
NVS7SC_{group=3-4,classYear} &= CLASS_SHARE_{class,group=3-4,Year} * NEWCLS12A_{Year} * (1 - FLTTRAT_{Year}) * SALES_{HR}_{group=3-4,Year}
\end{aligned}
\tag{93}$$

where,

- NVS7SC = Non-fleet, non-commercial sales
- CLASS_SHARE = The market share for each car class, from MTCM
- FLTCRAT = Fraction of new cars purchased by fleets by year
- FLTTRAT = Fraction of new light trucks purchased by fleets by year
- SALES_{HR} = Fraction of vehicle sales that are domestic/imported by year

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

$$\begin{aligned}
NCSTSCF_{class,Year} &= \sum_{group=1}^2 NVS7SC_{group,class,Year} \\
&\text{and} \\
NLTSTSCF_{class,Year} &= \sum_{group=3}^4 NVS7SC_{group,class,Year}
\end{aligned}
\tag{94}$$

where,

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

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

$$\begin{aligned}
PASSHR_{class,Year} &= PASSHR_{class,Year-1} * \frac{\left(\frac{NCSTSCF_{class,Year}}{\sum_{class=1}^6 NCSTSCF_{class,Year}} \right)}{\left(\frac{NCSTSCF_{class,Year-1}}{\sum_{class=1}^6 NCSTSCF_{class,Year-1}} \right)} \\
&\text{and} \\
LTSHR_{class,Year} &= LTSHR_{class,Year-1} * \frac{\left(\frac{NLTSTSCF_{class,Year}}{\sum_{class=1}^6 NLTSTSCF_{class,Year}} \right)}{\left(\frac{NLTSTSCF_{class,Year-1}}{\sum_{class=1}^6 NLTSTSCF_{class,Year-1}} \right)} \tag{95}
\end{aligned}$$

where,

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

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

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

$$\begin{aligned}
AHPCAR_{Year} &= \sum_{class=1}^6 HPW_{car,class} * \frac{PASSHR_{class,Year}}{\sum_{class=1}^6 PASSHR_{class,Year}} \\
&\text{and} \\
AHPTRUCK_{Year} &= \sum_{class=1}^6 HPW_{trk,class} * \frac{LTSHR_{class,Year}}{\sum_{class=1}^6 LTSHR_{class,Year}} \tag{96}
\end{aligned}$$

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

Determine Regional Values of Fuel Demand and Vehicle Sales

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

$$SEDSHR_{FUEL,REG,Year} = \frac{SEDSHR_{FUEL,REG,Year-1} * \left(\frac{TMC_YD_{REG,Year}}{TMC_YD_{REG,Year-1}} \right)}{\sum_{REG=1}^9 \left(SEDSHR_{FUEL,REG,Year-1} * \left(\frac{TMC_YD_{REG,Year}}{TMC_YD_{REG,Year-1}} \right) \right)} \quad (97)$$

where,

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

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

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

Determine the regional cost of driving per mile:

$$COSTMIR_{REG,Year} = 0.1251 * \left(\frac{PMGTR_{REG,Year}}{MPGFLT_{Year}} \right) \quad (98)$$

where,

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

Calculate regional income:

$$INCOMER_{REG,Year} = \left(\frac{TMC_YD_{REG,Year}}{MC_N_{REG,Year}} \right) \quad (99)$$

where,

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

Estimate regional driving demand:⁶

$$VMT16R_{REG,Year} = e^{(\rho LOG(VMT16R_{REG,Year-1}) + \beta_0(1-\rho) + \beta_1[LOG(VMT16R_{REG,Year-1}) - \rho LOG(VMT16R_{REG,Year-2})]) * (\beta_2[LOG(INCOMER_{REG,Year}) - \rho LOG(INCOMER_{REG,Year-1})] + \beta_3[LOG(COSTMIR_{REG,Year}) - \rho LOG(COSTMIR_{REG,Year-1})])} \quad (100)$$

and,

$$VMTEER_{REG,Year} = VMT16R_{REG,Year} * MC_N16N_{REG,Year} \quad (101)$$

where,

VMT16R = Vehicle-miles traveled per population over 16 years of age
ρ = Lag factor for the difference equation
VMTEER = Total VMT in region REG
MC_N16N = Total regional population over the age of 16

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,Year} = \frac{VMTEER_{REG,Year}}{\sum_{REG=1}^9 VMTEER_{REG,Year}} \quad (102)$$

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

$$NCS_{REG,class,Year} = NCSTSC_{class,Year} * RSHR_{REG,Year} \quad (103)$$

and,

$$NLTS_{REG,class,Year} = NLTSTSC_{class,Year} * RSHR_{REG,Year} \quad (104)$$

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

where,

- MPG = Vehicle fuel economy
- NCS = New car sales, by size class and region
- NLTS = New light truck sales, by size class and region

3A-3. Consumer Vehicle Choice Module

The CVCM is a forecasting tool designed to support the LDV Module of the NEMS Transportation Sector Model. The objective of the CVCM is to estimate the market penetration (market shares) of conventional and alternative-fuel vehicles during the period 1990-2025. The module uses estimates of new car fuel economy obtained from the MTCM subcomponent of the LDV Module, and fuel price estimates generated by NEMS to forecast technology market shares. The module is useful both to assess the penetration of conventional and alternative-fuel vehicles and to allow analysis of policies that might impact their penetration.

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

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

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_i X_i + \varepsilon_i \quad (105)$$

where P_i is the probability of a consumer choosing vehicle i , β_1 is the constant, β_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:

$$S_{it} = P_{it} = \sum_{n=1}^N \frac{P_{itn}}{N} \quad , \quad P_{itn} = \frac{e^{V_{itn}}}{\sum_{i=1}^I e^{V_{itn}}} \quad (106)$$

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.:

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

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

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

MODEL STRUCTURE

The CVCM 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 MTCM), the CVCM goes through two iterations; first, estimating sales volume using the previous year's volume-dependent prices, then re-estimating prices and consequent sales.

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

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

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

Calculate vehicle purchase price in nominal dollars:

$$PSPR_{vt, FuelType, class} = PRI_{vt, FuelType, class} * TMC_PGDP \quad (107)$$

where,

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

Calculate fuel costs:

$$FLCOST_{vt, FuelType, class, REG} = \frac{FPRICE_{FuelType, REG} * TMC_PGDP}{MPG_{vt, FuelType, class}} \quad (108)$$

where,

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

Calculate acceleration (0-60 mph) in seconds:

$$ACCL_{vt, FuelType, class} = e^{-0.00275} * \left(\frac{HPW_{vt, FuelType, class}}{WGT_{vt, FuelType, class}} \right)^{-0.776} \quad (109)$$

Calculate maintenance and battery costs in nominal dollars:

$$MAINT_{1, FuelType, class, REG} = MAINTCAR_{FuelType, REG} * TMC_PGDP * V$$

and

$$MAINT_{2, FuelType, class, REG} = MAINTTRK_{FuelType, REG} * TMC_PGDP * V \quad (110)$$

where,

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

Calculate Fuel Availability (TALT2) Subroutine Methodology

The fuel availability variable attempts to capture the dynamic associated with the increasing number of refueling stations. The premise is that the number of refueling stations is proportional to the number of vehicles. Therefore, as vehicle stocks accumulate over time, the number of refueling stations will increase as a function of a historical relationship between the number of refueling stations and vehicle stocks. Fuel availability is used in the CVCM Logit Module as an input in determining the proportion of travel associated with the use of alternative-fuels in a flex or bi-fuel vehicle. Fuel availability is also used in the utility function within the CVCM Logit

Module to determine the proportion of sales among various vehicle types or technology groups. The final fuel availability variable is configured as an index relative to the number of gasoline refueling stations.

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

<u>Engine technology fuel type</u>	<u>Highway fuel type</u>
Gasoline	Gasoline
Diesel and diesel hybrid	Diesel
Flex-fuel and dedicated ethanol	Ethanol/gasoline ⁷
Flex-fuel, dedicated and fuel cell methanol	Methanol/gasoline ⁷
Bi-fuel and dedicated CNG	CNG
Bi-fuel and dedicated LPG	LPG
Dedicated electricity	Electricity
Hydrogen fuel cell	Hydrogen

Estimate the vehicle stock used to calculate needed refueling stations:

$$PREDSTK_{hwy_fuel,Year} = LDVSTK_{FuelType,Year-1} + W * LDVSTK_{FuelType=flex:bi-fuel,Year-1} \quad (111)$$

where,

PREDSTK = Predicted vehicle stock used to calculate needed refueling stations

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

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

hwy_fuel = highway fuel type, 1...8

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

⁷ For flex-fuel vehicles.

$$ALTSTAT_{hwy_fuel,Year} = ALTSTAT_{hwy_fuel,Year-1} + \frac{PREDSTK_{hwy_fuel,Year} - PREDSTK_{hwy_fuel,Year-1}}{STARAT_{hwy_fuel}} \quad (112)$$

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:

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

$$AFVSHREG_{REG,hwy_fuel,Year} = \frac{FUELVSA_{REG,hwy_fuel,Year}}{\sum FUELVSA_{REG,hwy_fuel,Year}} \quad (113)$$

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

where,

MPG = Vehicle fuel economy

NCSTECH = Regional car sales by engine technology fuel type

NLTECH = Regional light truck sales by engine technology fuel type

FUELVSA = Regional vehicle sales within a highway fuel type

AFVSHREG = Regional vehicle sales shares within a highway fuel type

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

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

$$FAVAIL_{hwy_fuel,Year,REG} = \frac{ALTSTA_{REG,hwy_fuel,Year}}{ALTSTA_{REG,Gasoline,Year}} \quad (114)$$

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

$$FAVL_{FuelType,REG,Year} = FAVAIL_{hwy_fuel,Year,REG} \quad (115)$$

where the fuel type mapping is described above.

Operation of the module begins at the third level and progresses to the first level, because the valuations at the lower levels are used as a part of the evaluation at the upper levels of the logit model. We start at Level three because it is the first set of calculations we make, namely, the

value function for all vehicle technologies. We then calculate, at Level two, the share of technologies within each group, using the results of Level three. Next, at Level one, we compute the value function and the share of each group using the previous two level results. Finally, we calculate the market share of each vehicle technology using the shares computed in Level one and Level two.

Level Three

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

$$X3132 = X31_{vt,class} * \frac{X23_{vt,class}}{X22_{vt,class}} \tag{116}$$

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

where,

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

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

$$UISUM_{FuelType} = X31_{vt,class} * FLCOST_{vt,FuelType,class,REG} + X3132 * \frac{1}{VRNG_{vt,FuelType,class}} + BETAFA * e^{BETAFA2_{vt,class} * FAVL_{FuelType,REG}} \tag{117}$$

where,

- UISUM = Utility Value function for vehicle attributes at multi-fuel level for fuel type and region
- FLCOST = Fuel cost of driving for Alternative Vehicle fuel technology, *FuelType*, in cents per mile

VRNG = Vehicle range in miles
 FAVL = Fuel availability indexed relative to gasoline
 FuelType = Fuel technologies, gasoline, flex-fuels ethanol and methanol, and bi-fuels
 CNG and LPG

3) Utility values are exponentiated and summed:

$$ESUM_{FuelType} = e^{UISUM_{FuelType}} \quad (118)$$

$$ETOT = \sum ESUM$$

where,

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

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

$$GENCOST = \frac{1}{X 31_{vt,class}} * \log(ETOT) \quad (119)$$

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

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

$$\begin{aligned}
UISUM_{jt} = & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * GENCOST \\
& + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\
& + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\
& + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log(MMAVAIL_{vt,FuelType,class,Year}) \\
& + X210_{vt,FuelType}
\end{aligned} \tag{120}$$

where,

- UISUM_{jt} = Utility value for the jt vehicle type at the second level within one of the five jg groups at the first level
- X21 = Coefficient for vehicle price at the second level in dollars
- X22 = Coefficient for fuel cost per mile at the second level in cents per mile
- X24 = Coefficient for battery replacement cost at the second level
- X25 = Coefficient for vehicle acceleration time from 0 to 60 miles per hour in seconds
- X26 = Coefficient for electric vehicle home refueling capability
- X27 = Coefficient for maintenance cost in dollars
- X28 = Coefficient for luggage space indexed to gasoline vehicle
- X29 = Coefficient for vehicle make and model diversity availability relative to gasoline
- X210 = Coefficient for calibration coefficient determined in trninput.wk1 input file
- PSPR = Vehicle price at the second level in dollars
- BRCOST25 = Battery replacement cost at the second level
- ACCL = Vehicle acceleration time from 0 to 60 miles per hour in seconds
- HFUEL = Electric vehicle home refueling capability dummy variable (0,1 value)
- MAINT = Maintenance cost in dollars
- LUGG = Luggage space indexed to gasoline vehicle
- MMAVAIL = Vehicle make and model diversity availability relative to gasoline exogenously determined in trninput.wk1

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

$$\begin{aligned}
UISUM_{jt} = & X21_{vt,class} * PSPR_{vt,FuelType,class,Year} + X22_{vt,class} * FLCOST \\
& + X23_{vt,class} * \left(\frac{1}{VRNG_{vt,FuelType,class,Year}} \right) \\
& + X24_{vt,class} * BRCOST25_{vt,FuelType,class,Year} + X25_{vt,class} * ACCL_{vt,FuelType,class,Year} \\
& + X26_{vt,class} * HFUEL_{vt,FuelType,class,Year} + X27_{vt,class} * MAINT_{vt,FuelType,class,Year} \\
& + X28_{vt,class} * LUGG_{vt,FuelType,class,Year} + X29_{vt,class} * \log(MMAVAIL_{vt,FuelType,class,Year}) \\
& + X210_{vt,FuelType} + BETAFA2 * e^{BETAFA22_{vt,class} * FAVL_{FuelType,REG,Year}}
\end{aligned} \tag{121}$$

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

$$\begin{aligned}
ESUM_{jt} &= e^{UISUM_{jt}} \\
ETOT_{jg} &= \sum_{jt \subset jg} ESUM_{jt} \\
XSHARE_{jg,jt} &= \frac{ESUM_{jt}}{ETOT_{jg}}
\end{aligned} \tag{122}$$

Level One

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

$$GCOST_{jg} = \frac{1}{X21_{vt,class}} * \log(ETOT_{jg}) \tag{123}$$

where,

GCOST = Generalized cost function of the jg group

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

$$UISUM_{jg} = X11_{vt,class} * GCOST_{jg} \tag{124}$$

3) 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.

$$\begin{aligned}
 ESUM_{jg} &= e^{UISUM_{jg}} \\
 YSHARE_{jg} &= \frac{ESUM_{jg}}{\sum_{jg=1}^5 ESUM_{jg}} \\
 APSHR44_{vt,class,REG,FuelType} &= XSHARE_{jg,jt} * YSHARE_{jg}
 \end{aligned}
 \tag{125}$$

where,

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

Note, APSHR44 is used in equation (143), the vehicle sales equation in the LDV Fleet module.

3B. LDV Fleet Module

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

3B-1. LDV Fleet Module

Fleet Vehicles are treated separately in the transportation model because of the special characteristics of fleet light duty vehicles. The LDV Fleet Module generates estimates of the stock of cars and light trucks that are used in three different types of fleets, as well as VMT, fuel efficiency, and energy consumption estimates that are distinct from those generated for personal light duty vehicles in the LDV 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 Alternative Fuel Vehicle purchases, fleet fuel efficiencies, etc. can be incorporated through the subroutine TLEGIS, which has been set up specifically for this purpose.

The module uses the same variable names for cars and light trucks, which are distinguished by the value of an index designating vehicle type. Vehicles are also distinguished by the type of fleet to which they are assigned. Business, government, and utility fleets are assumed to have

different operating characteristics and retirement rates. This module includes three stages: 1) determine total vehicle purchases, surviving fleet stocks and travel demand, 2) calculate the fuel efficiency of fleet vehicles, and 3) estimate the consequent fuel consumption.

