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Model Documentation Report: Transportation Sector Model of the National Energy Modeling System

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NEMS TRANSPORTATION SECTOR MODEL

1. INTRODUCTION

Statement of Purpose

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

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

Model Summary

The NEMS Transportation Model comprises a series of semi-independent models which address different aspects of the transportation sector. The primary purpose of this model is to provide mid-term forecasts of transportation energy demand by fuel type including, but not limited to, motor gasoline, distillate, jet fuel, and alternative fuels (such as CNG) not commonly associated with transportation. The current NEMS forecast horizon extends to the year 2010 and uses 1990 as the base year. Forecasts are generated through the separate consideration of energy consumption within the various modes of transport, including: private and fleet light-duty vehicles; aircraft; marine, rail, and truck freight; and various modes with minor overall impacts, such as mass transit and recreational boating. This approach is useful in assessing the impacts of policy initiatives, legislative mandates which affect individual modes of travel, and technological developments.

The model also provides forecasts of selected intermediate values which are generated in order to determine energy consumption. These elements include estimates of passenger travel demand by automobile, air, or mass transit; estimates of the efficiency with which that demand is met; projections of vehicle stocks and the penetration of new technologies; and estimates of the demand for freight transport which are linked to forecasts of industrial output. Following the estimation of energy demand, TRAN produces forecasts of vehicular emissions of the following airborne pollutants by source: oxides of sulfur, oxides of nitrogen, total carbon, carbon dioxide, carbon monoxide, and volatile organic compounds.

Model Structure

The transportation sector encompasses a variety of vehicular modes which, in general, bear little physical resemblance to each other, save for their intended purpose of conveying passengers or freight. Consequently, these modes are addressed in separate modules whose interrelationship is tenuous, at best. Transportation sector energy consumption is the sum of energy consumption forecasts generated within each of these modules. Each module, in turn, may comprise more than one submodel, consistent with the methodological requirements of the sector, and commensurate with the relative impact the sector has on overall transportation demand. The NEMS Transportation Model consists of the following seven modules: Light-Duty Vehicle, Light Duty Stock, Light Duty Fleet, Air Travel, Freight Transport, Miscellaneous Transport, and Emissions. The components of these modules are briefly described in turn below.

Light-Duty Vehicle (LDV) Module

The LDV Module is the most extensive of the modules in TRAN, owing to the overwhelming contribution of automobile and light-truck use to total transportation energy demand. Forecasts of stocks and efficiencies of cars and light trucks are generated, disaggregated by vehicle size class, vintage, and engine technology, using the following submodels.

Fuel Economy Model (FEM)

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

Regional Sales Model (RSM)

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

Alternative Fuel Vehicle (AFV) Model

The Alternative Fuel Vehicle Model uses estimates of new car fuel efficiency, obtained from the FEM, and fuel price estimates generated by NEMS to generate market shares of each considered technology, as well as the overall market penetration of alternative fuel vehicles. This model is useful both to assess the penetration of AFV's and to allow analysis of policies that might impact this penetration.

Light-Duty Vehicle Stock Module

LDV Stock Accounting Model

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

Vehicle-Miles Traveled (VMT) Model

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

Light-Duty Vehicle Fleet Module

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

Air Travel Module

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

Air Travel Demand Model

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

Aircraft Fleet Efficiency Model (AFEM)

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

Freight Transport Module

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

Miscellaneous Energy Use Module

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

Vehicle Emissions Module

The Vehicle Emissions Module receives estimates of energy consumption, by mode, from all of the preceding modules, and calculates vehicular emissions based on both the mix of vehicle technologies utilized over time, and the age distribution of these vehicles.

Model Archival Citation

Archived as part of the NEMS production runs for the *Annual Energy Outlook 1994*.

Report Organization

Chapter 2 of this report discusses the purpose of the Transportation Model, detailing its objectives, primary input and output quantities, and the relationship of TRAN to the other modules of the NEMS system. In Chapter 3, each of the constituent modules is addressed in detail, describing the rationale behind the module's design. Where appropriate, alternative methodological approaches to the issues raised in each module are presented, thus permitting a ready comparison with the approaches chosen for NEMS. Each module's structure is then presented in detail, illustrating model flows and key computations. Chapter 4 provides an overview of the principal assumptions employed in constructing the Transportation Model.

The Appendices to this report provide micro level detail as supporting documentation for the TRAN files currently residing on the EIA mainframe. Appendix A lists and defines the input data used to generate parameter estimates and endogenous forecasts from TRAN, along with the parameter estimates and the outputs of most relevance to the NEMS system and the model evaluation process. Appendix B contains a mathematical description of the computational algorithms used in TRAN, including model equations and variable transformations. Appendix C is a bibliography of reference materials used in the development process. Appendix D consists of a model abstract. Appendix E discusses data quality and estimation methods. Appendix F contains a number of attachments which are meant to provide insight into the historical development of the NEMS Transportation Sector Model. Finally, Appendix G comprises two reports used in the development of the Fuel Economy Model.

Volume II of this report documents technical detail on model data and equations and sensitivity analysis and scenario output in support of the documentation of model performance.

2. MODEL PURPOSE AND SCOPE

Objectives

The development of the NEMS Transportation Model has achieved four objectives. First, it provides a policy-sensitive representation of the transportation sector within NEMS. Second, it generates mid- to long-term forecasts (ten to twenty years) of transportation energy demand at the census division level in support of the development of the *Annual Energy Outlook* (AEO). Third, it increases the level of disaggregation provided in previous transportation models, and fourth, it incorporates endogenous forecasts of the effects of technological innovation and vehicle choice.

Model Overview

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

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

The Air Travel Module receives macroeconomic and demographic input from NEMS, including jet fuel prices, population, per capita GDP, disposable income and merchandise exports, and subsequently uses an econometric estimation to determine the level of travel demand and a stock vintaging model to determine the size and characteristics of the aircraft fleet required to meet that demand. The output of this module also includes an estimate of the demand for jet fuel and aviation gasoline, which is subsequently passed to the Miscellaneous Energy Use Module. The Freight Transport Module uses NEMS forecasts of real fuel prices, trade indices, and selected industries' output to estimate travel demand and energy consumption in each of three primary freight modes: truck, rail, and marine. Travel and fuel demand estimates are subsequently passed to the Miscellaneous Energy Use Module.

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

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

Input and Output

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

A large number of data inputs exogenous to NEMS are supplied to the TRAN modules described above. These data sets remain constant throughout the forecast, and, to that extent, constitute a set of assumptions about current and future conditions. A comprehensive list of these invariant inputs, under the classification "data inputs", is provided in Table A-1 of Appendix A.