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

Calculate Fleet Sales and Stocks

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

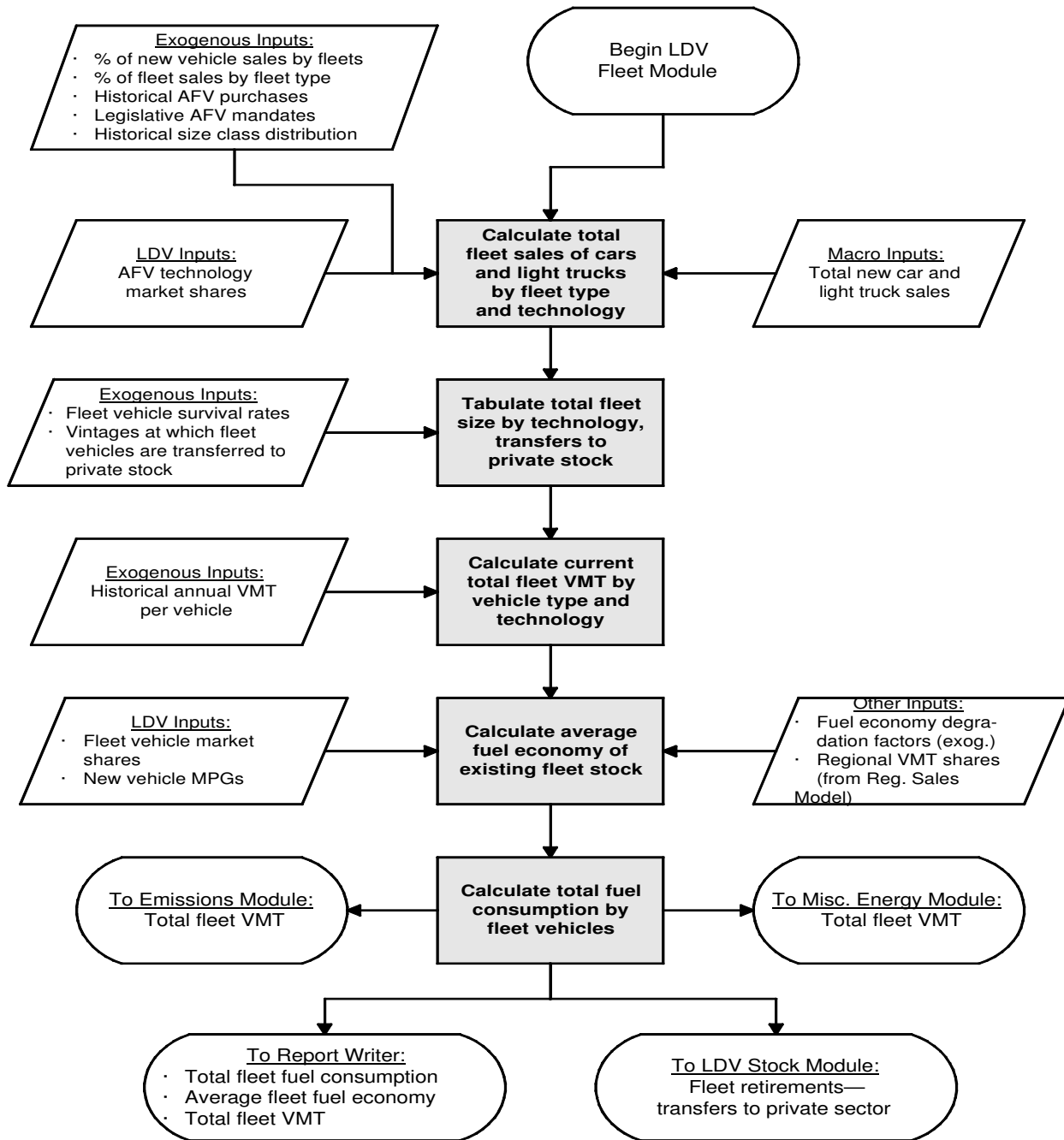
$$\begin{aligned}
 FLTSAL_{vt=1,flt,Year} &= FLTCRAT_{Year} * NEWCARS_{Year} * FLTCSR_{flt,Year} \\
 &\text{and} \\
 FLTSAL_{vt=2,flt,Year} &= FLTTRAT_{Year} * NEWCLS12A_{Year} * FLTTSHR_{flt,Year}
 \end{aligned}
 \tag{126}$$

where,

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

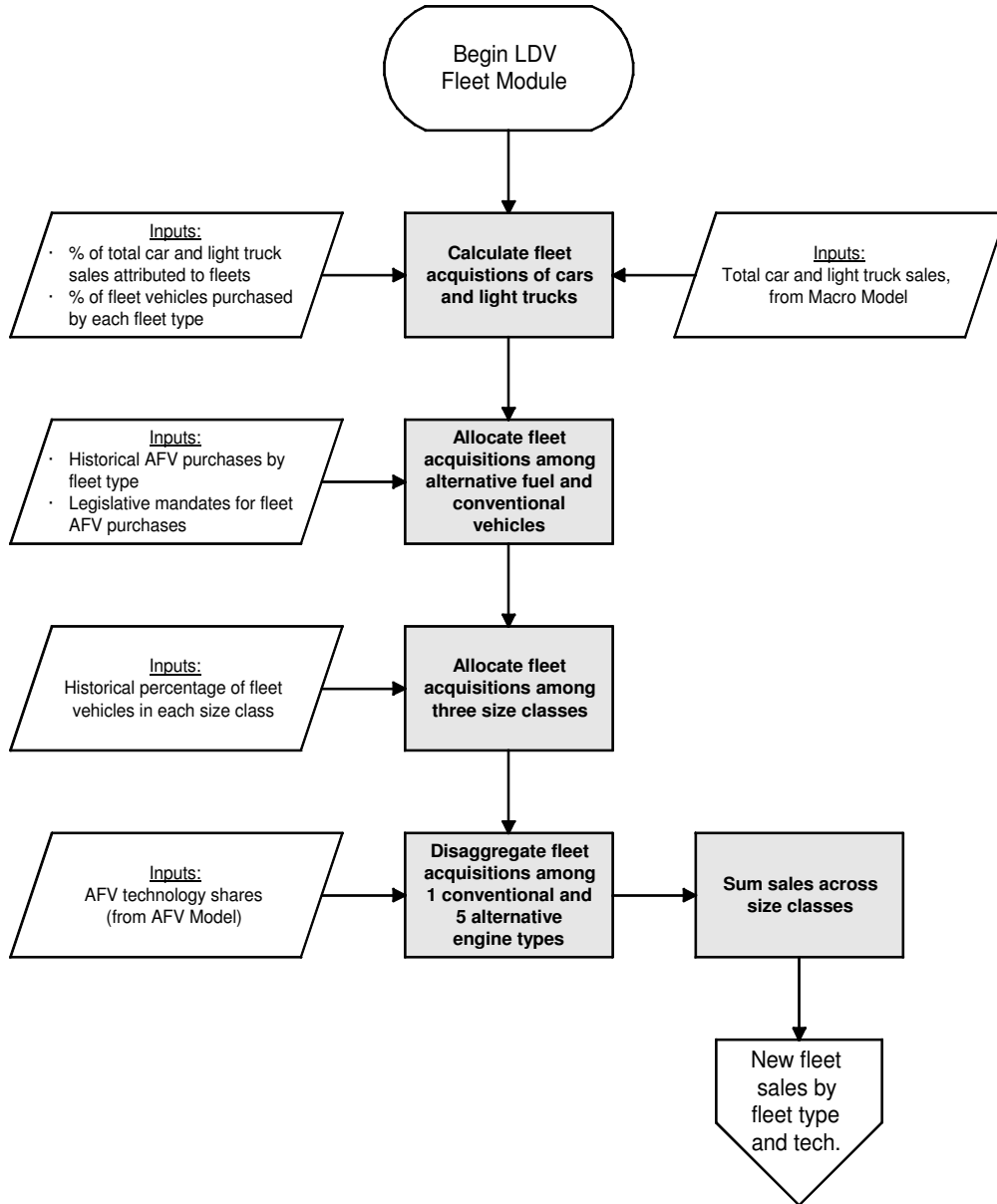
For cars only: separate the business fleet sales into covered and uncovered strata, reflecting the fact that EPACT regulations cover federal, state, and fuel provider fleet vehicles, and do not cover any other fleet vehicles. This separation is based on an extrapolation of historical trends in business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

Figure 7. Light Duty Vehicle Fleet Module



Note: the emissions module is currently inactive.

Figure 8. LDV Fleet Module 1: Process New Fleet Acquisitions



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

$$BFLTFRAC_{Year} = BFLTFRACMIN + (BFLTFRACMAX - BFLTFRACMIN) * e^{KBUS*(Year+1989-1971)} \quad (127)$$

and

$$BUSCOV_{Year} = FLTSAL_{vt=1,flt=1,Year} * BFLTFRAC_{Year} \quad (128)$$

where,

BUSCOV = Business fleet acquisitions covered by EPACT provisions

BFLTFRAC = Fraction of business fleet purchases covered by EPACT provisions in year ,
Year

KBUS = exponential coefficient, estimated to be -0.0404

BFLTFRACMIN = Minimum fraction of business fleet purchases, assumed to be 0.4

BFLTFRACMAX = Maximum fraction of business fleet purchases, assumed to be 0.612

1. For cars:

$$FLTPCT_{vt=1,flt=1} = k_3 * \left[\frac{1}{Ln(50)} \right] \quad (129)$$

2. For light trucks:

$$FLTPCT_{vt=2,flt=1,3} = (50)^{k_{2,flt}} \quad (130)$$

where,

k_3 = Normalized proportionality constant for car fleets, estimated to be 1.386

$k_{2,flt}$ = Proportionality constant for business and utility fleets, -0.747 and -0.111

Calculate the number of alternative vehicles sold for each fleet and vehicle type under EPACT mandates, taking into consideration the geographic and central-refueling constraints. These constraints are constant and are tabulated in Table 3.

1. For cars:

$$FLTALTE_{vt=1,flt=1,Year} = BUSCOV_{Year} * FLTPCT_{vt,flt} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year} \quad (131)$$

and

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

Table 3. Geographic Constraints of Fleet Vehicles

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

2. For light trucks:

$$\begin{aligned}
 FLTALTE_{vt=2,flt=1,3,Year} &= FLTSAL_{vt,flt,Year} * FLTPCT_{vt,flt} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year} \\
 &\text{and} \\
 FLTALTE_{vt=2,flt=2,Year} &= FLTSAL_{vt,flt,Year} * CTLREFUEL_{flt} * MSA_{flt} * FLT20_{flt} * EPACT3_{flt,Year}
 \end{aligned}
 \tag{132}$$

where,

FLTALTE = Alternative Fuel Vehicle sales to fleets under EPACT mandates

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

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

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

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

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

$$FLTALTH_{vt,flt,Year} = FLTSAL_{vt,flt,Year} * FLTAPSHR1_{flt,Year}
 \tag{133}$$

where,

FLTALTH = Fleet Alternative Fuel Vehicle purchases, using constant historical shares.

FLTAPSHR1 = Fleet percentage of Alternative Fuel Vehicle's, by fleet type.

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

$$FLTALT_{vt,flt,Year} = \text{MAX} \left[FLTALTE_{vt,flt,Year}, FLTALTH_{vt,flt,Year} \right]
 \tag{134}$$

where,

FLTALT = Number of Alternative Fuel Vehicle's purchased by each fleet type in a given year
 FLTALTH = Fraction of each fleets purchases that are Alternative Fuel Vehicle's, from historical data
 FLTALTE = Legislative mandates for Alternative Fuel Vehicle purchases, by fleet type

The difference between total and Alternative Fuel Vehicle sales represents conventional sales:

$$FLTCONV_{vt,flt,Year} = FLTSAL_{vt,flt,Year} - FLTALT_{vt,flt,Year} \quad (135)$$

where,

FLTCONV = Fleet purchases of conventional vehicles
 FLTSAL = Sales to fleets by vehicle and fleet type
 FLTALT = Number of Alternative Fuel Vehicle's purchased by each fleet type in a given year

Fleet purchases are subsequently divided by size class:

$$\begin{aligned}
 FLTSLSCA_{vt,flt,class,Year} &= FLTALT_{vt,flt,Year} * FLTSSHR_{flt,class,vt} \\
 &\text{and} \\
 FLTSLSCC_{vt,flt,class,Year} &= FLTCONV_{vt,flt,Year} * FLTSSHR_{flt,class,vt}
 \end{aligned} \quad (136)$$

where,

FLTSLSCA = Fleet purchases of Alternative Fuel Vehicle's, by size class, *class*
 FLTSLSCC = Fleet purchases of conventional vehicles, by size class, *class*
 FLTSSHR = Percentage of fleet vehicles in each size class, from historical data
class = 6 EPA size classes

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

$$\begin{aligned}
 FLTECHSAL_{vt,flt,class,engtech \neq 6} &= FLTSLSCA_{vt,flt,Year} * FLTECHSHR_{engtech \neq 6,flt} \\
 &\text{and} \\
 FLTECHSAL_{vt,flt,class,engtech = 6} &= FLTSLSCC_{vt,flt,class,Year}
 \end{aligned} \quad (137)$$

where,

FLTECHSAL = Fleet sales by size, technology, and fleet type
 FLTECHSHR = Alternative technology shares by fleet type

Engtech = Index of fuel types: 1-5 = alternative fuels (neat), 6 = gasoline

Sales are then summed across size classes:

$$FLTECH_{vt,flt,engtech} = \sum_{class=1}^6 FLTECHSAL_{vt,flt,class,engtech} \quad (138)$$

where,

FLTECH = Vehicle purchases by fleet type and technology

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

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

and

$$FLTSTKVN_{vt,flt,engtech,vint=1,Year} = FLTECH_{vt,flt,engtech} \quad (139)$$

where,

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

SURVFLTT = Survival rate of a given vintage

vint = Index referring to vintage of fleet vehicles

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

$$OLDFSTK_{vt,flt,engtech,vint,Year} = FLTSTKVN_{vt,flt,engtech,vint,Year} \quad (140)$$

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 Module to augment the fleet of private vehicles. The vintages at which these transitions are made are dependent on the type of vehicle and the type of fleet, as shown in Table 4.

Figure 9. LDV Fleet Module 2: Determine Characteristics of Existing Fleets

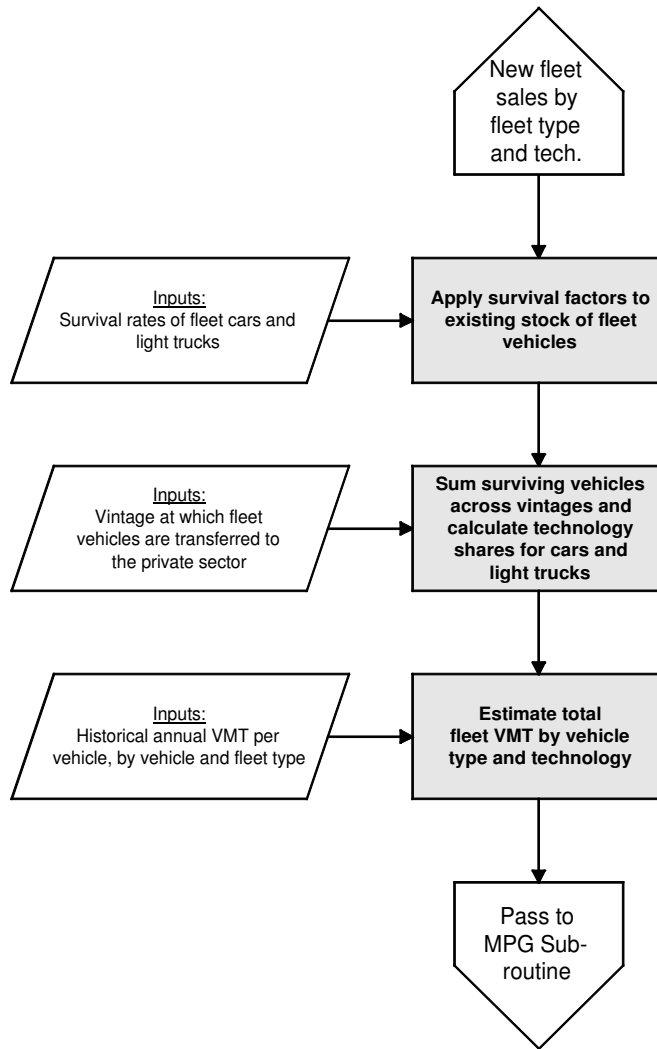


Table 4. Transfer Vintage of Fleet Vehicles

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

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{vt,flt,engtech,Year} = \sum_{vint=1}^6 FLTSTKVN_{vt,flt,engtech,vint,Year} \quad (141)$$

where,

TFLTECHSTK = Total stock within each technology and fleet type

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

$$VFSTKPF_{vt,flt,engtech,Year} = \frac{TFLTECHSTK_{vt,flt,engtech,Year}}{\sum_{vt=1}^2 \sum_{flt=1}^3 \sum_{engtech=1}^6 TFLTECHSTK_{vt,flt,engtech,Year}} \quad (142)$$

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 ZEV's and ultra-low emission vehicles (ULEV's), which have also been tentatively adopted by New York, Massachusetts, Maine, and Vermont.

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

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

and

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

where,

APSHR44 = Share calculated from equation 125

NCS = Regional non-fleet car sales by size class, calculated in equation 103.

NLTS = Regional non-fleet light truck sales by size class, calculated in equation 104.

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

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

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

$$ZEVST_{st} = TTLZEV_{Year} * (COEF1_{st} * NEWCARS_{Year} + COEF2_{st} * NEWCLS12A_{Year}) \quad (144)$$

where,

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

st = Index of participating state: CA = California, NY = New York

MA = Maine, Massachusetts, and Vermont

TTLZEV = Total percent of mandated sales of ZEV's, from input file, trninput.wk1
= ATPZEV + ZEV + ZFCV (found in equations 147, 148, and 149, respectively)

NEWCARS = Total new car sales

NEWCLS12A = Total new light truck sales

COEF1 = Fraction of total new car sales by participating state

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

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

$$TOTCRED_{REG} = \sum_{vt=1}^2 (VSALES_{EVGH}_{vt,REG} + VSALES_{FCM}_{vt,REG} + VSALES_{FCG}_{vt,REG}) \quad (145)$$

where,

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

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

size classes
VSALES_FCG = gasoline fuel cell vehicles sales = VSALES_{FuelType=15}, summed over size classes
TOTCRED = total ZEV sales for gasoline hybrid, methanol and gasoline fuel cell vehicles
REG = census region 1 (participating state MA), 2 (NY), and 9 (CA)

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

$$AVSALES_{vt,class,REG,Gasoline} = VSALES_{vt,class,REG,Gasoline} \quad (146)$$

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

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSAL_{REG,Year} * ATPZEV_{Year}}{TOTCRED_{REG,Year} * VSALES_EVGH_{vt,REG}} \right] \quad (147)$$

where,

AVSALES = total vehicle sales, adjusted for gasoline hybrid and fuel cell (excluding hydrogen) vehicles
ZEVSAL = total ZEV sales that are mandated in census region, REG=1,2, and 9
= ZEVST
= ZEVMA for REG=1 (state=MA)
= ZEVNY for REG=2 (state=NY)
= ZEVCA for REG=9 (state=CA)
ATPZEV = percent of total sales associated with sale of gasoline hybrid, methanol and gasoline fuel cell vehicles, from trinput.wk1

- b) If the total sale of electric vehicles, TZEVSAL, is less than the total maximum allowable Low Emission Vehicle Program (LEVP) sales, ZEVSAL * ZEV, then increase the resulting electric vehicle sales to meet these mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSAL_{REG,Year} * ZEV_{Year}}{TZEVSAL_{REG,Year}} \right] \quad (148)$$

where,

AVSALES = new total vehicle sales, adjusted for electric vehicles

TZEVSAL = total available ZEV sales of electric vehicles
 = VSALES_EV_{vt=1,REG} + VSALES_EV_{vt=2,REG}
 VSALES_EV = electric vehicle sales = VSALES_{FuelType=7}, summed over size classes
 ZEV = percent of total sales associated with sale of electric vehicles, from
 trninput.wk1