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

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

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

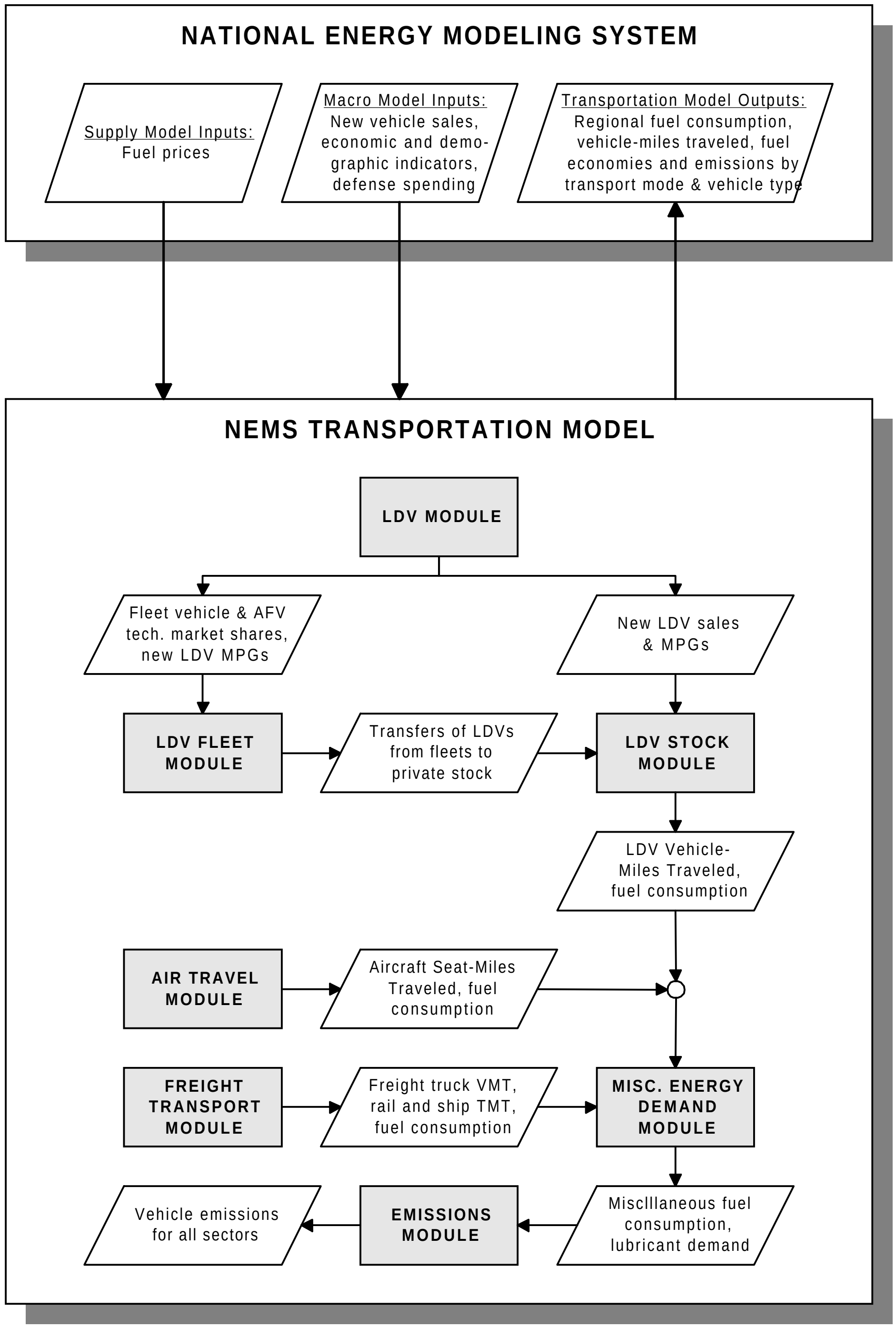
The LDV Stock Module uses vintage-dependent constants such as vehicle survival and relative driving rates, and fuel economy degradation factors to obtain estimates of stock efficiency.

The Air Travel Module receives exogenous estimates of aircraft load factors, new technology characteristics, and aircraft specifications which determine the average number of available seat-miles each plane will supply in a year. The Freight Module receives exogenous estimates of freight intensity and modal shares. Finally, the Emissions Module is supplied a set of coefficients which associate energy use by vehicle and fuel type with the consequent emissions of each of the six airborne pollutants considered by the model.

Each submodel performs calculations at a level of disaggregation commensurate with the nature of the mode of transport, the quality of the input data and the level of detail required in the output. For example, the FEM addresses seven size classes of car and light truck, while the Stock Module considers six separate classes, and the AFV Model only three. The Transportation Model maps the output of each submodel into variables of the appropriate dimension for use in subsequent steps. Due to the lack of a uniform stratification scheme among the various transportation sectors, the primary dimensions across which key variables vary in TRAN are discussed in the individual module descriptions in the following section.

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

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



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 field. In order to provide a consistent and lucid presentation of TRAN, each of these modules are discussed separately; where appropriate, individual module components are separately considered. Each section describes the general theoretical approach to the issue at hand, the assumptions which were incorporated in the development of the model, the methodology employed in predecessor models, and alternative approaches which were considered.

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

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

The various appendices following this section provide additional information on the model development process, including background research which contributed to the quantification of the various relationships influencing model output.

3A. Light Duty Vehicle Module

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

3A-1. Fuel Economy Model

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

RATIONALE

The FEM 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 vehicle, this model addresses the commercial viability of up to sixty-one separate technologies within each of fourteen vehicle market classes, four corporate average fuel economy (CAFE) groups, and thirteen fuel types. The seven automobile market classes include five classes based on interior passenger volume, ranging from "minicompact" to "large", and classes for "sports" and "luxury" cars. The seven classes of light truck are based mainly on utility and intertia weight and include vans, pickups, utility vehicles and mini-trucks. Market classes for automobiles and light trucks are described in more detail in Appendix A, Table A-2. The four groups for which CAFE standards are set are: Domestic Cars, Import Cars, Domestic Trucks, and Import Trucks.

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

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

Over the last 15 years, the single factor with the largest effect on fuel economy was the changing technological characteristics of cars. Except for the period immediately following the second oil shock of 1979, the vehicle class mix has not had a very large effect on fuel economy since the mix changes have not been large. In the last five years, rapidly increasing performance levels have had a significant impact on fuel economy.

The Fuel Economy Model developed for NEMS considers each of the first three factors when projecting fuel economy in the future. To forecast technological change, the entire fleet of new cars and light duty trucks are disaggregated into fourteen market classes (seven each for cars and light trucks) that are relatively homogenous in terms of consumer perceived attributes such as size, price and utility. Technological improvements to each of these market classes are then forecast based on the availability of new technologies to improve fuel economy as well as their cost effectiveness under two user-specified alternative scenarios. The central assumptions involved in this technological forecast are as follows:

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

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

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

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

Finally, the change in the mix of market classes sold is forecast as a function of fuel price and personal disposable income only and is documented in Appendix E, page E-1, of this report. The sales mix by class is used to calculate fleet fuel economy. The econometric model was derived from regression analysis of historical sales mix data over the 1978-1990 period. The model forecasts sales mix for the 7 car classes and the 7 light truck classes, while import market shares are held at fixed values by market class based on EEA estimates.

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

Finally, the model also accounts for all known safety and emission standard changes during the forecast period. These are generally limited to the 1990-2005 time frame, however. Emission standards and safety standards increase vehicle weight, and in some cases decrease engine efficiency. The model accounts for the 1994 Tier I emission standards as well as the 2001+ Tier II emission standards, but does *not* envisage that the California "Low Emission Vehicle" standards will be adopted nationwide. Safety standards include fuel economy penalties for air bags, side intrusion and roof crush (rollover) strength requirements that are mandatory over the next ten years. Separately, anti-skid brakes are assumed to be incorporated in all vehicles, although they are not required by law.

ALTERNATIVE SPECIFICATIONS

The methodology described is implemented in the Fuel Economy Model (FEM) which builds from the earlier Technology/Cost Segment Model (TCSM) which was developed for the Department of Energy. The FEM, however, has two changes relative to the TCSM, as detailed below:

1) The FEM forecast aggregates all manufacturers by domestic and import, while the TCSM forecasts fuel economy by manufacturer for all domestic and several select import manufacturers

2) The FEM technology data is more recently updated, and captures technologies that could be available over the next 40 years, whereas the TCSM incorporates only near term technology data.

As a result of its longer term focus, the FEM incorporates a more sophisticated technology adoption and market penetration calculation algorithm than the one incorporated in the TCSM. The adoption algorithm accounts for real world effects when cost-ineffective technologies are introduced in luxury cars for image or for performance reasons.

The forecasts are calculated at the most disaggregate level of manufacturer type (domestic/ import), vehicle type (car/light truck) and market class. Cars and light trucks are each separated into seven market classes. Each market class represents an aggregation of vehicle models that are similar in size and price, and are perceived by consumers to offer similar attributes. The car classes are similar to the EPA size classes except for the addition of sports and luxury classes that are not defined on the basis of interior volume. In addition, the classes utilized here are based on passenger volume, not passenger and trunk volume as per EPA, which results in some hatchback models differing in classification. Truck classification is essentially identical to the EPA classification. This leads to a total of 28 possible classes (7 classes x 2 vehicle types x 2 manufacturer types) but some have no vehicles, e.g., there are no domestic minicompact cars. The net result is 22 different classes which are individually forecast to 2030.

MODEL STRUCTURE

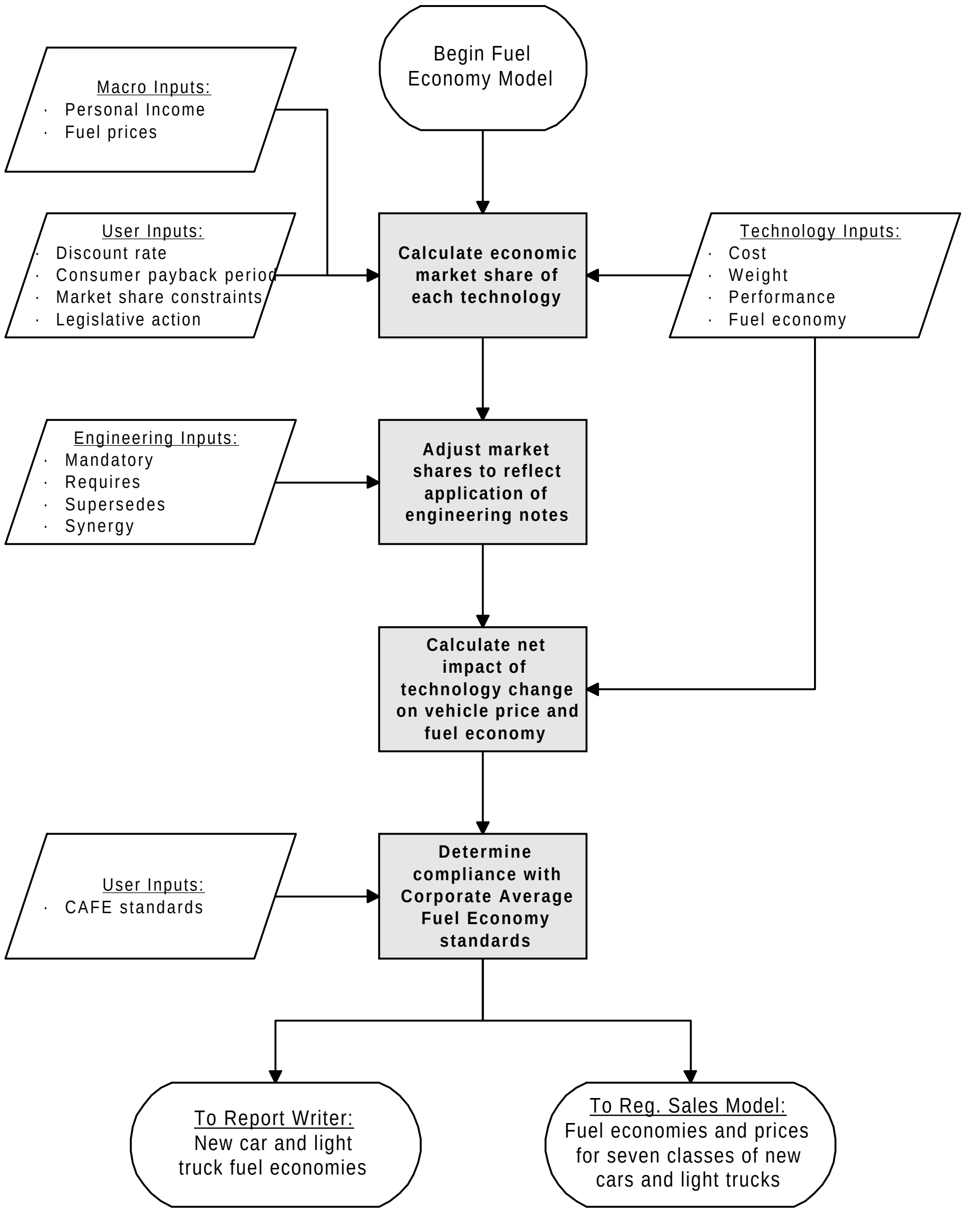
The Fuel Economy Model (FEM) uses a straightforward algorithm to forecast fuel economy by vehicle class. FEM begins with a baseline, describing the fuel economy, weight, horsepower and price for each vehicle class in 1990. In each forecast period, the model identifies technologies which are available in the current year. Each available technology is subjected to a cost effectiveness test which balances the cost of the technology against the potential fuel savings and the value of any increase in performance provided by the technology. The cost effectiveness is used to generate an economic market share for the technology.

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

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

Once these steps have been taken for all vehicle classes, the Corporate Average Fuel Economy (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 to meet 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 this second pass, the technology cost effectiveness calculation is modified to include the benefit of not having to pay the fine for failing to meet CAFE. After this second pass the CAFEs are recalculated. No further action is taken to force CAFE compliance; vehicles in failing groups are assumed to simply pay the fine.

Figure 3A-1. Fuel Economy Model



I. ESTABLISH AFV CHARACTERISTICS RELATIVE TO GASOLINE ICE

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

1) CalculateAFV base year values for automobile prices at different production levels.

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

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

where:

AFVADJPF(,1) = the incremental price adjustment for a low production AFV car

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

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

where:

AFVADJPF(,2) = Incremental price adjustment for a low production AFV truck

c) Luxury vehicles at 2,500 units/year

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

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

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

where:

AFVADJPF(,3) = Incremental price adjustment for a high production AFV car

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

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

where:

AFVADJPF(,4) = Incremental price adjustment for a high production AFV truck

f) Luxury at 25,000 units/year

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

2) CalculateAFV base year values for light duty truck prices at different production levels.

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

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

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

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

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

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

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

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

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

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

a) Electric Hybrid at 2,500 units/year

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

where:

AFVADJPF(11,3) = Incremental price adjustment for a midsize car EV/Hybrid

$WEIGHT_{Midsize}$ = Weight of a midsize car.

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

b) Electric Hybrid at 25,000 units/year (note different PRICE subscript)

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

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

a) Fuel Economy Calculation

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

where:

AFVADJFE = Fuel economy adjustment, relative to gasoline, for an AFV

b) Weight Calculation

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

where:

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

c) Horsepower Calculation

$$HP_{BaseYear,FuelType} = HP_{BaseYear,Gasoline} * (1 + AFVADJHP_{FuelType})$$

where:

AFVADJHP = Horsepower adjustment, relative to gasoline, for an AFV

II. CALCULATE TECHNOLOGY MARKET SHARES

FEM first determines the cost effective market shares of technologies for each vehicle class and then calculates the resulting Fuel Economy, Weight, Horsepower and Price through the subroutine FEMCALC. In each forecast period this function is called twice. During the first pass, technology market shares are calculated for all vehicle classes. In the second pass, the technology market shares are recalculated for vehicles in groups failing to meet the CAFE standards. During this pass, the cost effectiveness calculation is adjusted to include the regulatory cost of failing to meet CAFE[1]. 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, it is assumed that the manufacturers simply pay the penalty.

For each vehicle class, FEMCALC follows these steps:

A. Calculate the economic market share for each technology

B. Apply the engineering notes to control market penetration
  - Adjust the economic market shares though application of the mandatory, supersedes and requires engineering notes
  - Adjust the fuel economy impact through application of the synergy engineering notes

[1] See the variable REGCOST in Equation 6. During pass 1 REGCOST has a value of 0. During pass 2 it is set to REG$COST, which is a user input.

C. Calculate the net impact of the change in technology market share on fuel economy, weight and price

D. Adjust horsepower based on the new fuel economy and weight

E. Readjust fuel economy based on the new horsepower, and price based on the change in horsepower

Each step is described in more detail below. Readers should note that all of the calculations in this section take place within loops by Group, Class, and Fuel Type. In the interest of legibility, these dimensions are not shown in the subscripts.

A: Calculate the economic market share for each technology

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. These are addressed in turn below.