- c) If the total sale of hydrogen fuel cell vehicles, TZFCSAL, is less than the total maximum allowable Low Emission Vehicle Program (LEVP) sales, ZEVSAL * ZFCV, then increase the resulting hydrogen fuel cell vehicle sales to meet these mandates:

$$AVSALES_{vt,class,REG,FuelType} = AVSALES_{vt,class,REG,FuelType} * \left[\frac{ZEVSAL_{REG,Year} * ZFCV_{Year}}{TZFCSAL_{REG,Year}} \right] \quad (149)$$

where,

AVSALES = new total vehicle sales, adjusted for hydrogen fuel cell vehicles
 TZFCSAL = total available ZEV sales from hydrogen fuel cell vehicles
 = VSALES_FCH_{vt=1,REG} + VSALES_FCH_{vt=2,REG}
 VSALES_FCH = hydrogen fuel cell vehicle sales = VSALES_{FuelType=14}, summed over size classes
 ZFCV = percent of total sales associated with the sale of hydrogen fuel cell vehicles, in trninput.wk1

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

$$AVSALES_{vt,class,REG,Gasoline} = AVSALES_{vt,class,REG,Gasoline} - DEL_TECH_{vt,class,REG,FuelType} \quad (150)$$

where,

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

Sum the adjusted vehicle sales across technologies:

$$AVSALEST_{vt,class,REG} = \sum_{FuelType=1}^{16} AVSALES_{vt,class,REG,FuelType} \quad (151)$$

where,

AVSALEST = Total regional adjusted vehicle sales by size class

Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{vt,class,REG,FuelType} = \frac{AVSALES_{vt,class,REG,FuelType}}{AVSALEST_{vt,class,FuelType}} \quad (152)$$

where,

APSHR55 = Absolute regional market shares of adjusted vehicle sales

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

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

and

$$NLTECH_{REG,class,FuelType} = NLTS_{REG,class} * APSHR55_{vt=2,class,REG,FuelType} \quad (153)$$

where,

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

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

Calculate Fleet VMT

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

$$FLTVMT_{Year} = \sum_{vt=1}^2 \sum_{flt=1}^3 \sum_{engtech=1}^6 (TFLTECHSTK_{vt,flt,engtech,Year} * FLTVMTYR_{flt,Year,vt}) \quad (154)$$

where,

FLTVMT = Total VMT driven by fleet vehicles

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

TFLTECHSTK = total stock within each technology and flrrt type, calculated in equation 141

Total VMT is then disaggregated by vehicle type and technology:

$$FLTMTECH_{vt,flt,engtech,Year} = FLTVMT_{Year} * VFSTKPF_{vt,flt,engtech,Year} \quad (155)$$

where,

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

VFSTKPF = Share of fleet stock, calculated in equation 142

Calculate Fleet Stock MPG

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

$$FLTMPG_{vt,flt,engtech} = \left[\frac{\sum_{class=1}^6 FLTECHSAL_{vt,flt,class,engtech}}{\sum_{class=1}^6 \frac{FLTECHSAL_{vt,flt,class,engtech}}{MPG_{vt,FuelType,class}}} \right] \quad (156)$$

where,

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

Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{vt} = \left[\frac{\sum_{flt=1}^3 \sum_{engtech=1}^6 FLTECH_{vt,flt,engtech}}{\sum_{flt=1}^3 \sum_{engtech=1}^6 \frac{FLTECH_{vt,flt,engtech}}{FLTMPG_{vt,flt,engtech}}} \right] \quad (157)$$

where,

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

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

For *vint=1*:

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

and

$$TMPGFSTK_{flt,engtech,vint,Year} = FLTMPG_{vt=2,flt,engtech,Year} \quad (158)$$

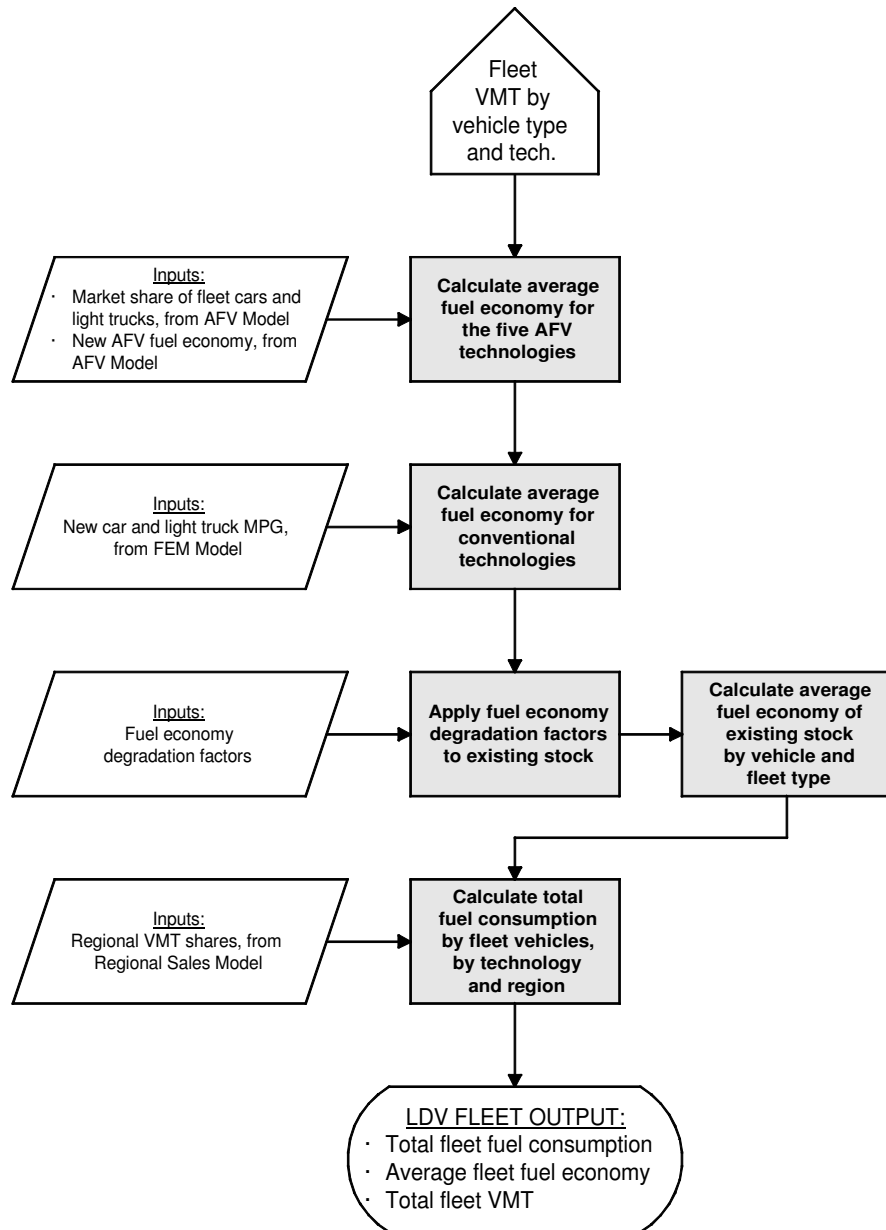
where,

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

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

For *vint=2,7*:

Figure 10. LDV Fleet Module 3: Determine Fleet Fuel Economy and Consumption



$$\begin{aligned}
CMPGFSTK_{flt,engtech,vint,Year} &= CMPGFSTK_{flt,engtech,vint-1,Year-1} \\
&\text{and} \\
TMPGFSTK_{flt,engtech,vint,Year} &= TMPGFSTK_{flt,engtech,vint-1,Year-1}
\end{aligned}
\tag{159}$$

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

$$\begin{aligned}
MPGFLTSTK_{vt=1,flt,engtech} &= \left[\frac{\sum_{vint=1}^{\max vint} FLTSTKVN_{vt=1,flt,engtech,vint}}{\sum_{vint=1}^{\max vint} \frac{FLTSTKVN_{vt=1,flt,engtech,vint}}{CMPGFSTK_{flt,engtech,vint} * CDFRFG}} \right] \\
&\text{and} \\
MPGFLTSTK_{vt=2,flt,engtech} &= \left[\frac{\sum_{vint=1}^{\max vint} FLTSTKVN_{vt=2,flt,engtech,vint}}{\sum_{vint=1}^{\max vint} \frac{FLTSTKVN_{vt=2,flt,engtech,vint}}{TMPGFSTK_{flt,engtech,vint} * LTDFRFG}} \right]
\end{aligned}
\tag{160}$$

where,

- MPGFLTSTK = Fleet MPG by vehicle and fleet type, and technology, across vintages
- Maxvint = Maximum vintage index, *vint*, associated with a given vehicle and fleet type
- CDFRFG = degradation factor for cars
- LTDFRFG = degradation factor for light trucks

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

$$FLTTOTMPG_{vt} = \left[\frac{\sum_{flt=1}^3 \sum_{engtech=1}^6 TFLTECHSTK_{vt,flt,engtech}}{\sum_{flt=1}^3 \sum_{engtech=1}^6 \frac{TFLTECHSTK_{vt,flt,engtech}}{MPGFLTSTK_{vt,flt,engtech}}} \right]
\tag{161}$$

where,

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

Calculate Fuel Consumption by Fleet Vehicles

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

$$FLTLDVC_{vt,flt,engtech} = \frac{FLTMTECH_{vt,flt,engtech,Year}}{MPGFLTSTK_{vt,flt,engtech}} * QBTU_{engtech} \quad (162)$$

where,

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

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

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

$$FLTFCLDVBTU_{vt,engtech,Year} = \frac{FLTMTECH_{vt,flt,engtech,Year}}{MPGFLTSTK_{vt,flt,engtech}} \quad (163)$$

where,

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

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

$$FLTFCLDVBTUR_{REG,engtech,Year} = \sum_{vt=1}^2 FLTFCLDVBTU_{vt,engtech,Year} * RSHR_{REG} \quad (164)$$

where,

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology

RSHR = Regional VMT shares, from the Regional Sales Module

REG = Index of census regions

3B-2. Class 2b Vehicle Module

The Class 2b Vehicle Module provides an accounting of sales, stocks, fuel economy, and energy use for vehicles weighting 8,500 to 10,000 pounds GVW.⁸ The module tracks travel and fuel efficiency for twenty vehicle vintages. The primary purpose of this module is to provide a mechanism to allocate the stock and new sales of Class 2b vehicles among the various major-use groups considered in this module, which includes five industrial categories (e.g., agriculture, mining, construction, total manufacturing, and utility) and one household segment (e.g., personal travel or personal VMT). Historical stock numbers are derived from the Oak Ridge National

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

Laboratory study using Polk data,⁹ and new sales are obtained from the macroeconomic model. The shares used for allocating the stock and new sales information are derived from the 1997 Vehicle Inventory and Use Survey (VIUS). VIUS provides data to use in distributing the VMT by major use group that allows estimation of the total annual miles traveled within each category.

Class 2b Vehicle Module Equations

Calculate the new Class 2b vehicle sales:

$$NEWCLS2B_{Year} = MC_VEHICLES_{4,Year} * 1000 \quad (165)$$

where,

MC_VEHICLES_{4,Year} = Sales of light trucks 8,500 to 10,000 pounds GVW, from the macro module

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

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

and

$$CLTSTK_{vint,Year} = CLTSTK_{vint-1,Year-1} * CLTSURV_{vint-1} \quad (166)$$

where,

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

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

$$CLTVMT_{vint,Year} = CLTSTK_{vint,Year} * CLTVMTV_{vint,1995} * \left(\frac{growth2_{Year}}{growth1_{Year}} \right)^{Year-1995} \quad (167)$$

where,

CLTVMTV = Class 2b vehicle miles traveled per truck for 1995, from trninput.wk1
 growth1 = annual growth in Class 2b vehicle miles traveled
 = $\sum_{vint=1,20}(cltvmt_{vint,Year}) / \sum_{vint=1,20}(cltvmt_{vint,Year-1})$

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

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

Estimate Class 2b vehicle fuel economy by vintage:

$$\begin{aligned}
 CLTMPG_{vint,Year} &= CLTMPGV_{vint}, vint = 1, \dots, 20, Year = 1995 \\
 &\text{and} \\
 CLTMPG_{vint,Year} &= CLTMPG_{vint,Year-1}, vint = 1, Year \geq 1996 \\
 &\text{and} \\
 CLTMPG_{vint,Year} &= CLTMPG_{vint-1,Year-1} * \left[\frac{MPGT_{Gasoline,Year}}{MPGT_{Gasoline,Year-1}} \right], vint \geq 2, Year \geq 1996
 \end{aligned}
 \tag{168}$$

where,

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

CLTMPGV = Base year light-duty truck miles per gallon (gasoline technology)

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

$$\begin{aligned}
 CLTGAL_{Year} &= \sum_{vint=1}^{20} \frac{CLTVMT_{vint,Year}}{CLTMPG_{vint,Year}} \\
 &\text{and} \\
 CLTBTU_{Year} &= CLTGAL_{Year} * \frac{5.253}{42}
 \end{aligned}
 \tag{169}$$

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

$$CLTMPGT_{Year} = \frac{\sum_{vint=1}^{20} CLTVMT_{vint,Year}}{CLTGAL_{Year}}
 \tag{170}$$

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 11.

3C-1. LDV Stock Accounting Module

The LDV stock module is perhaps the most important transportation sector module, since the largest portion of transportation energy consumption, by far, 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 that are transferred from fleets to private ownership. The result is a snapshot of the "average" car for each region.

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

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

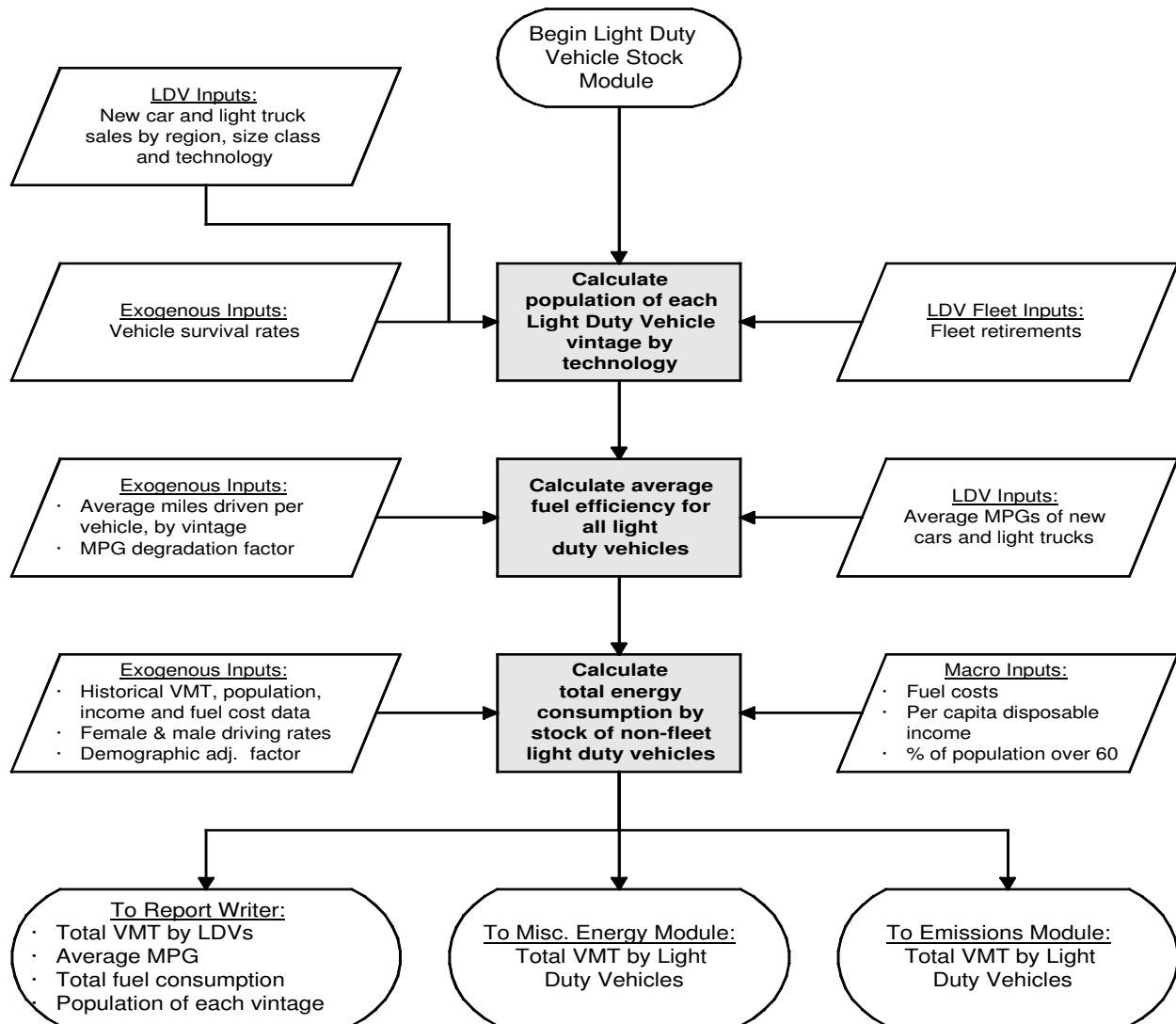
$$\begin{aligned}
 \text{TECHNCS}_{FuelType} &= \sum_{class=1}^6 \sum_{REG=1}^9 \text{NCSTECH}_{REG,class,FuelType} \\
 &\text{and} \\
 \text{TECHNLT}_{FuelType} &= \sum_{class=1}^6 \sum_{REG=1}^9 \text{NLTECH}_{REG,class,FuelType}
 \end{aligned}
 \tag{171}$$

where,

- TECHNCS = Total new car sales, by engine technology fuel type
- TECHNLT = Total new light truck sales, by engine technology fuel type
- NCSTECH = New car sales, by region, size class, and technology, from the CVCM
- NLTECH = New light truck sales, by region, size class, and technology, from the CVCM
- FuelType* = Engine technology fuel types (1-16)

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

Figure 11. Light Duty Vehicle Stock Module



Note: the emissions module is currently inactive.