Fuel Savings Value

The "expected" price of fuel is based on the rate of change of fuel prices over a two year period prior to the year when the technology adoption decision is made. The time decision to introduce a particular technology is made at least three years before actual introduction in the marketplace, and is based on the expected fuel prices at the time of introduction rather than actual fuel prices. The expected present value of fuel savings is dependant on the "expected" price of fuel, how long the purchaser is willing to wait to recover the initial investment (the payback period); and the distance driven over the period. This estimation involves the following three steps:

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

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

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

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

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

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

where:

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

Technology Cost

Technology cost has both absolute and weight dependant components. The absolute component is a fixed dollar cost for installing a particular technology on a vehicle. Most technologies are in this category. The weight dependant component is associated with the material substitution technologies. In these technologies a heavy material is replaced with a lighter one. The technology cost is a function of the amount of material, which is in turn a function of how heavy the vehicle was to begin with. The technology cost equation includes both components, although in practice one or the other term is always zero:

$$TECHCOST_{itc} = DEL\$COSTABS_{itc} - \left(DEL\$COSTWGT_{itc} * DEL\$WGTWGT_{itc} * WEIGHT_{BASEYR} \right) \quad \textbf{(19)}$$

where:

TECHCOST = The cost per vehicle of technology *itc*
DEL$COSTWGT = The weight-based change in cost ($/lb)
DEL$WGTWGT = The fractional change in weight associated with technology *itc*
WEIGHT = The original vehicle weight

Performance Value

Although there are a number of tecnological factors which affect the perceived "performance" of a vehicle, in the interests of clarity and simplicity it was decided to use the vehicle's horsepower as a proxy for the general category of performance. An increase in horsepower is assumed to reduce the fuel economy based on the relationship given in Equation 21. The perceived value of performance is also a factor in the cost effectiveness calculation. The value of performance for a given technology is positively correlated with both income and vehicle fuel economy and negatively correlated with fuel prices. In addition, purchasers of sports and luxury vehicles tend to place a higher value on performance:

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

where:

VAL$PERF = The dollar value of performance of technology *itc*
VALUEPERF = The value associated with an incremental change in performance
FE = Vehicle's fuel economy
DEL$FE = The fractional change in fuel economy of technology *itc*
DEL$HP = The fractional change in horsepower of technology *itc*
FUELCOST = The actual price of fuel (in the previous year)

Economic Market Share

The market share of the considered technology is determined by first evaluating the cost effectiveness of technology *itc* as a function of the values described above:

$$COSTEFFECT_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + VAL\$PERF_{itc} + \left(REGCOST * FE_{YEAR-1} * DEL\$FE_{itc}\right)}{ABS\left(TECHCOST_{itc}\right)} \tag{21}$$

where:

COSTEFFECT = A unitless measure of cost effectiveness
REGCOST = A factor representing regulatory pressure to increase fuel economy, in $ per MPG

and:

$$ACTUAL\$MKT_{itc} = MMAX_{itc} * PMAX_{itc} * \left(1 + e^{-2 * COSTEFFECT_{itc}}\right)^{-1} \tag{22}$$

where:

ACTUAL$MKT = The economic share, prior to consideration of engineering or regulatory constraints.
MMAX = The maximum market share for technology *itc*
PMAX = The institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in a separate subroutine. This subroutine (FUNCMAX) sets the current year maximum market share based on the previous year's share. The values are tabulated in Appendix A, Table A-3.

Market Share Overrides

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

$$ACTUAL\$MKT_{itc} = MAX\,(\,MKT\$PEN_{YEAR-1}\ ,\ ACTUAL\$MKT_{itc}\,) \qquad \textbf{(23)}$$

where:

MKT$PEN = Temporary variable which stores value of ACTUAL$MKT, calculated in Equation 7, from previous year

B: 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 first three types of notes (mandatory, supersedes and requires) directly affect the technology market share results obtained above. The fourth type of note, synergy, does not affect the market share and is applied after all other engineering notes have been applied.

Mandatory Notes

These are usually associated with safety or emissions technology which must be in place by a certain year. For example, air bags are mandatory in 1994. If the cost effectiveness calculations do not produce the mandated level of technology then those results are overridden as follows:

$$ACTUAL\$MKT_{itc} = MAX\left(ACTUAL\$MKT_{itc}\ ,\ MANDMKSH_{itc}\right) \qquad \textbf{(24)}$$

where:

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

Supersedes Notes

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

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

1) Add the three market shares together:

$$SUM\$MKT = ACTUAL\$MKT_A + ACTUAL\$MKT_B + ACTUAL\$MKT_C \qquad \textbf{(25)}$$

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

$$MMAX = MAX\left(MKT\$MAX_A\ , MKT\$MAX_B\ , MKT\$MAX_C\right) \qquad \textbf{(26)}$$

where:

MKT$MAX = Maximum market share of technology *itc*

3) If SUM$MKT <= MMAX, then make no adjustments.
4) If SUM$MKT > MMAX, then subtract market share from technology C until the sum of the market shares equals MMAX, or until $ACTUAL\$MKT_C = 0$.
5) If SUM$MKT is still greater than MMAX, subtract market share from technology B until the sum of the market shares equals MMAX.

Requires Notes

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

1) For a given technology *itc*, define a group of potential matching technologies, one of which must be present for *itc* to be present.
2) Sum the market shares of the matching technologies (*req*):

$$REQ\$MKT = \sum_{req}^{RQ} ACTUAL\$MKT_{req} \tag{27}$$

where:

REQ$MKT = The market share of required complementary technologies to technology *itc*.
req = Index referring to all required complementary technologies to technology *itc*.
RQ = Number of required complementary technologies to technology *itc*.

3) Compare REQ$MKT to the market share of technology *itc*: $ACTUAL\$MKT_{itc}$.
4) If $ACTUAL\$MKT_{itc}$ <= REQ$MKT, then make no change.
5) If $ACTUAL\$MKT_{itc}$ > REQ$MKT, then set $ACTUAL\$MKT_{itc}$ = REQ$MKT

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

Synergistic Notes

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

Synergy adjustments are made once all other engineering notes have been applied. For each synergistic pair of technologies the fuel economy is adjusted as follows:

$$\begin{aligned} FE_{YEAR} = FE_{YEAR} &+ \left(MKT\$PEN_{itc1,YEAR} - MKT\$PEN_{itc1,YEAR-1}\right) \\ &* \left(MKT\$PEN_{itc2,YEAR} - MKT\$PEN_{itc2,YEAR-1}\right) * SYNR\$DEL_{itc1,itc2} \end{aligned} \tag{28}$$

where:

FE = Fuel economy, by size class and group, initialized to the previous year's value and subsequently modified with each iteration of the model.
itc1 = First synergistic technology
itc2 = Second synergistic technology
SYNR$DEL = The synergistic effect of the two technologies on fuel economy

C: Calculate Net Impact of Technology Change

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

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,YEAR} - MKT\$PEN_{itc,YEAR-1} \quad \textbf{(29)}$$

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

Fuel Economy

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

$$FE_{YEAR} = FE_{YEAR} + \sum_{itc=1}^{NUMTECH} FE_{YEAR-1} * DELTA\$MKT_{itc} * DEL\$FE_{itc} \quad \textbf{(30)}$$

where:

NUMTECH = Number of newly adopted technologies

Vehicle Weight

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

$$WEIGHT_{YEAR} = WEIGHT_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \Big[DEL\$WGTABS_{itc} + \Big(WEIGHT_{BASEYR} * DEL\$WGTWGT_{itc} \Big) \Big] \quad (31)$$

where:

DEL$WGTABS = The change in weight (lbs) associated with technology *itc*

DEL$WGTWGT = The fractional change in vehicle weight due to technology *itc*

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

Vehicle Price

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

$$PRICE_{YEAR} = PRICE_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \Big[DEL\$COSTABS_{itc} + (WEIGHT_{YEAR} - WEIGHT_{BASEYR}) * DEL\$COSTWGT_{itc} \Big] \quad (32)$$

where:

DEL$COSTABS = The cost of technology *itc*

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

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

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

D: Estimate EV and Fuel Cell Characteristics

Electric Vehicles

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

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

1) Weight and cost of a lead acid battery

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

$$and \qquad \textbf{(33)}$$

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

where:

BATTERY1$WT = Weight of a lead acid battery large enough to provide adequate range and performance
BATTERY1$COST = Cost of a lead acid battery
0.60 = Fraction of vehicle weight accounted for by the battery system
$2.30 = Cost/pound of a lead acid battery
1.75 = Cost multiplier to determine retail price
$1,500 = Fixed cost amortization per unit EV