For $vint = 2-19$:

$$\begin{aligned}
 PASSTK_{FuelType,vint,Year} &= PASSTK_{FuelType,vint-1,Year-1} * SSURVP_{vint-1} \\
 &\text{and} \\
 LTSTK_{FuelType,vint,Year} &= LTSTK_{FuelType,vint-1,Year-1} * SSURVLT_{vint-1}
 \end{aligned}
 \tag{172}$$

For $vint = 20$:

$$\begin{aligned}
 PASSTK_{FuelType,vint=20,Year} &= PASSTK_{FuelType,vint=19,Year-1} * SSURVP_{vint=19} + PASSTK_{FuelType,vint=20,Year-1} * SSURVP_{vint=20} \\
 &\text{and} \\
 LTSTK_{FuelType,vint=20,Year} &= LTSTK_{FuelType,vint=19,Year-1} * SSURVLT_{vint=19} + LTSTK_{FuelType,vint=20,Year-1} * SSURVLT_{vint=20}
 \end{aligned}
 \tag{173}$$

where,

- PASSTK = Surviving car stock, by technology and vintage
- LTSTK = Surviving light truck stock, by technology and vintage
- SSURVP = Fraction of a given vintage's cars that survive
- SSURVLT = Fraction of a given vintage's light trucks that survive

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

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

$$\begin{aligned}
 PASSTK_{FuelType,vint,Year} &= PASSTK_{FuelType,vint,Year} + OLDFSTK_{car,flt,FuelType,vint,Year} \\
 &\text{and} \\
 LTSTK_{FuelType,vint,Year} &= LTSTK_{FuelType,vint,Year} + OLDFSTK_{truck,flt,FuelType,vint,Year}
 \end{aligned}
 \tag{174}$$

where,

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

OLTFSTK = Number of fleet vehicles rolled over into corresponding private categories
vint = Transition vintage: vintage at which vehicles of a given type are transferred

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

$$\begin{aligned}
 STKCAR_{Year} &= \sum_{vint=1}^{20} \sum_{FuelType=1}^{16} PASSTK_{FuelType,vint,Year} \\
 &\quad \text{and} \\
 STKTR_{Year} &= \sum_{vint=1}^{20} \sum_{FuelType=1}^{16} LTSTK_{FuelType,vint,Year}
 \end{aligned}
 \tag{175}$$

where,

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

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

$$VSPLDV_{FuelType,Year} = \frac{\sum_{vint=1}^{20} (PASSTK_{FuelType,vint,Year} + LTSTK_{FuelType,vint,Year})}{STKCAR_{Year} + STKTR_{Year}}
 \tag{176}$$

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:

$$\begin{aligned}
NNSALES_{vt=1,class,FuelType,Year} &= \sum_{REG=1}^9 NCSTECH_{REG,class,FuelType,Year} \\
&\text{and} \\
NNSALES_{vt=2,class,FuelType,Year} &= \sum_{REG=1}^9 NLTECH_{REG,class,FuelType,Year}
\end{aligned}
\tag{177}$$

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

$$\begin{aligned}
MPGC_{FuelType,Year} &= \left[\frac{\sum_{class=1}^6 \frac{NNSALES_{vt=1,class,FuelType,Year}}{MPG_{vt=1,FuelType,class}}}{\sum_{class=1}^6 NNSALES_{vt=1,class,FuelType,Year}} \right]^{-1} \\
&\text{and} \\
MPGT_{FuelType,Year} &= \left[\frac{\sum_{class=1}^6 \frac{NNSALES_{vt=2,class,FuelType,Year}}{MPG_{vt=2,FuelType,class}}}{\sum_{class=1}^6 NNSALES_{vt=2,class,FuelType,Year}} \right]^{-1}
\end{aligned}
\tag{178}$$

where,

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

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

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

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

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

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

and

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

(179)

where,

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

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

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

and

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

(180)

where,

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

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

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

and

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

(181)

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

vehicles:

$$MPGFLT_{Year} = \frac{TOTMICT_{Year} + TOTMITT_{Year}}{CMPGT_{Year} + TMPGT_{Year}} \quad (182)$$

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

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

and

$$TMPG_IT_{FuelType,Year} = \left[\frac{\sum_{vint=1}^{20} \frac{LTSTK_{FuelType,vint,Year} * LVMT_{vint}}{TTMPGSTK_{FuelType,vint,Year} * LTDFRFG}}{\sum_{vint=1}^{20} LTSTK_{FuelType,vint,Year} * LVMT_{vint}} \right]^{-1} \quad (183)$$

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 Module

The travel demand component of the NEMS Transportation Model is a sub-component of the Light Duty Vehicle Stock Module that 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 per driver. This is subsequently combined with forecasts of car fleet efficiency to estimate fuel consumption.

Model Structure

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

Federal Highway Administration Vehicle Data

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

$$\text{LOG}(\text{VMTPD}_{\text{Year}}) - \rho \text{LOG}(\text{VMTPD}_{\text{Year}-1}) = \alpha(1 - \rho) + \sum_{N=1}^3 \beta_N [\text{LOG}(X_{N,\text{Year}}) - \rho \text{LOG}(X_{N,\text{Year}-1})] \quad (184)$$

where,

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

Of greater significance is the historical VMT and stock inputs provided by FHWA. In the past, FHWA's estimate of the number and driving patterns of 2-axle, 4-tire trucks has been interpreted as representing that of Light Duty Trucks, defined as having a weight of less than 8,500 pounds, and thus properly within the purview of the LDV Module. To further refine the module, a category of truck has been defined: Class 2b vehicles, which comprise all single-unit trucks in the 8,500 to 10,000 pound range. The travel demands of these trucks are now modeled separately, based on aggregate measures of industrial output from the Macroeconomic Model.¹³

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

$$\text{VMTPD}_{\text{Year}} = e^{(\rho \text{LOG}(\text{VMTPD}_{\text{Year}-1}) + 1.3004(1 - \rho) + 0.5501[\text{LOG}(\text{VMTPD}_{\text{Year}-1}) - \rho \text{LOG}(\text{VMTPD}_{\text{Year}-2})])} * e^{(0.2564[\text{LOG}(\text{YPC96}_{\text{Year}}) - \rho \text{LOG}(\text{YPC96}_{\text{Year}-1})] + 0.0976[\text{LOG}(\text{CPM96}_{\text{Year}}) - \rho \text{LOG}(\text{CPM96}_{\text{Year}-1})])} \quad (185)$$

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.
 ρ = the lag factor, estimated using the Cochrane-Orcutt iterative procedure to be 0.1829.

¹³ Decision Analysis Corporation, *Development of the Light Commercial Truck Model*, April 23, 1997.

3D. Air Travel Module

The air travel component of the NEMS Transportation Model comprises two separate submodules: the Air Travel Demand Module and the Aircraft Fleet Efficiency Module. These modules 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 Module

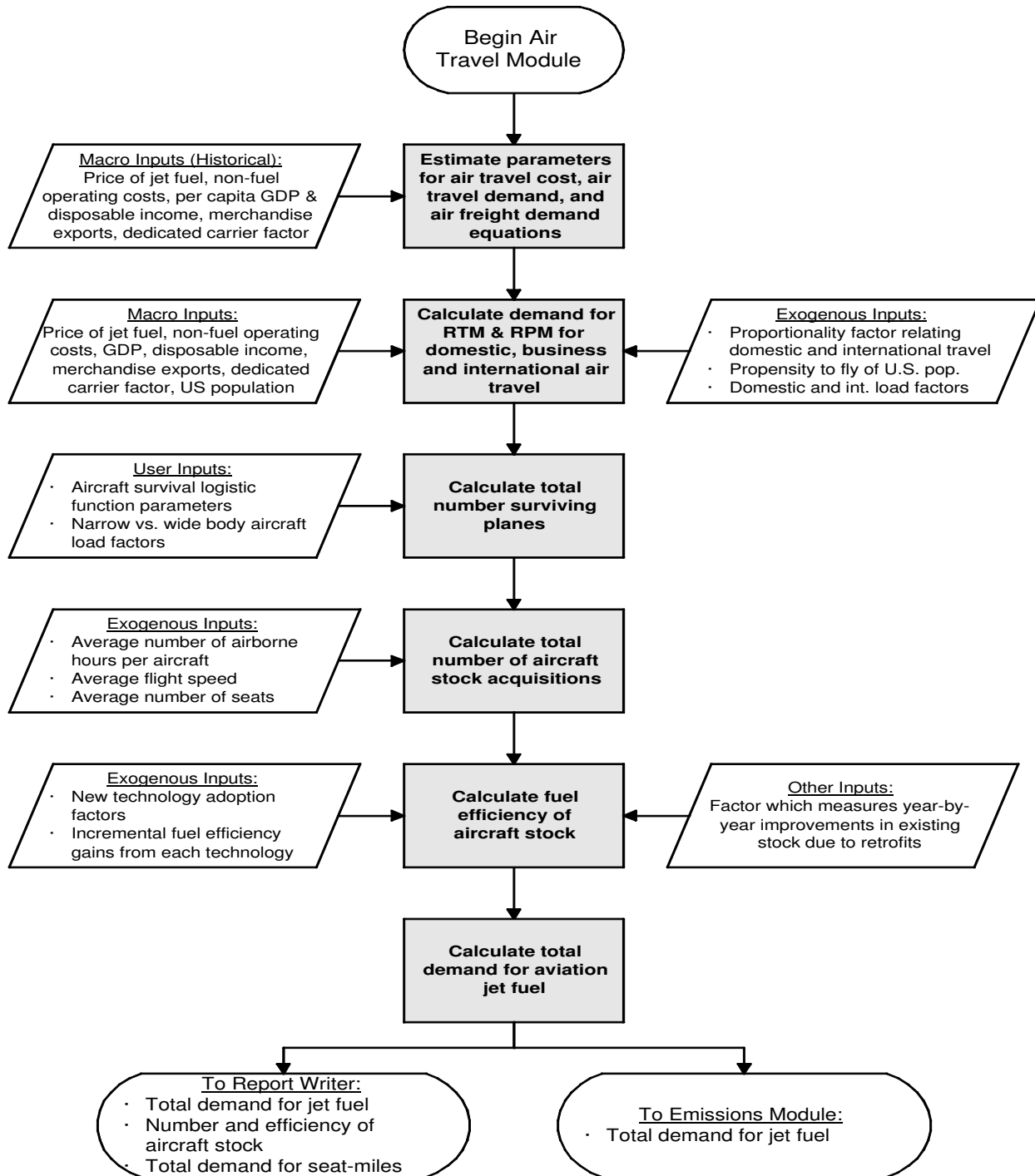
The Air Travel Demand Module produces forecasts of domestic and international passenger travel demand, expressed in revenue passenger-miles (RPMD and RPMI), and air freight demand, measured in revenue ton-miles. RPMD and RPMI are combined into a single demand for seat-miles, and passed to the Aircraft Fleet Efficiency Module, which adjusts aircraft stocks to meet that demand. Aircraft stock is made up of three types of aircraft, wide body, narrow body, and regional jets. To increase the sensitivity of the forecast to economic and demographic parameters, the module incorporates separate treatment of domestic and international passenger travel. Separate forecasts of passenger and freight travel are generated, influenced by economic, demographic and fuel price factors.

The Air Travel Demand Module is based on several assumptions about consumer behavior and the structure of the airline industry. Of greatest significance is the assumption that the deregulation of the industry has substantially altered the dynamics of passenger travel; model parameters have therefore been estimated using only post-deregulation data. It is further assumed that travel demand is influenced by economic conditions. Finally, it is assumed that growth in air travel demand is constrained by airport infrastructure and capacity, and forecasts for each type of travel should not exceed system capacity.

MODEL STRUCTURE

The Air Travel Demand Module, as implemented in NEMS, is a series of linear equations estimated over the period 1980 to 2002. As noted above, it is assumed that domestic and international travel is motivated by economic measures and ticket prices. Key model relationships are presented below. Where numbers appear in place of variable names, parameters have been estimated statistically from historical trends. Also presented in Figure 12 is the flowchart for the Air Travel Module.

Figure 12. Air Travel Module



Note: the emissions module is currently inactive.

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

$$\begin{aligned}
 YIELD_{Dom,Year} &= ALPHAYD * (1 - RHOYD) + RHOYD * YIELD_{Dom,Year-1} + BETAFUELD * (PJFTR_{Year} - RHOYD * PJFTR_{Year-1}) \\
 &\quad - BETATIMED * (YEAR + 11 - RHOYD * (Year + 10)) \\
 &\quad \text{and} \\
 YIELD_{Intl,Year} &= ALPHAYI * (1 - RHOYI) + RHOYI * YIELD_{Intl,Year-1} + BETAFUELI * (PJFTR_{Year} - RHOYI * PJFTR_{Year-1}) \\
 &\quad - BETATIMEI * (YEAR + 11 - RHOYI * (Year + 10))
 \end{aligned}
 \tag{186}$$

where,

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

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

1A) Re-compute the cost of flying if yield is less than the lowest cost-per-mile for domestic and international travel.

$$\begin{aligned}
 YIELD_{Dom,Year} &= \frac{LCPMD}{LFDOMAVG_{Year}} \\
 &\quad \text{and} \\
 YIELD_{Intl,Year} &= \frac{LCPMI}{LFINTAVG_{Year}}
 \end{aligned}
 \tag{187}$$

where,

LCPMD = Lowest Cost-per-mile for Domestic Travel in base year 2002.

LFDOMAVG = Average Domestic Load Factor across the three aircraft types.

LCPMI = Lowest Cost-per-mile for International Travel in base year 2002.

LFINTAVG = Average International Load Factor across the three aircraft types.

2) Calculate total revenue passenger-miles for domestic and international travel:

Domestic:

$$\begin{aligned}
 RPMTD_{Year} &= ALPHARD * (1 - RHORD) + RHORD * RPMTD_{Year-1} + BETARPMD * (RPMTD_{Year-1} - RHORD * RPMTD_{Year-2}) \\
 &\quad + BETAINCD * (INCOME00_{Year} - RHORD * INCOME00_{Year-1}) - BETAYLDD * (YIELD_{Dom,Year} - RHORD * YIELD_{Dom,Year-1}) \\
 &\quad - BETADMYD * (DUMMYD_{Year} - RHORD * DUMMYD_{Year-1})
 \end{aligned}
 \tag{188}$$

where,

RPMTD = Total revenue passenger-miles for domestic travel.

INCOME96 = Personal Income in 1996 dollars.

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

International:

$$\begin{aligned} \text{RPMTI}_{\text{Year}} = & -\text{ALPHARI} * (1 - \text{RHORI}) + \text{RHORI} * \text{RPMTI}_{\text{Year-1}} + \text{BETARMPI} * (\text{RPMTI}_{\text{Year-1}} - \text{RHORI} * \text{RPMTI}_{\text{Year-2}}) \\ & + \text{BETAINCI} * (\text{INCOME00}_{\text{Year}} - \text{RHORI} * \text{INCOME00}_{\text{Year-1}}) - \text{BETAYLDI} * (\text{YIELD}_{\text{Intl, Year}} - \text{RHORI} * \text{YIELD}_{\text{Intl, Year-1}}) \\ & - \text{BETADMYI} * (\text{DUMMYI}_{\text{Year}} - \text{RHORI} * \text{DUMMYI}_{\text{Year-1}}) \end{aligned} \quad (189)$$

where,

RPMTI = Total revenue passenger-miles for international travel.
DUMMYI = Dummy Variable to reflect the impact of 9/11 and industry re-structuring.

2A) Calculate domestic and international revenue-passenger miles by aircraft type

$$\begin{aligned} \text{RPMD}_{\text{atyp, Year}} &= \text{RPMTD}_{\text{Year}} * \text{SRPMD}_{\text{atyp, Year}} \\ &\text{and} \\ \text{RPMI}_{\text{atyp, Year}} &= \text{RPMTI}_{\text{Year}} * \text{SRPMI}_{\text{atyp, Year}} \end{aligned} \quad (190)$$

where,

RPMD = Revenue passenger-miles for domestic travel by aircraft type.
SRPMD = Share of domestic travel performed by aircraft type.
RPMI = Revenue passenger-miles for international travel by aircraft type.
SRPMI = Share of international travel performed by aircraft type.

2B) Calculate maximum total revenue-passenger miles if supply constraint is violated (see (5) for discussion on supply constraint):

$$\text{RPM_MAXTOT} = \text{RPM_MAXCAP}_{\text{Year}} * \left[\frac{\frac{\text{LFDOMAVG}_{\text{Year}} * \text{RPMTD}_{\text{Year}} + \text{LFINTAVG}_{\text{Year}} * \text{RPMTI}_{\text{Year}}}{\text{RPMTD}_{\text{Year}} + \text{RPMTI}_{\text{Year}}}}{\frac{\text{LFDOMAVG}_{\text{Year}} * \text{RPMTD}_{2000} + \text{LFINTAVG}_{\text{Year}} * \text{RPMTI}_{2000}}{\text{RPMTD}_{2000} + \text{RPMTI}_{2000}}} \right] \quad (191)$$

where,

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

RPM_MAXCAP = Maximum capacity available for a given year (see (5) for discussion).

2C) Re-compute revenue-passenger miles for domestic and international travel if supply constraint is violated:

$$\begin{aligned}
 RPMD_{atyp,Year} &= RPMD_{atyp,Year} * \frac{RPM_MAXTOT}{RPMTOT_{Year}} \\
 &\text{and} \\
 RPMI_{atyp,Year} &= RPMI_{atyp,Year} * \frac{RPM_MAXTOT}{RPMTOT_{Year}}
 \end{aligned}
 \tag{192}$$

where,

$RPMTOT = \text{Total revenue passenger miles demanded in the given year} = RPMTD_{Year} + RPMTI_{Year}$.

2D) Re-compute total domestic and international revenue-passenger miles:

$$\begin{aligned}
 RPMTD_{Year} &= \sum_{atyp=1}^3 RPMD_{atyp,Year} \\
 &\text{and} \\
 RPMTI_{Year} &= \sum_{atyp=1}^3 RPMI_{atyp,Year}
 \end{aligned}
 \tag{193}$$

3) Calculate the dedicated RTM of air freight:

$$RTM_{Year} = ALPHARTM - BETAPJFR * PJFTR_{Year} + BETAXIM * MC_EXDAN96C_{Year}
 \tag{194}$$

where,

$MC_EXDAN96C = \text{Value of merchandise exports, in 1996 dollars}$

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

$$\begin{aligned}
 ASMDEMD_{atyp,Year} &= \frac{RPMD_{atyp,Year}}{LFDOM_{atyp,Year}} + \frac{RPMI_{atyp,Year}}{LFINTER_{atyp,Year}} \\
 &\text{and} \\
 SMDEMD_{Year} &= \sum_{atyp=1}^3 ASMDEMD_{atyp,Year}
 \end{aligned}
 \tag{195}$$

where,

$ASMDEMD = \text{Demand for available seat-miles, by aircraft type}$

SMDEMD = Total demand for available seat-miles.

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

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

5) Derivation of Supply Constraint:

The Air Travel Demand Module supply constraint is based on data from the FAA Airport Capacity Benchmark Report.¹⁴ Variables used to establish constraint on total revenue passenger miles are:

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

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

$$RPM_MAXCAP_{Year} = (RPMTOT_{2000} + 514.0) * \left(1 + e^{(n-13) * \ln\left(\frac{.07}{13}\right)} \right) \quad (196)$$

where,

n = Index to year (for base year: 2000, n = 0)

3D-2. Aircraft Fleet Efficiency Module

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

The intent of this component is to provide a quantitative approach for estimating aircraft fleet energy efficiency. To this end, the module estimates surviving aircraft stocks and average characteristics at a level of disaggregation that is supportable by available data, and projects the fuel efficiencies of new acquisitions under different sets of economic and technological scenarios. The resulting fleet average efficiencies are returned to the Air Travel Demand

Module to support the forecast of commercial passenger and freight carriers' jet fuel consumption to the year 2025.

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

Total fleet efficiency is based on separate estimates of the stock and efficiency of the three types of aircraft considered by the module: narrow body, wide body, and regional jets.¹⁵ The development of the hub and spoke system lead airlines to invest in smaller aircraft for years. In 1991, narrow body aircraft accounted for approximately 54 percent of total available seat-miles, and wide body aircraft accounted for 41 percent, with regional jets accounting for the remaining 5 percent. By 2000, narrow body aircraft accounted for approximately 60 percent of total available seat-miles, and wide body aircraft accounted for 33 percent, with regional jets accounting for the remaining 7 percent.

MODEL STRUCTURE

The module operates in three stages: 1) estimates the sales of new aircraft; 2) determines the total fleet of each type of aircraft required to meet projected demand in any given year; and 3) determines the stock efficiency, given assumptions about the retirement rate of aircraft and the incorporation of energy-efficient technologies in new acquisitions.

Sales of New Aircraft

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

¹⁴ Federal Aviation Administration, *Airport Capacity Benchmark Report 2004*, U.S. Department of Transportation (2004).

¹⁵ Narrow body aircraft, such as the Airbus 320 and Boeing 737, have seating for approximately 120-180 passengers, and are characterized by two banks of seats separated by a center aisle. Wide body aircraft, such as the Boeing 747, carry from 200-500 passengers in three banks of seats. Regional Jets, such as the Canadair RJ-100, have seating for approximately 50-110 passengers.

from three years ago:

$$STKAC_SALES_{Year} = ALPHASAL + BETARPMs * RPMTOT_{Year-3} + BETAGDPS * LOG(MC_GDPR_{Year}) - BETATIMS * (Year + 9) \quad (197)$$

where,

$$STKAC_SALES = \text{Total Sales of New Aircraft}$$

Sales of new aircraft are then allocated between the three aircraft types considered by the module. The fraction of sales attributable to each aircraft type is derived from Boeing's Current Market Outlook 2003 forecast.

$$STKAC_SUP_{atyp,age=1,Year} = STKAC_SALES_{Year} * SHR_NEW_STK_{atyp,Year} \quad (198)$$

where,

$$\begin{aligned} STKAC_SUP &= \text{Stock of new aircraft, age=1, by the three aircraft types.} \\ SHR_NEW_STK &= \text{Fraction of total sales attributable to each aircraft type} \end{aligned}$$

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

Stock Estimation

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

It is important to provide an accurate portrayal of the age distribution of airplanes because of the relatively small size of the U.S. commercial fleet, slightly fewer than eight thousand five hundred aircraft.¹⁶ This distribution determines the number of aircraft retired from service each year, and consequently has a strong influence on the number of new aircraft acquired to meet air travel demand. Due to the international nature of the market for aircraft, constructing a survival

¹⁶ Bureau of Transportation Statistics, *National Transportation Statistics*, U.S. Department of Transportation (2003), March 2004, Table 1-11.

algorithm using only domestic deliveries and stocks is not feasible because aircraft of different vintages are regularly bought and sold on the international market and the surviving domestic stock of a given vintage may exceed the number of aircraft of that vintage that had originally been delivered domestically. The problem is mitigated by assuming that the scrappage rate of aircraft on a worldwide basis also characterizes that of domestic aircraft. The available aircraft capacity is calculated once the number of surviving aircraft by type is established. Historical data on aircraft stocks and scrappage rates are taken from the World Jet Inventory Year publication.¹⁷ The stock of surviving passenger aircraft are subsequently estimated with the following equation:

$$STKAC_SUP_{atyp,age,Year} = STKAC_SUP_{atyp,age-1,Year-1} * SURVAC_{atyp,age} \quad (199)$$

where,

STKAC_SUP = Stock of surviving passenger aircraft by aircraft type, of a given age.

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

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

$$STK_CARGO_{atyp,age,Year} = STK_CARGO_{atyp,age-1,Year-1} * SURVAC_{atyp,age} \quad (200)$$

where,

STK_CARGO = Stock of surviving cargo aircraft by aircraft type

Older passenger planes are often converted for use in cargo service. Starting with passenger aircraft of vintage 25 years, the aircraft stock module moves aircraft into cargo service.

Reflecting this, the stock of cargo aircraft is defined by:

$$STK_CARGO_{atyp,age,Year} = STK_CARGO_{atyp,age-1,Year-1} + STKAC_SUP_{atyp,age,Year} * CARGO_PCT_{age} \quad (201)$$

where,

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

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

¹⁷ Jet Inventories Inc., *World Jet Inventory: Year-End 2003*, (March 2004).

$$STKAC_SUP_{atyp,age,Year} = STKAC_SUP_{atyp,age,Year} * (1 - CARGO_PCT_{age}) \quad (202)$$

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

$$STKAC_SUP_TOT_{atyp,Year} = \sum_{age} STKAC_SUP_{atyp,age,Year} \quad (203)$$

where,

STKAC_SUP_TOT = Total stock of passenger aircraft by aircraft type.

Parked and Active Aircraft

The demand for commercial aircraft is then calculated. The demand for commercial aircraft is based on the growth of travel demand. The seat miles flown per aircraft have historically grown slowly. Available seat-miles demanded is obtained from the air travel demand module, and the demand for aircraft is:

$$STKAC_DMD_{atyp,Year} = \frac{ASMDEMD_{atyp,Year}}{ASMACH_{atyp,Year}} \quad (204)$$

where,

STKAC_DMD = Stock of aircraft demanded to meet travel demand, by aircraft type.
 ASMACH = Available seat-miles flown per aircraft

Surviving aircraft capacity is then compared with the travel demand estimates described above. The difference represents the additional capacity required to meet demand. If in any given year, the demand for aircraft, STKAC_DMD, is greater than the supply of aircraft available, STKAC_SUP_TOT, the aircraft supply module parks excess aircraft. If the demand for aircraft is greater than the supply of aircraft, then new aircraft are unparked and placed into active service.

The distribution of parked planes is based on historical data taken from World Jet Inventory for year-end 2002 and is defined as follows:

$$STKAC_MOD_{atyp,age,Year} = STKAC_SUP_{atyp,age,Year} * PCT_PARKED_{atyp,age} \quad (205)$$

where,

STKAC_MOD = Stock of passenger aircraft that is to be parked, by aircraft type and age.

Passenger aircraft is parked, $STKAC_PARKED_{atyp,age,Year}$, starting with the oldest aircraft, according to the stock of parked aircraft, $STKAC_MOD$, until the supply and demand difference is met.

The active aircraft stock in any year, consists of the total stock of aircraft less aircraft that are parked, which is defined as:

$$STKAC_ACTIVE_{atyp,age,Year} = STKAC_SUP_{atyp,age,Year} - STKAC_PARKED_{atyp,age,Year} \quad (206)$$

where,

$STKAC_ACTIVE$ = Active stock of passenger aircraft, by aircraft type and age.

Fleet Efficiency Improvements

Efficiency improvements of newly acquired aircraft are determined by technology choice that is dependent on the year in question, the type of aircraft and the price of fuel. There are six new technologies, ifx , to choose from, including: ultra-high bypass (engine), propfan (engine), thermodynamics (engines), hybrid laminar flow (aerodynamics), advanced aerodynamics (aerodynamics), and weight-reducing materials. In order to model a smooth transition from old to new technologies, the efficiencies of new aircraft acquisitions are based on several logistic functions that reflect the commercial viability of each technology. The two arguments, the time effect (TIMEFX) and the price effect (COSTFX), are based on the assumption that the rate of technology incorporation is determined not only by the length of time the technology has been commercially viable, but also by the magnitude of a given technology's price advantage as shown in the following:

$$TIMEFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year-1} + (TIMECONST_{atyp} * TPN_{ifx,atyp} * TYRN_{ifx,atyp}) \quad (207)$$

where,

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

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

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

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

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

The cost effect is now calculated:

$$COSTFX_{ifx,atyp,Year} = \left[\frac{TPJFGAL_{Year} - TRIGPRICE_{ifx,atyp}}{TPJFGAL_{Year}} \right] * TPN_{ifx,atyp} * TYRN_{ifx,atyp} * TPZ_{ifx,atyp} \quad (208)$$

where,

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

TPJFGAL = Price of jet fuel.

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

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

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

$$TOTALFX_{ifx,atyp,Year} = TIMEFX_{ifx,atyp,Year} + COSTFX_{ifx,atyp,Year} - BASECONST \quad (209)$$

where,

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

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

$$TECHPEN_{ifx,atyp,Year} = \left[1 + e^{-TOTALFX_{ifx,atyp,Year}} \right]^{-1} \quad (210)$$

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

$$FRACIMP_{atyp,Year} = 1.0 + EFFIMP_{ifx=1} * (TECHPEN_{ifx=1,atyp,Year} - TECHPEN_{ifx=2,Year}) + \sum_{ifx=2}^6 EFFIMP_{ifx} * TECHPEN_{ifx,atyp,Year} \quad (211)$$

and

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

where,

FRACIMP = Fractional efficiency improvement for the three aircraft types.

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

atyp = Narrow Body and Regional Jet Aircraft.

WB = Wide Body Aircraft.

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

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

$$\begin{aligned}
 ASMPGD_{atyp,age=1,Year} &= ASMPGD_{atyp,age=1,Year=2002} * FRACIMP_{atyp,Year} \\
 &\text{and} \\
 ASMPGI_{atyp,age=1,Year} &= ASMPGI_{atyp,age=1,Year=2002} * FRACIMP_{atyp,Year}
 \end{aligned}
 \tag{212}$$

where,

ASMPGD = Domestic aircraft fuel efficiency in available seat-miles per gallon.

ASMPGI = International aircraft fuel efficiency in available seat-miles per gallon.

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

$$\begin{aligned}
 ASMPGD_{atyp,age,Year} &= ASMPGD_{atyp,age-1,Year-1} \\
 &\text{and} \\
 ASMPGI_{atyp,age,Year} &= ASMPGI_{atyp,age-1,Year-1}
 \end{aligned}
 \tag{213}$$

Total available seat miles per gallon, $ASMPGT_{Year}$, is computed as the harmonic average of domestic fuel efficiency and international fuel efficiency, weighted by domestic and international available seat-miles.

Estimating Fuel Consumption

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

$$SMD_TOT_{Year} = SMDEMD_{Year} + RTM_{Year} * EQSM
 \tag{214}$$

where,

SMD_TOT = Total seat-miles demanded
 EQSM = Factor that converts Revenue Ton Miles to Seat-miles

The demand for jet fuel is then defined by:

$$JFGAL_{Year} = \frac{SMDTOT_{Year}}{ASMPGT_{Year}} \quad (215)$$

The demand for aviation gasoline is defined as:

$$AGD_{Year} = BASEAGD + GAMMA * e^{-KAPPA*(Year-1979)} \quad (216)$$

where,

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

Jet fuel demand is converted from gallons into Btu using the following relationships:

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

and

$$AGDBTU_{Year} = AGD_{Year} * \frac{5.048MMBtu / bbl}{42 gal / bbl} \quad (217)$$

Jet fuel and aviation gasoline demand by region is estimated by the following:

$$QJETR_{REG,Year} = JFBTU_{Year} * SEDSHR_{JetFuel,REG,Year}$$

and

$$QAGR_{REG,Year} = AGDBTU_{Year} * SEDSHR_{AvGas,REG,Year} \quad (218)$$

where,

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

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 module 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 retrofitting. This results in a low turnover of capital stock and the consequent dampening of improvement in average energy efficiency. Given the long forecast horizon, however, this component will provide estimates of modal efficiency growth, driven by assumptions about systemic improvements modulated by fuel price forecasts.

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

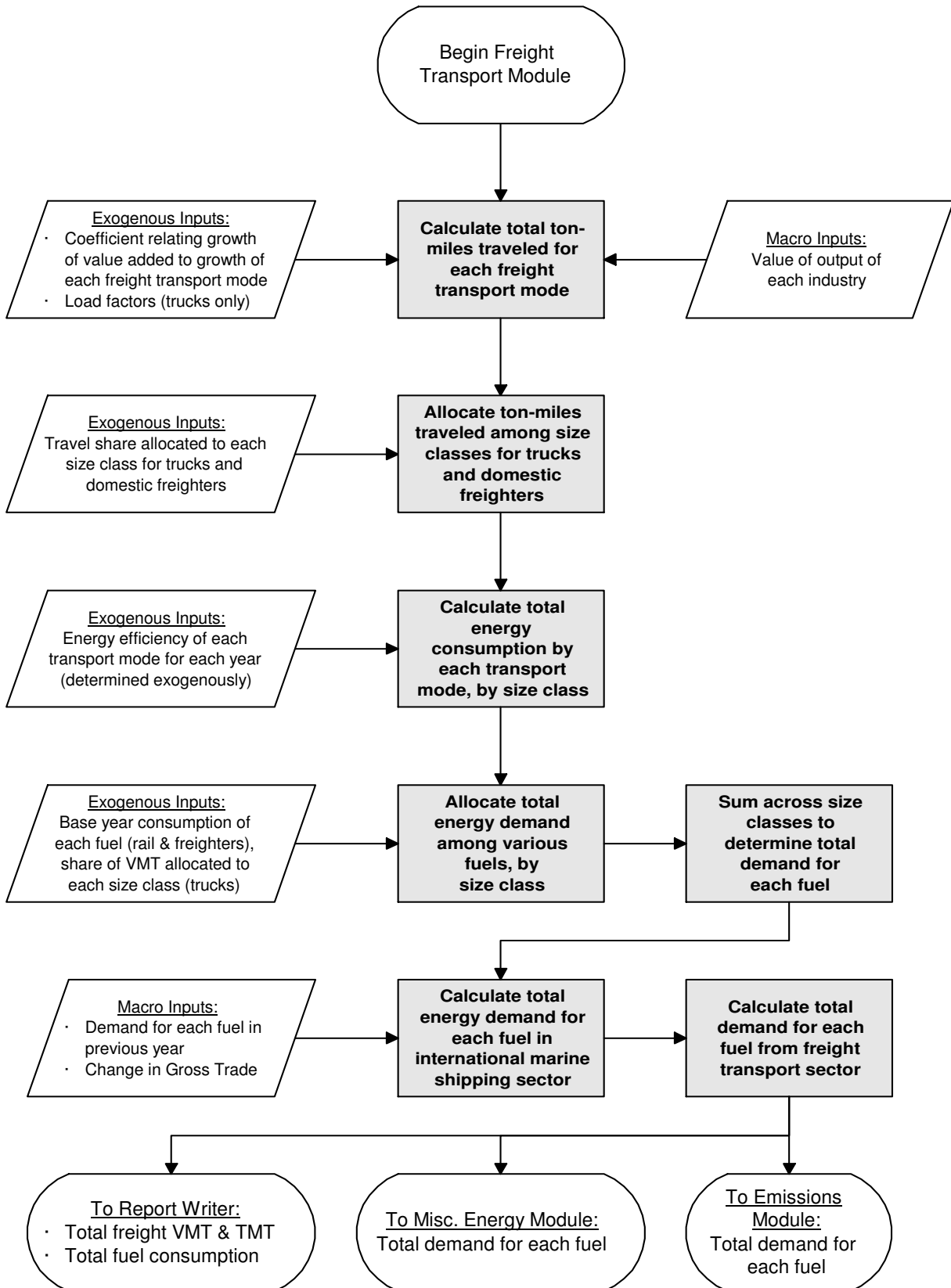
The freight transport module developed for NEMS incorporates additional levels of detail. This is accomplished by stratifying the trucking sector according to size class and developing a stock adjustment model for each size class and fuel type. Parameters relating industrial output tonnage to changes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

The NEMS Freight Transport Module aggregates the value of output from various industries into a reduced classification scheme, relating the demand for transport to the growth in the value of output of each industrial category. The relationships used for truck, rail, and waterborne freight are presented in sequence below. The flowchart for the Freight Transport Module is presented in Figure 13.