2) Weight and cost of a nickel metal hydride battery

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

$$and \qquad \textbf{(34)}$$

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

where:

BATTERY2$WT = Weight of a Ni-MH battery large enough to provide adequate range and performance
BATTERY2$COST = Cost of a Ni-MH battery
$8.20 = Cost/pound of a Ni-MH battery
1.75 = Cost multiplier to determine retail price
$1,500 = Fixed cost amortization per unit EV

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

3) Learning curve adjustment for battery costs

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

$$and \tag{35}$$

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

where:

LEADACID$COST = Cost reduction learning curve for a lead acid battery

NIMHY$COST = cost reduction learning curve for a Ni-MH battery

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

4) Average price of an electric vehicle battery

$$\begin{aligned} BATTERY_{Year,Electric\,Vehicle} &= BATTERY1\$COST * (1 - NIMHY\$MKTSH_{Year}) \\ &+ BATTERY2\$COST * NIMHY\$MKTSH_{Year} \end{aligned} \tag{36}$$

where:

BATTERY = Average price of an electric vehicle battery

NIMHY$MKTSH = Expected market share of Ni-MH batteries

Finally, Price, Weight and Fuel Economy are calculated:

5) Electric Vehicle Price

$$PRICE_{Year,ElectricVehicle} = PRICE_{Year,ElectricVehicle} + BATTERY_{Year,ElectricVehicle} \tag{37}$$

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

6) Electric Vehicle Weight

$$WEIGHT_{Year,ElectricVehicle} = \frac{BATTERY1\$WT}{0.33} * (1 - NIMHY\$MKTSH_{Year}) + \frac{BATTERY2\$WT}{0.22} * NIMHY\$MKTSH_{Year} \quad \textbf{(38)}$$

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

$$FE_{Year,Electric\,Vehicle} = \left[\frac{0.8 \cdot (2{,}200)}{0.16 \cdot WEIGHT_{Year,ElectricVehicle}} \right] \quad \textbf{(39)}$$

Fuel Cell Vehicles

The subroutines FCMCALC and FCHCALC calculate fuel cell cost, vehicle price (low and high volume sales), and fuel economy for methanol and hydrogen 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 2010. Hydrogen supply is expected to be a major problem for the corresponding vehicles. In the following equations the *FC* subscript refers to Fuel Cell.

1) Fuel Cell Cost

$$FUELCELL_{Year,FC} = 30 * \frac{WEIGHT_{Year,Gasoline}}{2200} * FUELCELL\$COST_{Year,MFC} \quad \textbf{(40)}$$

where:

FUELCELL = Cost of the fuel cell.
FUELCELL$COST = Cost of the fuel cell in $/kw

2) Battery Power Required to start vehicle

$$BATTERY\$POWER = 20 * \frac{WEIGHT_{Year,Gasoline}}{2200} \quad \textbf{(41)}$$

where:

BATTERY$POWER = Required battery power in Kw

3) Weight of Battery

$$BATTERY\$WT = 2.2 * \frac{BATTERY\$POWER}{0.5} \quad \textbf{(42)}$$

where:

BATTERY$WT = Weight of battery

4) Cost of Battery

$$BATTERY_{Year,FC} = 2.30 * BATTERY\$WT * LEADACID\$COST_{Year} \quad \textbf{(43)}$$

where:

BATTERY = Cost of the lead acid battery

$2.30 = Initial cost per pound for the battery

$LEADACID\$COST_{Year}$ = Cost reduction learning curve for a lead acid battery

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

$$FUELCELL_{Year,FC} = (FUELCELL_{Year,FC} + BATTERY_{Year,FC} + HTANK_{FC}) * 1.75 + 1500 \quad \textbf{(44)}$$

where:

HTANK = Cost of the hydrogen storage tank: $0 for Methanol FC, $3000 for Hydrogen FC.

1.75 = Cost multiplier to determine retail price

$1,500 = Fixed cost amortization per unit fuel cell vehicle

6) Fuel Cell Vehicle Price

$$PRICE_{Year,FC} = PRICE_{Year,FC} + FUELCELL_{Year,MFC} \quad \textbf{(45)}$$

7) Fuel Cell Fuel Economy (gasoline equivalent mpg)

$$FE_{Year,FC} = \frac{1}{0.00625 * \frac{WEIGHT_{Year,Gasoline}}{1000}} \quad \textbf{(46)}$$

E: Adjust Horsepower

Calculating the net impact of changes in technology share on vehicle horsepower is a two step process. First, horsepower is calculated on the basis of weight; this step assumes no change in performance. This initial estimate simply maintains the weight to horsepower ratio observed in the base year:

Unadjusted Horsepower

Assuming a constant weight/horsepower ratio:

$$HP_{YEAR} = HP_{BASEYR} * \frac{WEIGHT_{YEAR}}{WEIGHT_{BASEYR}} \quad \textbf{(47)}$$

where:

HP = Vehicle horsepower
WEIGHT = Vehicle weight

Adjustment Factor

The second step adjusts horsepower for changes in performance. This calculation is based on household income, vehicle price, fuel economy, fuel cost, and the perceived desire for performance (PERFFACT):

$$ADJHP = PERFFACT * \left[\left(\frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} \right)^{0.9} * \left(\frac{PRICE_{YEAR-1}}{PRICE_{YEAR}} \right)^{0.9} * \left(\frac{FE_{YEAR}}{FE_{YEAR-1}} \right)^{0.2} * \left(\frac{FUELCOST_{YEAR-1}}{FUELCOST_{YEAR}} \right)^{0.2} - 1 \right] \quad \textbf{(48)}$$

where:

ADJHP = Vehicle horsepower adjustment factor

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

Adjusted Horsepower

The current year horsepower is then calculated as follows:

$$HP_{YEAR} = HP_{YEAR} * \left(1 + \sum_{1990}^{YEAR} ADJHP \right) \qquad \textbf{(49)}$$

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

F: Readjust Fuel Economy and Price

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

Fuel Economy Adjustment Factor

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

$$ADJFE = -0.22*ADJHP - 0.560*ADJHP^2 \qquad \textbf{(50)}$$

Adjusted Fuel Economy

The final vehicle fuel economy is then determined as follows:

$$FE = FE * (1 + ADJFE) \quad \textbf{(51)}$$

Adjusted Vehicle Price

Vehicle price is finally estimated:

$$PRICE = PRICE + ADJHP * VALUEPERF \quad \textbf{(52)}$$

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.

G: Estimate Vehicle Range

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

1) Vehicle Range Calculation

$$RANGE_{Year,FuelType} = TANKSIZE * FE_{Year} * (1 + AFVADJRN_{FuelType}) \quad \textbf{(53)}$$

where:

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

The range adjustment factor (AFADJRN) 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. Of necessity, the range estimate is less accurate than the AFV fuel economy projections.

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.

III. 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.) Market shares for each class are derived by calculating an increment from the base year (1990) market share. The market share increment (or decrement) is determined by one of the following equations (depending on vehicle class):

All Vehicle Classes Except Luxury Cars:[2]

$$\ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR} - \$13{,}000}{INCOME_{1990} - \$13{,}000}\right) \quad \textbf{(54)}$$

where $CLASS\$SHARE_i$ is the market share of the i^{th} market class, and the values of the coefficients A, B, and C are tabulated in Table E-1 of Appendix E.

Luxury Cars:

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

$$\ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR}}{INCOME_{1990}}\right) \quad \textbf{(55)}$$

CALCULATE CORPORATE AVERAGE FUEL ECONOMY

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

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

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[2] Note: Market shares for Mini and Sub-Compact cars are solved jointly using equation 24. The resulting combined market share is allocated between the two classes based on the original 1990 allocation. Special treatment of these two classes was made necessary by the small sample size in the analysis data sets.