3E-1. Freight Truck Stock Adjustment Module

This section describes the methodology of the freight truck stock module that has been integrated

Figure 13. Freight Transport Module



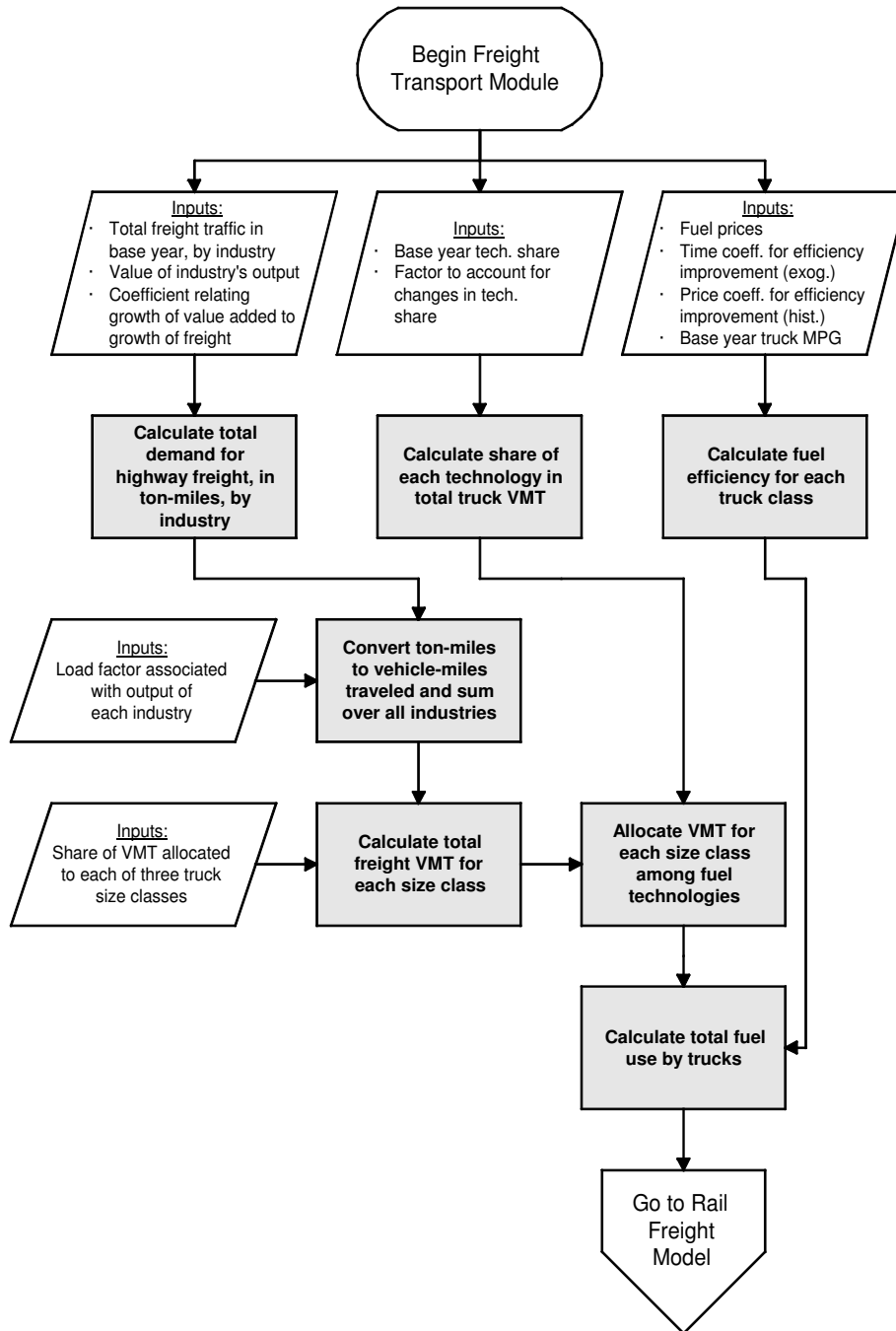
into the Transportation Demand Sector Model of the NEMS. The Freight Truck Stock Adjustment Module (FTSAM) allows for manipulation of a number of important parameters, including the market penetration of existing and future fuel-saving technologies as well as alternatively-fueled heavy-duty vehicles.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

Forecasts are made for three modes of freight transport: trucks, rail, and ships. In each case, travel forecasts are based on the industrial production of specific industries, travel growth in most cases being directly proportional to increases in value of goods produced. Rail additionally uses NEMS coal forecasts to account for part of the travel. The Rail and Ship modules 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 Module utilizes vintage, size class, sector, and fuel technology-specific freight truck fuel economies to derive energy demand.

The Freight Truck Stock Adjustment Module forecasts the consumption of diesel fuel, motor gasoline, liquefied petroleum gas (LPG), and CNG accounted for by freight trucks in each of twelve industrial sectors. Twenty truck vintages, three truck size classes and two fleet types are tracked throughout the module, each having its own average fuel economy and average number of miles driven per year. The three truck size classes are defined as follows: class 3 trucks 10,001 to 14,000 pounds GVW, classes 4-6 trucks 14,001 to 26,000 pounds GVW, and classes 7-8 trucks > 26,000 pounds GVW. This section presents and describes the methodology used by the module to forecast each of these important variables. See Figure 14 for the flow chart of the Highway Freight module.

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

Figure 14. Highway Freight Module



fuel economy to determine fuel consumption. Finally, the truck stocks are rolled over into the next vintage, and the module is prepared for the next year's run.

1. Estimate New Truck Fuel Economies

The first step in the FTSAM is to determine the characteristics of the incoming class of truck purchases. Estimates of new light, medium heavy, and heavy truck fuel economies are generated endogenously and depend on the market penetration of specific fuel-saving technologies. Currently existing fuel-saving technologies are based on the report, *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis for the NEMS Transportation Sector Model*, Argonne National Laboratory¹⁸ 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 *The Potential Effect of Future Energy Efficiency and Emissions Improving Technologies on Fuel Consumption of Heavy Trucks*, Argonne National Laboratory,¹⁹ and include advanced transmissions, lightweight materials, synthetic gear lube, advanced drag reduction, advanced tires, electronic engine controls, turbocompounding, hybrid power trains, and port-injection. Place holders allow for the introduction of four additional technologies. Future technologies can enter the market at various times throughout the module 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.

The first step the module executes in each year is to calculate the average fuel price over the previous three years:

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

where,

¹⁸ *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.

¹⁹ *The Potential Effect of Future Energy Efficiency and Emissions Improving Technologies on Fuel Consumption of Heavy Trucks*, Argonne National Laboratory, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 2002.

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

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

$$TGPRC_{XG_{Year,SC,Fr_t_Fuel,Fr_t_Tech}} = \frac{CAPCXG_{SC,Fr_t_Fuel,Fr_t_Tech}}{\sum_{IP=1}^{PAYBKXG_{SC,Fr_t_Tech}} \frac{MBTUTKXG_{SC} * MPGIPXG_{SC,Fr_t_Fuel,Fr_t_Tech}}{1 + (.01 * DISCRTXG)^{IP}}} \quad (220)$$

where,

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

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

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

$$PREFF_{Year,Fr_t_Fuel,Fr_t_Tech} = 1 + PRVRXG_{SC,Fr_t_Fuel,Fr_t_Tech} * \left[\frac{CFAVPC_{Year,Fr_t_Fuel}}{TGPRC_{XG_{SC,Fr_t_Fuel,Fr_t_Tech}}} - 1 \right] \quad (221)$$

where,

PREFF = Effect of fuel price on market penetration rates for each freight technology
 PRVRXG = Exogenously determined fuel price sensitivity parameter for each freight technology, representing the percent increase in technology market share if

fuel price exceeds cost effective price by 100 percent

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

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

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

where,

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

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

MIDPT = Exogenous parameter for existing technologies

COEFF = Market penetration curve for existing technologies

STYEAR = First year technology is available

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

$$TECHSHR_{Year, SC, Frt_Fuel, Frt_Tech} = PREFF_{Year, Frt_Fuel, Frt_Tech} * PEN_{Year} \quad (223)$$

where,

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

However, if this is a fuel efficiency technology, and if the fuel price has not reached the trigger price, but the previous years technology market share is non-zero, then the current years market share grows at the same rate as the market penetration price sensitivity multiplier as follows:

$$TECHSHR_{Year, SC, Frt_Fuel, Frt_Tech} = TECHSHR_{Year-1, SC, Frt_Fuel, Frt_Tech} * \frac{PREFF_{Year, Frt_Fuel, Frt_Tech}}{PREFF_{Year-1, Frt_Fuel, Frt_Tech}} \quad (224)$$

Finally, if this is a fuel efficiency technology, and if the fuel price has not reached the trigger price, and the previous years technology market share is zero, then the current years market share is as follows:

$$TECHSHR_{Year,SC,Frt_Fuel,Frt_Tech} = MINP \quad (225)$$

If technology A is superseded by another mutually exclusive technology B at any time during the module run, technology A's market share must be adjusted to reflect the smaller pool of vehicles in its base market according to the relationship:

$$TECHSHR_{Year,SC,Frt_Fuel,Frt_Tech} = TECHSHR_{Year,SC,Frt_Fuel,Frt_Tech} * (1 - SPRSDEFF_{Year,SC,Frt_Fuel,Frt_Tech}) \quad (226)$$

where,

SPRSDEFF = Superseding effect, equal to the market share of the superseding technology

Once the market shares in a given year are established, the effects of the technologies on the base fuel cost are tallied and combined to form a vector of "MPG Effects", which is used to augment the base fuel economy of new trucks of each size class and fuel type as defined by:

$$MPGEFF_{Year,SC,Frt_Fuel} = \prod_{Frt_Tech=1}^{40} (1 - MPGIPXG_{SC,Frt_Fuel,Frt_Tech} * TECHSHR_{Year,SC,Frt_Fuel,Frt_Tech}) \quad (227)$$

where,

MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in a given year

MPGIPXG = Exogenous factor representing percent improvement in fuel economy due to each technology

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

$$CFMPG_{Year,SC,AGE=1,Frt_Fuel} = \frac{BSMPGXG_{SC,Frt_Fuel}}{MPGEFF_{Year,SC,Frt_Fuel}} \quad (228)$$

where,

BSMPGXG = Fuel economy of new freight trucks with no fuel-saving technologies

2. Determine the Share of Each Fuel Type in Current Year's Class of New Trucks

Another major characteristic of the current year's class of new trucks, the market share of each fuel type, is calculated in the second FTSAM routine. Market penetration of alternative fuel freight trucks is more likely to be driven by legislative and/or regulatory action than by strict

economics. For this reason, separate trends are incorporated for fleet vehicles, which are assumed to be more likely targets of future legislation, and non-fleet vehicles. The fuel technology routine described below is intended to simulate economic competition among fuel technologies after the creation of a market for alternative fuel trucks by government action. The user specifies the market share alternative fuel trucks are likely to achieve if they have no cost advantage over conventional technologies. The inherent sensitivity of each fuel technology to the cost of driving is also specified exogenously. The latter parameter represents the commercial potential of each fuel technology over and above what is mandated by government, and serves to modify the exogenous trend based on relative fuel prices and fuel economies. Additional user-specified parameters include the year in which the market penetration curves are initiated and the length of the market penetration cycle.

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

$$FCOST_{Year,SC,Frt_Fuel} = \frac{CFAVPC_{Year,Frt_Fuel}}{CFMPG_{Year,SC,Frt_Fuel}} * HTRATE \quad (229)$$

where,

FCOST = Fuel cost of driving a truck of fuel type Frt_Fuel, in dollars per mile
HTRATE = Heat rate of gasoline, in million Btu per gallon
Frt_Fuel = 1, 3, 4 = non-gasoline trucks

Market Share of Alternative Fuel Vehicles

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

$$DCOST_{Year,SC,Frt_Fuel} = 1 - PRAFDXG_{SC,Frt_Fuel} * \left[\frac{FCOST_{Year,SC,Frt_Fuel}}{FCOST_{Year,SC,Frt_Fuel=1}} - 1 \right] \quad (230)$$

where,

DCOST = Fuel cost per mile of diesel relative to LPG and CNG
PRAFDXG = Exogenously determined parameter representing inherent variation in Alternative Fuel Vehicle market share due to difference in fuel prices
= 1, for LPG and CNG vehicles
Frt_Fuel = 3, 4

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

$$SLOPE_{SC,Fr t_Fuel,FLT} = \frac{\ln(0.01)}{0.5 * CYAFVXG_{SC,Fr t_Fuel,FLT}}$$

and

$$MIDYR_{SC,Fr t_Fuel,FLT} = TRGSHXG_{SC,Fr t_Fuel,FLT} + 0.5 * CYAFVXG_{SC,Fr t_Fuel,FLT} \quad (231)$$

where,

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

SLOPE = Endogenously determined logistic market penetration curve parameter
 CYAFVXG = Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration

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

TRGSHXG = Exogenously determined year in which each alternative fuel begins to increase in market share, due to EPACT or other factors

Fr t_Fuel = 3, 4

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

$$MPATH_{Year,SC,Fr t_Fuel,Flt} = DCOST_{Year,SC,Fr t_Fuel} * \left[BFSHXG_{SC,Fr t_Fuel,Flt} + \frac{EFSHXG_{SC,Fr t_Fuel,Flt} - BFSHXG_{SC,Fr t_Fuel,Flt}}{1 + e^{SLOPE_{SC,Fr t_Fuel,Flt} * (Year - MIDYR_{SC,Fr t_Fuel,Flt})}} \right] \quad (232)$$

where,

BFSHXG = Base year (1997) market share of each fuel type

EFSHXG = Exogenously determined final market share of each fuel type

Fr t_Fuel = 3, 4

The market share of alternative fuel trucks is assumed never to dip below the historical level in each sector. The actual Alternative Fuel Vehicle market share is thus calculated as the maximum of historical and forecast shares as follows:

$$FSHFLT_{Year,SC,Fr t_Fuel,FLT} = \max \left[BAFSHXG_{SC,Fr t_Fuel,FLT}, MPATH_{Year,SC,Fr t_Fuel,FLT} \right] \quad (233)$$

where,

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

$$Frt_Fuel = 3, 4$$

Market Share of Diesel Trucks

The share of diesel, $Frt_Fuel = 1$, in conventional truck sales is forecast through a time-dependent exponential decay function based on historical data that is defined by:

$$MPATH_{Year,SC,Fr t_Fuel=1,Flt} = BFSHXG_{SC,Fr t_Fuel=1,FLT} + \left[EFSHXG_{SC,Fr t_Fuel=1,Flt} - BFSHXG_{SC,Fr t_Fuel=1,FLT} \right] * \left[1 - e^{CSTDVG_{SC,FLT} + CSTDVXG_{SC,FLT} * Year} \right] \quad (234)$$

where,

$CSTDVG, CSTDVXG$ = Exogenously determined market penetration curve parameters for diesel trucks

Because of the potential for any fuel type to exceed the user-specified “maximum” due to cost advantages over other technologies, market penetration must be capped at one hundred percent.

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

$$FSHFLT_{Year,SC,Fr t_Fuel=1,FLT} = \min \left[\left(1 - \sum_{Fr t_Fuel=3}^4 FSHFLT_{Year,SC,Fr t_Fuel,FLT} \right) * MPATH_{Year,SC,Fr t_Fuel=1,FLT}, 1 \right] \quad (235)$$

The remainder of truck purchases are assumed to be gasoline, $Frt_Fuel=2$ and are defined by:

$$FSHFLT_{Year,SC,Fr t_Fuel=2,FLT} = 1 - \sum_{Fr t_Fuel=1,3,4} FSHFLT_{Year,SC,Fr t_Fuel,FLT} \quad (236)$$

3. Determine Composition of Existing Truck Stock

Once the characteristics of the incoming class of new trucks are determined, the next step is to determine the composition of the stock of existing trucks. Scrappage rates are applied to the current truck population based on:

$$TRKSTK_{Year,SC,AGE,Fr t_Fuel,FLT} = TRKSTK_{Year-1,SC,AGE-1,Fr t_Fuel,FLT} * (1 - SCRAP_{SC,AGE-1}) \quad (237)$$

where,

TRKSTK = Existing stock of trucks
 SCRAP = Exogenously determined factor which consists of the percentage of trucks of each vintage that are scrapped each year
 AGE = 2, 20; AGE = 1 refers to new truck sales

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

$$TRF_{Year,SC,AGE,Frt_Fuel} = TFFXGRT_{SC,AGE} * TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT=2} \quad (238)$$

where,

TRF = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks
 TFFXGRT = Exogenously determined percentage of trucks of each vintage to be transferred from fleets to non-fleets

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

$$TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT=2} = TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT=2} - TRF_{Year,SC,AGE,Frt_Fuel}$$

and

$$TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT=1} = TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT=1} - TRF_{Year,SC,AGE,Frt_Fuel} \quad (239)$$

4. Calculate Purchases of New Trucks

New truck purchases are based on class 3 truck sales and on the macroeconomic models forecasts of classes 4-8 truck sales that is split between truck classes 4-6 and classes 7-8 as defined at the beginning of this section on the Freight Truck Stock Adjustment Module:

$$\begin{aligned}
 NEWTRUCKS_{SC=1} &= MC_VEHICLES_{5,Year} * 1000 \\
 NEWTRUCKS_{SC=2} &= NEWCLS46_{Year} * NEWTRUCKS_TOT_{Year} \\
 NEWTRUCKS_{SC=3} &= (1 - NEWCLS46_{Year}) * NEWTRUCKS_TOT_{Year}
 \end{aligned} \quad (240)$$

where,

NEWTRUCKS_TOT = Total new truck sales for classes 4-8, from the macroeconomic model.
 NEWCLS46 = Truck classes 4-6 share of total truck sales.
 MC_VEHICLES_{5,Year} = Sales of class 3 trucks from the macroeconomic model

SC = 1 refers to class 3; SC = 2 refers to class 4-6; SC = 3 refers to class 7-8

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

$$TRKSTK_{Year,SC,AGE=1,Frt_Fuel} = NEWTRUCKS_{SC} * FSHFLT_{Year,SC,Frt_Fuel,FLT} \quad (241)$$

5. Calculate Fuel Consumption

The next stage of the module takes the total miles driven by trucks of each size class, fuel type and age and divides by fuel economy to determine fuel consumption.

The aggregate VMT growth by economic sector, SEC , is estimated. First, calculate Freight Adjustment coefficient, $FOUT$, which represents the relationship between the value of industrial output and freight demand in terms of VMT. It is used to factor industry growth to get VMT growth. $FOUT$ is defined by:

$$FOUT_{SEC} = FAC_T0_{SEC} + \frac{1 - FAC_T0_{SEC}}{1 + e^{FAC_K * (FAC_T5 - Year)}} \quad (242)$$

where,

FAC_T0 = Base year freight adjustment coefficient, by sector, exogenously determined

FAC_K = $\log(9.0) / (FAC_T9 - FAC_T5)$

FAC_T5 = Year of 50 percent freight adjustment coefficient decay = 2002

FAC_T9 = Year of 90 percent freight adjustment coefficient decay = 2007

Now calculate the adjustment VMT per truck as:

$$VMTADJ_{Year} = \frac{\sum_{SEC=1}^{12} VMTDMD_{Year-1,SEC} * (1 + OUTPUT_{Year,SEC}) * FOUT_{SEC}}{\sum_{SC,AGE,Frt_Fuel,FLT} ANNVMT_{SC,AGE,Frt_Fuel} * TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT}} \quad (243)$$

where,

$VMTDMD$ = Annual sectoral VMT based on base year FHWA estimates of VMT

$ANNVMT$ = Base year VMT per truck by 3 freight size classes.