4) Import Trucks

For each vehicle group the CAFE calculation proceeds as follows:

$$CAFE_{i,k,YEAR} = \frac{\sum_{i=1}^{7} CLASS\$SHARE_{i,k,YEAR}}{\sum_{i=1}^{7} \frac{CLASS\$SHARE_{i,k,YEAR}}{FE_{i,k,YEAR}}} \qquad \textbf{(56)}$$

where:

i = Vehicle Class
k = CAFE Group

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

IV. 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 fuel economy for each class of car and light truck. Aggregate fuel economy is determined by weighting each vehicle class by their relative share of the market. These figures are assumed to be constant across classes and time, and have been obtained from Oak Ridge estimates of the domestic and imported market shares:[3]

For Cars (except mini-compacts):

$$FE_{CLASS} = \left[\frac{.742}{FE_{CLASS,Domestic}} + \frac{.258}{FE_{CLASS,Import}} \right]^{-1} \qquad \textbf{(57)}$$

For Light Trucks (except standard pickups, standard vans, and standard utility vehicles):

[3] Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 12*, ORNL-6710, 3/92. For Cars: Table 3.9, 1990 data. For Light Trucks: Table 3.16, 1990 data.

$$FE_{CLASS} = \left[\frac{.868}{FE_{CLASS,Domestic}} + \frac{.132}{FE_{CLASS,Import}} \right]^{-1} \tag{58}$$

All mini-compact cars are imported, and all standard pickups, standard vans, and standard utility vehicles are produced domestically.

The fuel economies of the seven size classes described above are subsequently collapsed into six size classes considered by the remainder of the Transportation Model, and benchmarked to correspond to 1992 NHTSA estimates of fuel economy for each size class. These numbers are then passed to the Alternative Fuel Vehicle (AFV) Model, and the overall fleet stock model to produce estimates of fleet efficiencies.

3A-2. Regional Sales Model

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

RATIONALE

Nationwide estimates of new car sales come from the the NEMS Macro Module. In order to comply with the NEMS requirement for regional fuel consumption estimates, the Regional Sales Model allocates new car and light truck sales among the nine Census divisions and permits regional variations in vehicle attributes. This also gives the Transportation Model the capability to analyze regional differences in alternative vehicle legislation. For example, California has implemented legislation requiring that 2% of all vehicles sold by the year 2000 be "zero emissions" vehicles (essentially electric vehicles). Massachusetts and New York have taken steps to adopt the California standards, and the Transportation Model assumes that they will be successful.

ALTERNATIVE SPECIFICATIONS

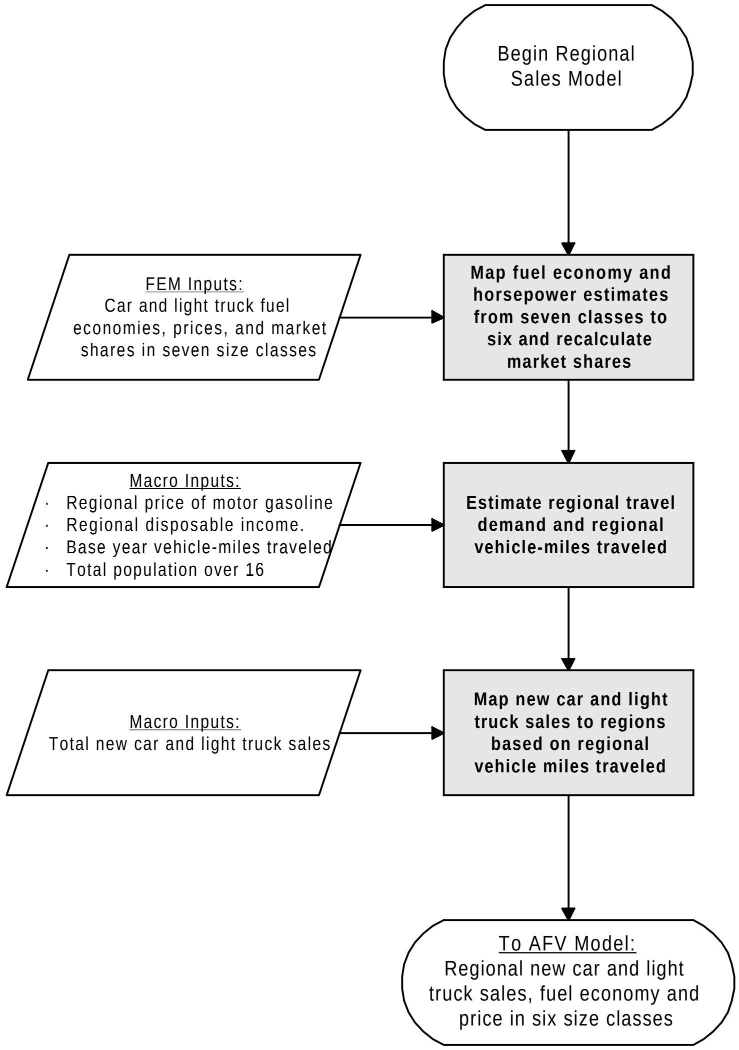
No alternative models were considered.

MODEL STRUCTURE

This is not a separate model in itself, but rather a series of intermediate calculations used to generate several regional variables which are used in subsequent steps in the Transportation Model. It comprises two subroutines, TSIZE and TREG; the first is used to compress the seven vehicle size classes generated by the Fuel Economy Model into six size classes used in subsequent calculations and the second generates regional shares of fuel consumption, driving demand, and sales of vehicles by size class.

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

Figure 3A-2. Regional Sales Model



Redistribute FEM Results Among Six Size Classes

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

It is first necessary to reallocate the estimates of car and light truck sales supplied by the Macro Module. This is required due to the fact that definitions used in the Transportation Module differ from those used in the Macro Module. The trucks enumerated by the Macro Module's definition of "light trucks" includes those of less than 14,000 pounds GVW, and are not identified by axle configuration. In the Transportation Module these trucks are addressed in three separate sections: trucks under 8,500 pounds are included in the LDV Model; trucks between 8,500 and 10,000 pounds are modeled separately in the Light Commercial Truck Model; and trucks over 10,000 pounds are included in the Highway Freight Model. Additionally, the LDV Module uses a different methodology to estimate the allocation of LDV sales between cars and light trucks, reflecting the changing purchase patterns of consumers who have been shifting their attentions toward minivans and sport utility vehicles in recent years.

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

$$\begin{aligned} T\_LDT\_MAC_N &= MC\_SQDTRUCKS_N * LT10K \\ &* \left[(LT2A4 * LT2A4LDV) + (LTOSU * LTOSULDV) \right] \end{aligned} \qquad \textbf{(59)}$$

where:

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

Calculate total LDV sales:

$$T\_LDV\_MAC_N = MC\_SQTRCARS_N + T\_LDT\_MAC_N \quad \textbf{(60)}$$

where:

T_LDV_MAC = Total car and adjusted light truck sales
MC-SQTRCARS = Total car sales, from the Macro Module

Allocate LDV sales between cars and light trucks:

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

$$and \quad \textbf{(61)}$$

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

where:

TMC_SQTRCARS = Total sales of new cars
TMC_SQDTRUCKS = Total sales of new light trucks
CARLTSHR = Allocation factor representing LDT fraction of LDV sales (Appendix F, Attachment 8)

Allocate sales among size classes:

For Cars:

$$NCS7SC_{CLASS,T} = MKTC_{CLASS,T} * TMC\_SQTRCARS_T * \left(1 - FLTCRAT_{1990}\right) \quad \textbf{(62)}$$

where:

NCS7SC = New car sales in the original seven FEM size classes
MKTC = The market share for each automobile class, from FEM
FLTCRAT = Fraction of new cars purchased by fleets in 1990
T = Index referring to model run year

Similarly for Trucks:

$$NTS7SC_{CLASS,T} = MKTT_{CLASS,T} * TMC\_SQDTRUCKSL_T * \left(1 - FLTTRAT_{1990}\right) \quad \textbf{(63)}$$

where:

NTS7SC = New light truck sales in the original seven FEM size classes
MKTT = The market share for each light truck class, from FEM
FLTTRAT = Fraction of new light trucks purchased by fleets in 1990

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

$$NCSTSC_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} \left(NCS7SC_{CLASS,GROUP} \right) * \beta 1_{CLASS,GROUP,SC} \tag{64}$$

and:

$$NLTSTSC_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} \left(NTS7SC_{CLASS,GROUP} \right) * \beta 2_{CLASS,GROUP,SC} \tag{65}$$

where:

NCSTSC = New car sales in the modified six size classes, *SC*
SC = Index for six size classes
NLTSTSC = New light truck sales
β1,β2 = Weighting coefficients associated with cars and trucks, respectively
GROUP = Index indicating domestic or imported vehicles

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

$$PASSHRR_{SC} = \frac{NCSTSC_{SC}}{\sum_{SC=1}^{6} NCSTSC_{SC}} \tag{66}$$

and:

$$LTSHRR_{SC} = \frac{NLTSTSC_{SC}}{\sum_{SC=1}^{6} NLTSTSC_{SC}} \tag{67}$$

where:

PASSHRR = Non-fleet market shares of automobiles, by size class *SC*
LTSHRR = Non-fleet market shares of light trucks, by size class *SC*

Similarly, horsepower estimates generated in FEM are compressed from seven to six size classes for cars and light trucks, combining domestic and import groups:

$$HPCAR_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} \left(HPC_{CLASS,GROUP}\right) * CARSHR_{GROUP} * \beta 1_{CLASS,GROUP,SC} \tag{68}$$

and:

$$HPTRUCK_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} \left(HPT_{CLASS,GROUP}\right) * TRKSHR_{GROUP} * \beta 1_{CLASS,GROUP,SC} \tag{69}$$

where:

HPCAR = Average horsepower of automobiles, by size class *SC*
HPTRUCK = Average horsepower of light trucks, by size class *SC*
HPC = Automobile horsepower by FEM size class *CLASS*
HPT = Light truck horsepower by FEM size class *CLASS*
CARSHR = Domestic vs. import market share for automobiles, from ORNL
TRKSHR = Domestic vs. import market share for light trucks, from ORNL

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

$$AHPCAR_{SC} = \sum_{SC=1}^{6} HPCAR_{SC} * PASSHRR_{SC} \tag{70}$$

and:

$$AHPTRUCK_{SC} = \sum_{SC=1}^{6} HPTRUCK_{SC} * LTSHRR_{SC} \tag{71}$$

where:

AHPCAR = Average automobile horsepower
AHPTRUCK = Average light truck horsepower

Determine Regional Values of Fuel Demand and Vehicle Sales

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

$$SEDSHR_{FUEL,REG,T} = \frac{SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)}{\sum_{REG=1}^{9} SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)} \quad \textbf{(72)}$$

where:

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

These shares are passed to other modules in the Transportation Model.

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

Determine the regional cost of driving per mile:

$$COSTMIR_{REG,T} = 0.1251 * \left(\frac{TPMGTR_{REG,T}}{MPGFLT_{T-1}} \right) \quad \textbf{(73)}$$

where:

COSTMIR = The cost per mile of driving in region *REG*, in $/mile
TPMGTR = The regional price of motor gasoline, in $/MMBTU
MPGFLT = The previous year's stock MPG for non-fleet vehicles
.1251 = A conversion factor for gasoline, in MMBTU/gal

Calculate regional income:

$$INCOMER_{REG,T} = \left(\frac{TMC\_YD_{REG,T}}{TMC\_POPAFO_{REG,T}} \right) \quad \textbf{(74)}$$

where:

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

Estimate regional driving demand:[4]

$$VMT16R_{REG,T} = \rho\, VMT16R_{REG,T-1} + \beta_0 (1 - \rho) + \beta_1 \left(COSTMIR_{REG,T} - \rho\, COSTMIR_{REG,T-1} \right) + \beta_2 \left(INCOMER_{REG,T} - \rho\, INCOMER_{REG,T-1} \right) + \beta_3 \left(PRFEM_T - \rho\, PRFEM_{T-1} \right) \quad (75)$$

and:

$$VMTEER_{REG,T} = VMT16R_{REG,T} * TMC\_POP16_{REG,T} * DAF_T \quad (76)$$

where:

VMT16R = Vehicle-miles traveled per population over 16 years of age
PRFEM = Ratio of female to male driving rates
ρ = Lag factor for the difference equation
VMTEER = Total VMT in region *REG*
TMC_POP16 = Total regional population over the age of 16
DAF = A demographic adjustment factor, to reflect different age groups' driving patterns

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,T} = \frac{VMTEER_{REG,T}}{\sum_{REG=1}^{9} VMTEER_{REG,T}} \quad (77)$$

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

$$NCS_{REG,SC,T} = NCSTSC_{SC,T} * RSHR_{REG,T} \quad (78)$$

and:

$$NLTS_{REG,SC,T} = NLTSTSC_{SC,T} * RSHR_{REG,T} \quad (79)$$

where:

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

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

3A-3. AFV Model

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

RATIONALE

The objective of the AFV model is to estimate the market penetration (market shares) of alternative-fuel vehicles during the period 1990-2030. The model provides market shares for fourteen alternative-fuel technologies in addition to the conventional gasoline and diesel technologies. The shares are projected in three stages. In the first stage the two conventional technologies are allowed to compete with a single representative alternative-fuel vehicle technology. In the second stage the overall alternative-fuel vehicle share is disaggregated among eleven competitive alternative-fuel technologies. In the third stage the electric vehicle (EV) share is distributed among four EV and hybrid technologies. Forecasts of vehicle-technology shares are developed for each of the nine U.S. Census regions.

The AFV model is an improvement over the predecessor model used in the AEO 93, which assigned market shares to four basic alternative technologies based on legislative mandates. That model left no room for consideration of technological or market-driven limitations on the penetration of AFV's, thereby limiting its usefulness in evaluating the impacts of alternative policies.

ALTERNATIVE SPECIFICATIONS

There are very few current models which attempt to estimate the market penetration of alternative fuel vehicles. The methodology used in the AFV module is based on attribute-based discrete choice techniques and logit-type choice functions described in previous reports.[5] The attribute coefficients used in the module are derived from a logit discreet-choice consumer preference model commissioned

[5] See Fulton, L., *New Technology Vehicle Penetration: A Proposal for an Analytical Framework,* Submitted to EIA, Office of Energy markets and End Use, March 17, 1991.

by the state of California.[6] The methodology consists of the estimation of a demand function for vehicle sales in the U.S. market and the derivation of coefficients for the vehicle and fuel attributes which portrays consumer demand. Once the demand function has been determined, projections of the changes in vehicle and fuel attributes for the considered technologies are multiplied by the corresponding attribute coefficients to produce the market share penetration for the various technologies.

An important limitation in estimating market share penetration of alternative fuel technologies is the lack of experience in consumer use of alternative technologies. Only a limited number of alternative-fuel technologies are commercially available at the present time and the vehicle options which are available are still in experimental stages of development resulting in significantly high vehicle prices. Lack of data on previous consumer purchases of alternative fuel vehicles poses a significant obstacle in estimating an equation to forecast future market share penetration. A stated preference survey performed for the California Energy Commission (CAC) which asked consumers their vehicle choice preference in reference to hypothetical scenarios is used in the AFV module. The demand function for personal vehicle choice determined from this survey is used as the source for the attribute coefficients for the AFV module.[7]

The demand estimation incorporates a logit discrete choice model to calculate consumer vehicle preference in relation to vehicle and fuel attributes. A survey was conducted in which respondents were asked to express their preferences for vehicles based on vehicle and fuel attributes. The stated preference survey consisted of a sample size of 692 respondents yielding 3460 observations. Based on the stated preference surveys a mathematical model was estimated to account for consumer preferences in vehicle choice.

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

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

where P_i is the probability of a consumer choosing vehicle *i*, $ß_1$ is the constant, $ß_i$ are the coefficients

[6] The coefficients of the vehicle attributes derived from the Logit discrete choice model are taken from Bunch, D.S.; Bradley, M.; Golob, T.F.; Kitamura, R.; Occhiuzzo, G.P., *Demand For Clean Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey, CAC, Dec. 1991.*

[7] For a detailed explanation of the demand function estimation, see Bunch,D.S.; Bradley,M.; Bolob, T.F.; Kitamura,R. and Occhiuzzo, G.P., *Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey,* California Energy Commission, December 1991.

of vehicle and fuel attributes and X_i are vehicle and fuel attributes.