Finally, adjust VMT to obtain VMT across all sectors using the equation:

$$VMTFLT_{Year,SC,AGE,Frt_Fuel,FLT} = ANNVT_{SC,AGE,Frt_Fuel} * VMTADJ_{Year} * TRKSTK_{Year,SC,AGE,Frt_Fuel,FLT} \quad (244)$$

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

$$FUELDMD_{Year,SC,Frt_Fuel,FLT} = \sum_{AGE=1}^{20} \frac{VMTFLT_{Year,SC,AGE,Frt_Fuel,FLT}}{CFMPG_{Year,SC,AGE,Frt_Fuel}} \quad (245)$$

where,

FUELDMD = Total freight truck fuel consumption by size class and fuel type, in gallons of gasoline equivalent

CFMPG = Fuel economy of freight trucks, by size class, fuel, and vintage

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

$$FUELBTU_{Year,SC,Frt_Fuel,FLT} = FUELDMD_{Year,SC,Frt_Fuel,FLT} * HEATRATE * 10^{-12} \quad (246)$$

where,

FUELBTU = Total fleet truck fuel consumption by size class and fuel type, in trillion Btu

3E-2. Rail Freight Module

Rail forecasts represent a simplification of the freight truck approach, in that only one class of freight rail and vehicle technology is considered. Projections of energy use by rail are driven by forecasts of coal production and of ton-miles traveled for each of the industrial categories used in the trucking sector. See Figure 15. The algorithm used to estimate energy consumption of rail freight is similar to the one used for trucks and is calculated in the following steps.

First, calculate ton-miles traveled for coal as follows:

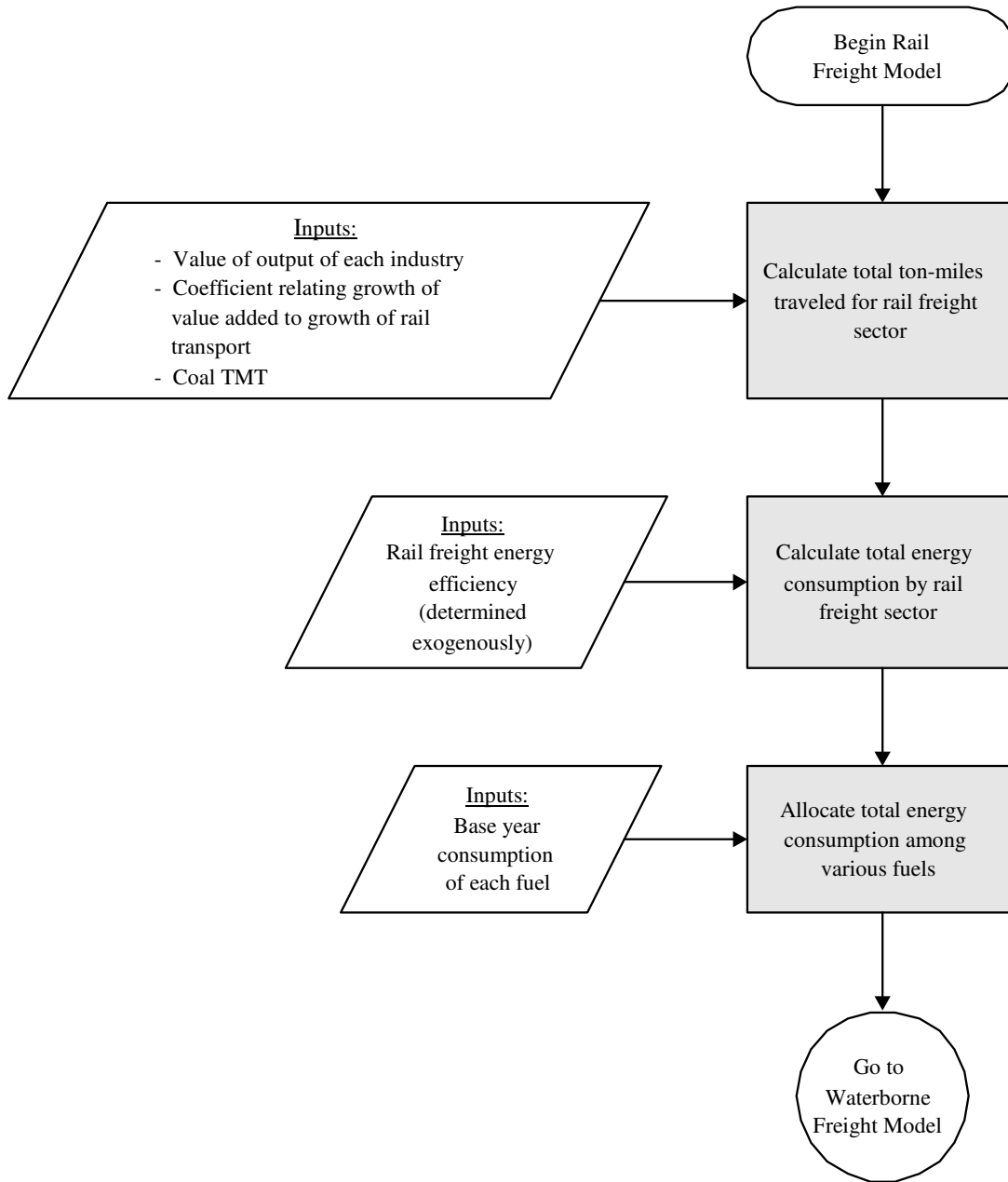
$$COALT_{Year} = \sum_{Coal_Reg=1}^2 COALP_{Coal_Reg,Year} * COALD_{Coal_Reg} \quad (247)$$

where,

COALT = Total ton-miles traveled for coal in region, Coal_Reg, (east/west) in a given year

COALP = The production of coal in region, Coal_Reg, in a given year in tons

Figure 15. Rail Freight Module



COALD = Distance coal has to travel in region, Coal_Reg.

Ton-miles traveled is calculated as follows:

$$RTMT_{ISIC,Year} = RTMT_{ISIC,Year_0} * FACR_{ISIC} * \frac{OUTPUT_{ISIC,Year}}{OUTPUT_{ISIC,Year_0}} \quad (248)$$

where,

RTMT = Total rail ton-miles traveled for industry, $ISIC=1,10$, in year, $Year$
 OUTPUT = Value of output of industry $ISIC$, in base year, $Year_0$, dollars
 FACR = Coefficient relating growth of value of goods produced with growth of rail transport

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

$$RTMT - C_{ISIC=10,Year} = 0.1 * RTMT_{ISIC=10,Year_0} + 0.9 * RTMT_{ISIC=10,Year} * \frac{COALT_{Year}}{COALT_{Year_0}} \quad (249)$$

$$RTMTT_{Year} = RTMT - C_{ISIC=10,Year} + \sum_{ISIC=1}^{10} RTMT_{ISIC,Year} \quad (250)$$

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

$$TQRAILT_{Year} = FERAIL_{Year} * RTMTT_{Year} \quad (251)$$

where,

TQRAILT = Total energy consumption by freight trains
 FERAIL = Exogenously determined rail energy efficiency

Rail efficiency gains resulting from technological development and increased system efficiency are based on an exogenous analysis of trends.

This aggregate energy demand is used to estimate the demand for the various fuels used for rail transport, adjusting the previous year's demand for a given fuel by the fractional increase in overall energy requirements. This is defined by the following:

$$TQRAIL_{Rail_Fuel,Year} = TQRAIL_{Rail_Fuel,Year-1} * \frac{TQRAILT_{Year}}{TQRAILT_{Year-1}} \quad (252)$$

where,

$TQRAIL$ = Total demand for each fuel by rail freight sector in year, $Year$

This approach is based on the assumption that the relative shares of each fuel remain constant across the forecast horizon, and that there is little or no room for fuel substitution as prices vary.

Fuel consumption is then allocated to each region by:

$$TQRAILR_{Rail_Fuel,REG,Year} = TQRAIL_{Rail_Fuel,Year} * SEDSHRXX_{REG,Year} \quad (253)$$

where,

$TQRAILR$ = Total regional fuel consumption for each technology
 $SEDSHRXX$ = Regional share of rail freight fuel consumption, from SEDS, by fuel,
 $XX=DS$ (distillate), $XX=RS$ (residual), $XX=EL$ (electricity)

The module then calculates the fractional change in fuel efficiency as follows:

$$XRAILEFF_{Year} = \frac{FERAIL_{Year}}{FERAIL_{Year_0}} \quad (254)$$

where,

$XRAILEFF$ = Growth in rail efficiency from base year, $Year_0$

3E-3. Waterborne Freight Module

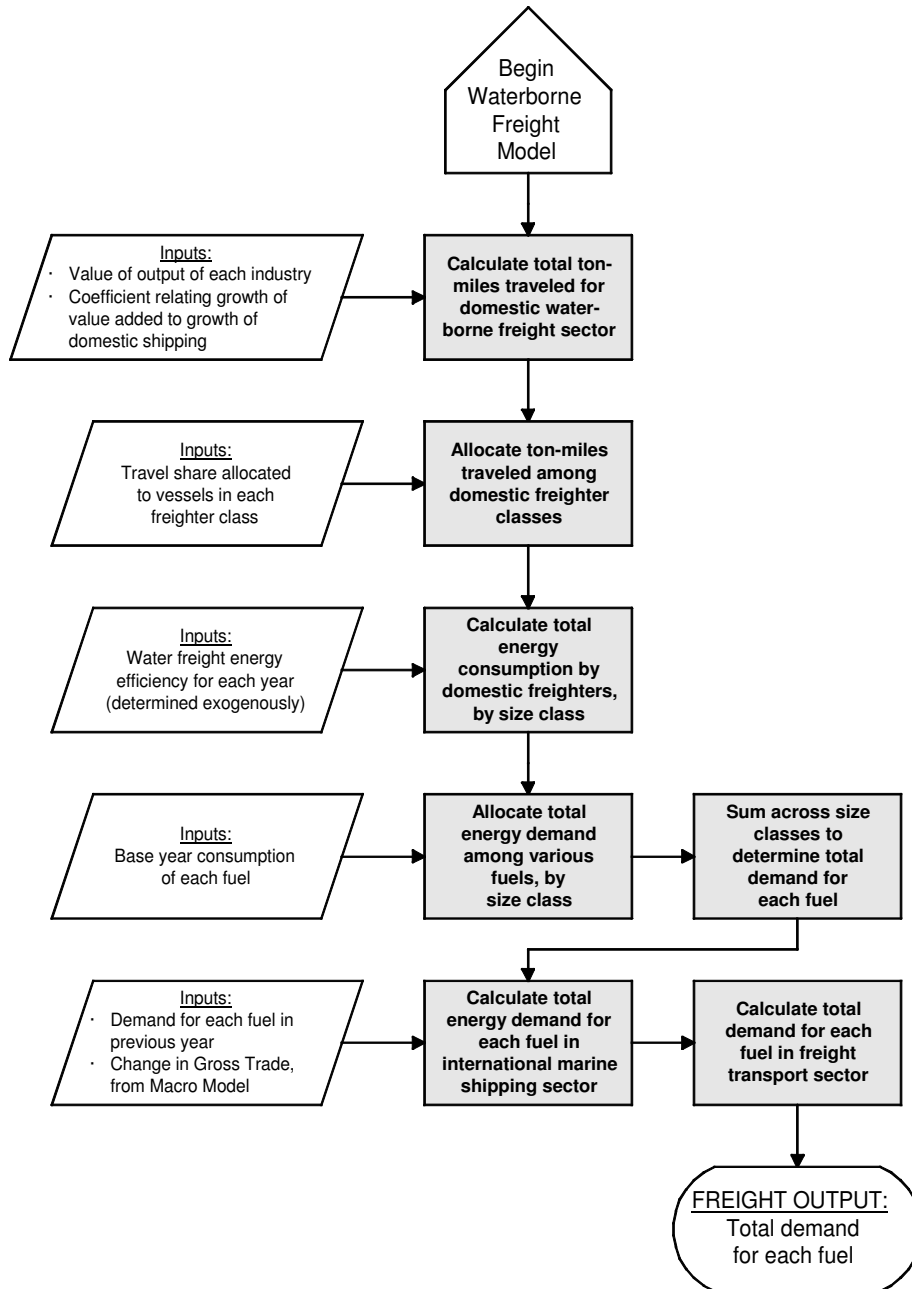
Two classes of waterborne transit are considered in this component: domestic marine traffic and freighters conducting foreign trade. This is justified on the grounds that vessels that comprise freighter traffic on rivers and in coastal regions have different characteristics than those which ply international waters. See Figure 16.

Domestic Marine

The estimate of total domestic waterborne travel demand is driven by forecasts of industrial output as defined by:

$$STMTT_{Year} = \sum_{ISIC=1}^{10} \left[STMT_{ISIC,Year_D} * FACS_{ISIC} \frac{OUTPUT_{ISIC,Year}}{OUTPUT_{ISIC,Year_D}} \right] \quad (255)$$

Figure 16. Waterborne Freight Module



where,

STMT = Total ton-miles of waterborne freight for industry, ISIC, in year, Year.
OUTPUT = Value of output of industry, ISIC, in base year dollars
FACS = Exogenous determined coefficient relating growth of value added with growth of shipping transport
Year_D = Year of most recent data update

Fuel use is subsequently estimated, using average energy efficiency as defined by:

$$SFDT_{Year} = FESHIP_{Year} * STMT_{Year} \quad (256)$$

where,

SFDT = Domestic ship energy demand
FESHIP = Average fuel efficiency

Estimated changes in energy efficiency are exogenous. The next step the module takes is allocating total energy consumption among three fuel types (distillate fuel, residual fuel oil and gasoline), which is defined by:

$$SFD_{Ship_Fuel,Year} = SFDT_{Year} * SFSHARE_{Ship_Fuel,Year} \quad (257)$$

where,

SFD = Domestic ship energy demand, by fuel
SFSHARE = Domestic shipping fuel allocation factor
Ship_Fuel = Index referring to the three shipping fuel types

The factor that allocates energy consumption among the three fuel types is based on 2004 data²⁰ and is held constant throughout the run period.

Total energy demand is then regionalized as follows:

$$TQSHIPR_{Ship_Fuel,REG,Year} = SFD_{Ship_Fuel,Year} * SEDSHR_{Ship_Fuel,REG,Year} \quad (258)$$

where,

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

²⁰ Oak Ridge National Laboratory, Transportation Energy Data Book Edition 24, December 2004.

The fractional change in domestic ship travel and fuel efficiency is then calculated as:

$$XSHIPEFF_{Year} = \frac{FESHIP_{Year}}{FESHIP_{Year_0}} \quad (259)$$

where,

XSHIPEFF = Growth in ship efficiency from base year, $Year_0$

International Marine

Fuel demand in international marine shipping is directly estimated, linking the level of international trade with the lagged consumption of the fuel in question as follows:

$$ISFDT_{Year} = ISFDT_{Year-1} + 0.5 * ISFDT_{Year-1} * \left[\frac{GROSST_{Year}}{GROSST_{Year-1}} - 1 \right] \quad (260)$$

where,

ISFDT = Total international shipping energy demand in year, $Year$

GROSST = Value of Gross Trade (imports + exports), from Macro Model

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

$$ISFD_{Ship_Fuel,Year} = ISFDT_{Year} * ISFSHARE_{Ship_Fuel,Year} \quad (261)$$

where,

ISFD = International freighter energy demand, by fuel

ISFSHARE = International shipping fuel allocation factor

Regional fuel consumption is then calculated as:

$$TQISHIPR_{Ship_Fuel,REG,Year} = ISFD_{Ship_Fuel,Year} * SEDSHR_{Ship_Fuel,REG,Year} \quad (262)$$

where,

TQISHIPR = Total regional energy demand by international freighters

SEDSHR = Regional shares of fuel demand, from SEDS

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. Figure 17 presents the flowchart for the MED Module.

3F-1. Military Demand Module

See Figure 18 for flowchart of Military Demand Module. Fuel demand for military operations is considered to be proportional to the projected military budget. The fractional change in the military budget is first calculated as follows:

$$MILTARGR_{Year} = \frac{TMC_GFML_{Year}}{TMC_GFML_{Year-1}} \quad (263)$$

where,

MILTARGR = The growth in the military budget from the previous year
 TMC_GFML = Total defense budget in year, *Year*, from the macroeconomic model in NEMS

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

$$MFD_{Mil_Fuel,Year} = MFD_{Mil_Fuel,Year-1} * MILTARGR_{Year} \quad (264)$$

where,

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

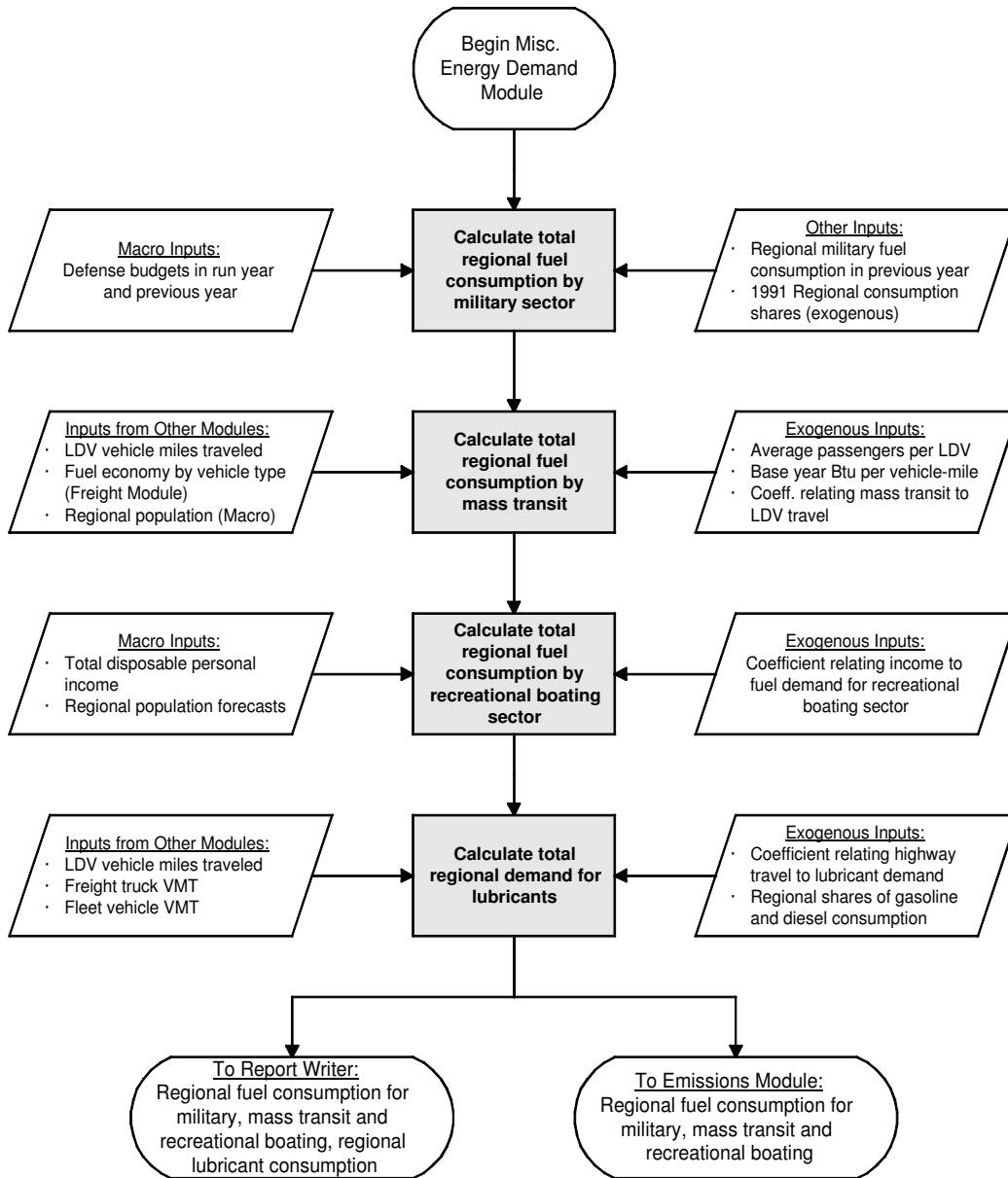
Consumption is finally distributed among the nine census regions by the following equation:

$$QMILTR_{Mil_Fuel,REG,Year} = MFD_{Mil_Fuel,Year} * MILTRSHR_{Mil_Fuel,REG} \quad (265)$$

where,

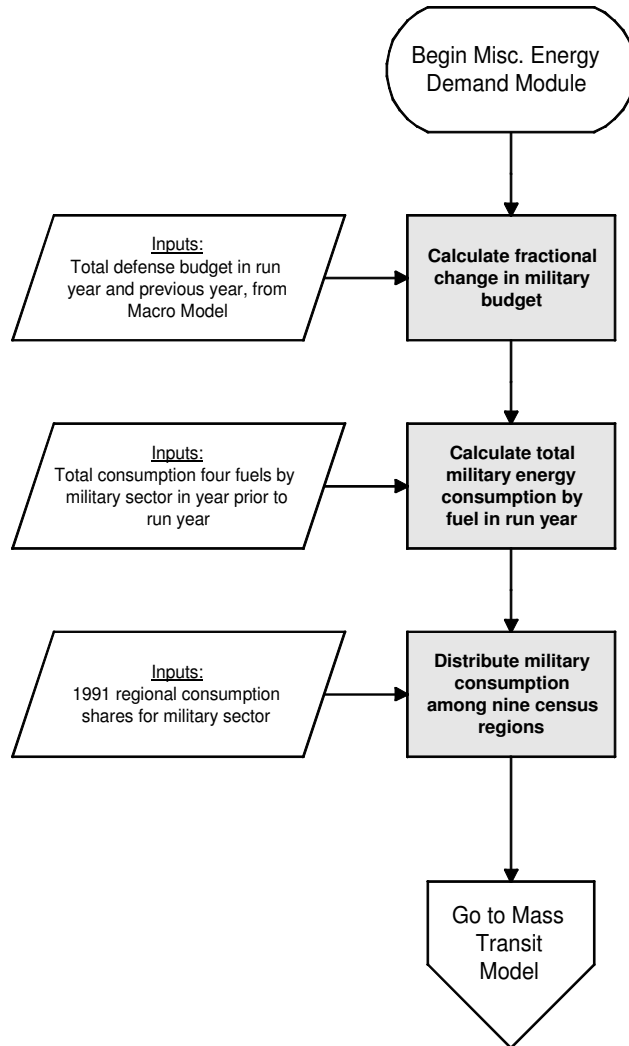
QMILTR = Regional fuel consumption, by fuel type, in Btu
 MILTRSHR = Regional consumption shares, from 1991 data, held constant

Figure 17. Miscellaneous Energy Demand Module



Note: the emissions module is currently inactive

Figure 18. Military Demand Module



3F-2. Mass Transit Demand Module

See Figure 19 for flowchart of Mass Transit Demand Module. 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. This is defined by the equations:

$$\begin{aligned}
 TMOD_{IM=1,Year} &= VMTEE_{Year} \\
 &\text{and} \\
 TMOD_{IM \neq 1,Year} &= TMOD_{IM \neq 1,Year-1} * \left[\frac{TMOD_{IM=1,Year}}{TMOD_{IM=1,Year-1}} \right]^{BETAMS}
 \end{aligned}
 \tag{266}$$

where,

- TMOD = Passenger-miles traveled, by mode
- VMTEE = LDV vehicle-miles traveled, from the VMT module
- BETAMS = Coefficient of proportionality, relating mass transit to LDV travel
- IM = Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail

Fuel efficiencies, in Btu per vehicle-mile, are obtained from the Freight Module for buses and rail; and mass transit efficiencies, in Btu per passenger-mile, are calculated as:

$$TMEFF_{IM,Year} = TMEFF_{IM,Year-1} * \frac{FMPG_{TYPE,Year}}{FMPG_{TYPE,Year-1}}
 \tag{267}$$

where,

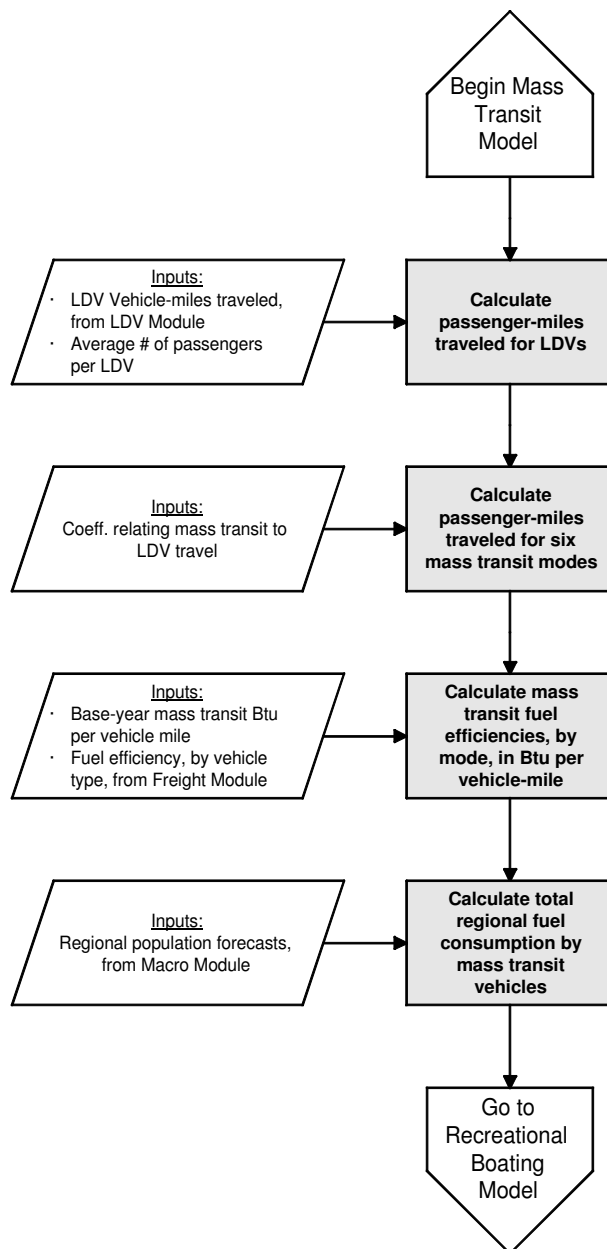
- TMEFF = Btu per passenger-mile, by mass transit mode
- FMPG = Fuel efficiency, by vehicle type, from the Freight Module
- TYPE = Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail

Total fuel consumption is calculated and distributed among regions according to their populations based on the following:

$$QMODR_{IM,REG,Year} = TMOD_{IM,Year} * TMEFF_{IM,Year} * \frac{TMC_POPAFO_{REG,Year}}{\sum_{REG=1}^9 TMC_POPAFO_{REG,Year}}
 \tag{268}$$

where,

Figure 19. Mass Transit Demand Module



QMODR = Regional consumption of fuel, by mode
TMC_POPAFO = Regional population forecasts, from the Macro Module

3F-3. Recreational Boating Demand Module

See Figure 20 for flowchart of Recreational Boating Demand Module. The growth in fuel use by recreational boats is considered to be proportional to the growth in disposable personal income and is defined as:

$$RECFD_{Year} = RECFD_{Year-1} * \left[\frac{TMC_YD_{Year}}{TMC_YD_{Year-1}} \right]^{BETAREC} \quad (269)$$

where,

RECFD = National recreational boat gasoline consumption in year, Year
TMC_YD = Total disposable personal income, from the Macro Module
BETAREC = Coefficient of proportionality relating income to fuel demand for boats

Regional consumption is calculated according to population, as with mass transit. It is defined by:

$$QRECR_{REG,Year} = RECFD_{Year} * \frac{TMC_POPAFO_{REG,Year}}{\sum_{REG=1}^9 TMC_POPAFO_{REG,Year}} \quad (270)$$

where,

QRECR = Regional fuel consumption by recreational boats in year, Year

3F-4. Lubricant Demand Module

See Figure 21 for flowchart of Lubricant Demand Module. The growth in demand for lubricants is considered to be proportional to the growth in highway travel by all types of vehicles. Total highway travel is first determined as:

$$HYWAY_{Year} = VMTEE_{Year} + FTVMT_{Year} + FLTVMT_{Year} \quad (271)$$

where,

HYWAY = Total highway VMT
FTVMT = Total freight truck VMT, from the Freight Module
FLTVMT = Total fleet vehicle VMT, from the Fleet Module

Figure 20. Recreational Boating Demand Module

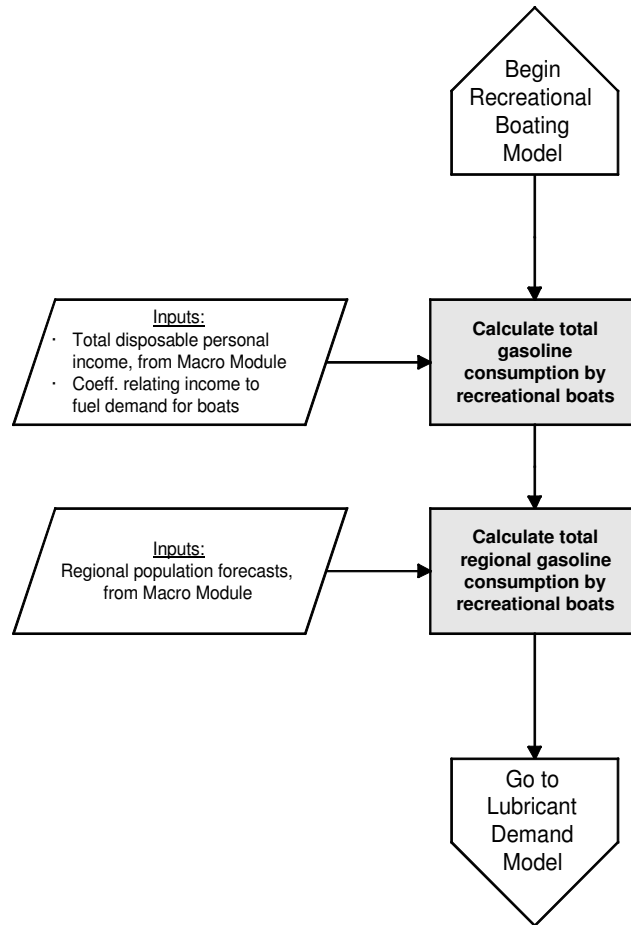
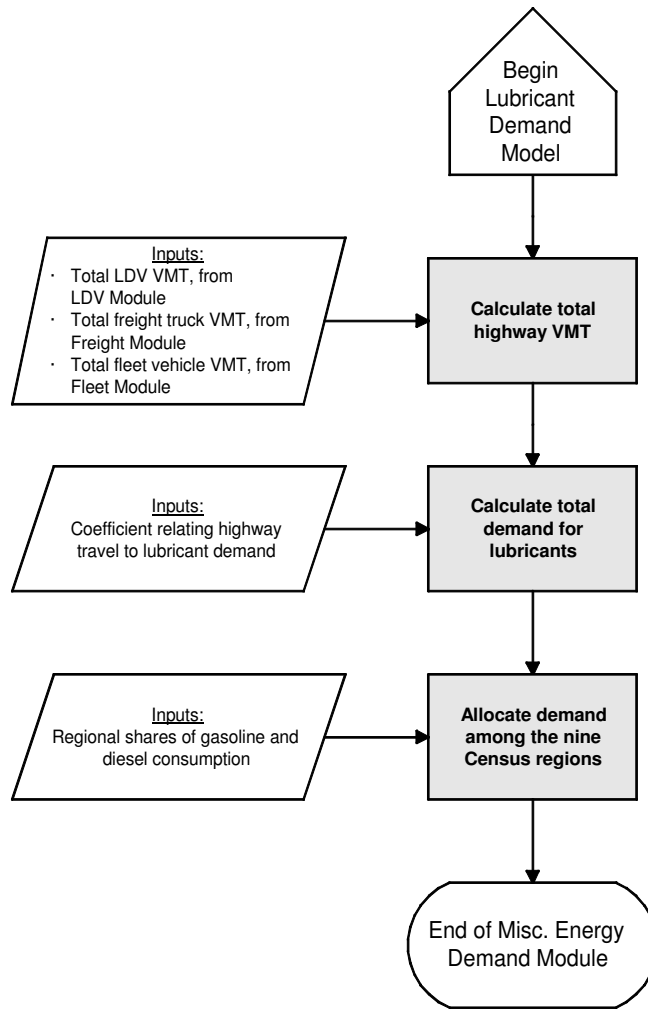


Figure 21. Lubricant Demand Module



Lubricant demand is then estimated based on the following:

$$LUBFD_{Year} = LUBFD_{Year-1} * \left[\frac{HYWAY_{Year}}{HYWAY_{Year-1}} \right]^{BETALUB} \quad (272)$$

where,

LUBFD = Total demand for lubricants in year, Year
 BETALUB = Constant of proportionality, relating highway travel to lubricant demand

The lubricant demand is allocated to regions by a regional weighting of all types of highway travel as shown in the following:

$$QLUBR_{REG,Year} = LUBFD_{Year} * \left[\frac{(VMTEE_{Year} + FLTVMT_{Year}) * SHRMG_{REG,Year} + FTVMT_{Year} * SHRDS_{Year}}{HYWAY_{Year}} \right] \quad (273)$$

where,

QLUBR = Regional demand for lubricants in year, Year, in Btu
 SHRMG = Regional share of motor gasoline consumption, from SEDS
 SHRDS = Regional share of diesel consumption, from SEDS

APPENDIX A

Model Abstract

Model Name

Transportation Sector Model

Model Acronym

TRAN

Description

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

Purpose of the Model

As a component of the National Energy Modeling System integrated forecasting tool, the transportation model generates mid-term forecasts (through 2025) 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, 2004

Model Interfaces

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

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Documentation

Model Documentation Report: *Transportation Sector Model of the National Energy Modeling System*, DOE/EIA-M070(2005), June 2005.

Energy System Described

Domestic transportation sector energy consumption.

Coverage

- Geographic: Nine Census Divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific.
- Time Unit/Frequency: Annual, 1995 through 2025.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants, pipeline fuel, and natural gas.
- Economic Sectors: Forecasts are produced for personal and commercial travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Model Interfaces

Model outputs are provided to the Integrating Module, which then sends them 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-light, medium-heavy, and heavy-duty size classes. Buses are subdivided

into commuter, intercity, and school buses. The air transport module contains wide- and narrow-body aircraft, and regional jets. Rail transportation is composed of freight rail and three modes of personal rail travel: commuter, intercity and transit. Shipping is divided into domestic and international categories.

Special Features

The Transportation Sector Model has been created to allow the user to change various exogenous 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 judgment 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.

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

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

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

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- 1999 State Energy Data Report (SEDS), DOE/EIA-0214(99) May 2001.
- Short Term Energy Outlook, Sept. 2004, <http://www.eia.doe.gov/emeu/steo/pub/contents.html>
- Macroeconomic Model Inputs: New vehicle sales, economic and demographic indicators, and defense spending.
- NEMS Supply Models: Fuel prices.

Non-DOE Input Sources:

- National Energy Accounts
- Federal Highway Administration, Highway Statistics, FHWA-PL-01-1011, 2003
- U.S. Department of Transportation, Federal Aviation Administration: Airport Capacity Benchmark Report, 2004
- U.S. Department of Transportation, Bureau of Transportation Statistics: Air Carrier Summary Data, 2003
- Jet Information Services Inc., World Jet Inventory: Year-End 2003, March 2004.
- National Highway Traffic and Safety Administration, Fuel Economy Report to Congress, Sep. 2001
- Oak Ridge National Laboratory, Transportation Energy Data Book Ed. 24, ORNL-6973, December 2004
- Oak Ridge National Laboratory, Stacy C. Davis and Lorena F. Truett, Fleet Characteristics and Data Issues, Feb. 2003
- Department of Commerce, Bureau of the Census, Vehicle Inventory and Use Survey 1997, Oct 1999
- California Air Resources Board, Proposed 2003 Amendments to the California Zero Emission Vehicle Regulation, July 29, 2003