The resulting specifications of the nested multinomial logit discrete choice model for estimating market share penetration of alternative fuel technologies from the stated preference survey are presented in Table E-2 of Appendix E. The independent variables, coefficients, t-statistics, sample size, and log-likelihood calculations are listed. The coefficient signs of the five fundamental independent variables correspond with *a priori* expectations for consumer preference and all the fundamental independent variables are significant in the model.[8]

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*.[9]

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

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

where:

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

$$V = ß_1X_1 + ß_2X_2 + \ldots + ß_kX_k$$

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

[8] Several variations for the discrete-choice stated preference model for alternative fuel vehicle choice were presented in the California Energy Commission report; however, the nested multinomial logit model presented in Table 2 is the preferred model to use in the AFV module.

[9] The forecasting methodology is based on the methodology defined in the Decision Analysis Corporation of Virginia Report, *Alternative Vehicle Sales Module: Design of the Modeling Framework and Prototype Module Description*, for Energy Information Administration,Task 91-137, September 30, 1991.

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 *C* matrix represented below is a simple illustration of the matrix format used in the market share calculation. For simplicity, a 4 by 4 matrix of four vehicle types (i = 4) and four attributes (k = 4), for individual n in year t, has been chosen.

	$C_{ik}=(ß_{ik}X_{ik})$	k=1	k=2	k=3	k=4
$V_1=\Sigma C_{1k}$	i=1	C_{11}	C_{12}	C_{13}	C_{14}
$V_2=\Sigma C_{2k}$	i=2	C_{21}	C_{22}	C_{23}	C_{24}
$V_3=\Sigma C_{3k}$	i=3	C_{31}	C_{32}	C_{33}	C_{34}
$V_4=\Sigma C_{4k}$	i=4	C_{41}	C_{42}	C_{43}	C_{44}

The factor C_{ik} represents the product of the coefficient $ß_{ik}$ derived from the demand function and the attribute value X_{ik} for vehicle type i and attribute k.

The coefficients of the vehicle attributes in the AFV module are assumed to remain constant over time. This enables the calculation of the *C* matrix to be less cumbersome; however, the methodology can utilize either changing or constant coefficient values for the vehicle attributes. The *C* matrix is replicated for each year of the analysis and for each target group incorporated in the study. The scope of the AFV module covers a 40 year time period with 9 regional target groups, three size classes and three scenarios. 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.

A separate *IKT* matrix must be calculated for each individual in the population, or at least for each group of similar individuals. It is necessary to calculate P_{itn} separately for each group and average to obtain an aggregate probability and market share for each vehicle type. However, a single *IKT* matrix can be calculated by taking one additional step. An aggregate *IKT* matrix which approximates the results obtained by taking an average probability can be calculated over the individual matrices. This is dependent on the condition that the average probability function over the population equals each group probability function, not just the average of all functions. Demographic variables can be used to subdivide the population into similar groups in order to approximate this condition. These variables can be incorporated into the V_{it} expression as dummy variables, which produce separate coefficients for each population group. An example of demographic variables which subdivide the population could be family size or income level. A separate dummy variable would be used for each family size category or income level category found in the population[10].

The following equation illustrates how including demographic variables, the aggregate probability function approximates each individual probability function.

$$P_{it} \approx P_{itn} \; for \; all \; n \quad \therefore \quad P_{it} \approx \frac{e^{V_{it}}}{\sum_{i=1}^{I} e^{V_{it}}}$$

Where V_{it} is a function of the K-size attribute vector containing elements taken as averages over segments of the population N, with these segments defined by dummy variables.

This allows estimation of the model using a single *IKT* matrix over the population.

MODEL STRUCTURE

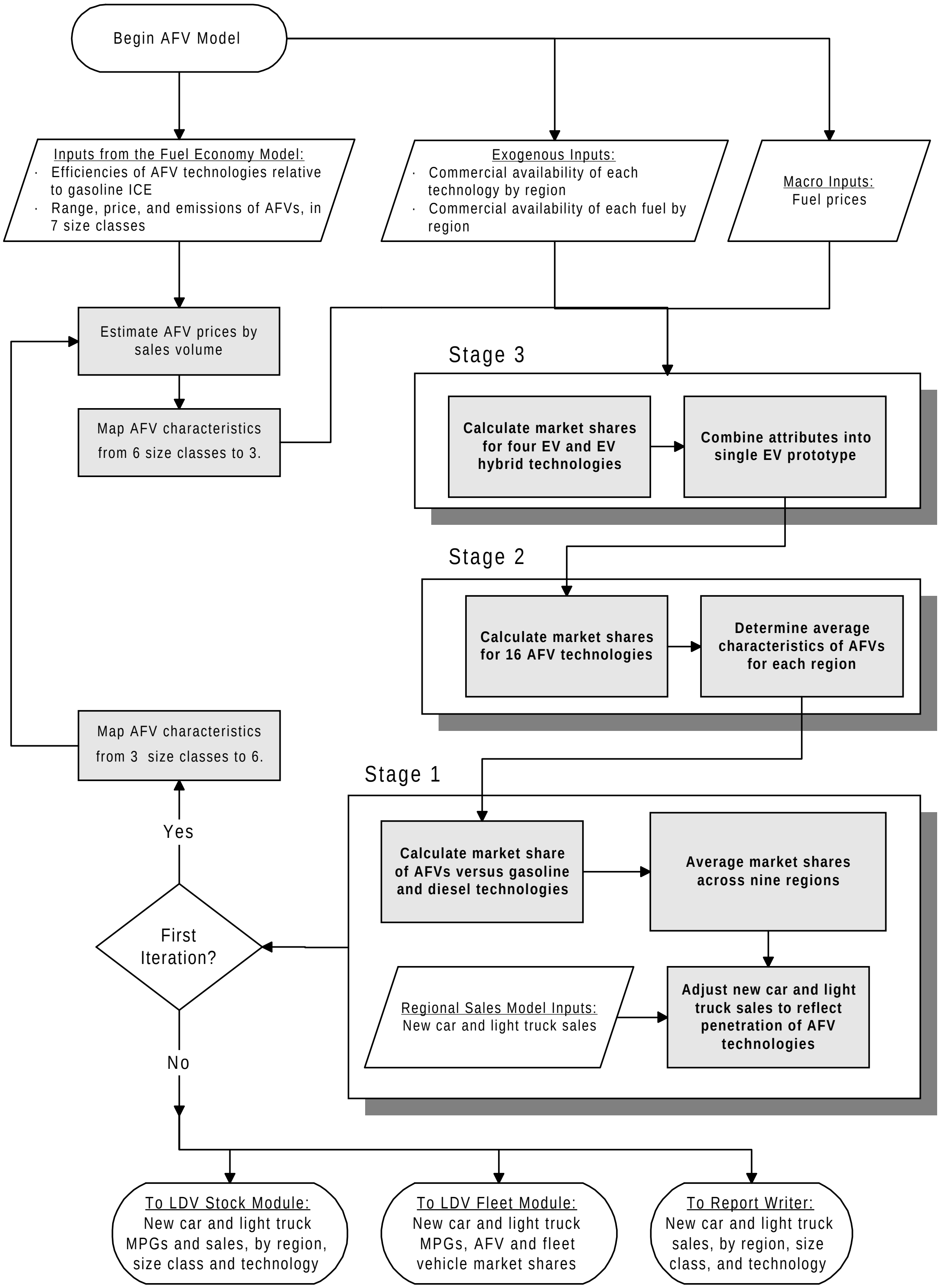
The AFV module operates in three stages, using a bottom-up approach to determine the eventual market shares of conventional and alternative vehicles. Results from the lower stages are passed to the next higher stage in the sequence. At this stage of the LDV Model, vehicle sales and characteristics are mapped from the seven or six size classes considered in previous sections to three aggregate size classes. As the prices of alternative fuel vehicles are functions of sales volume (estimated in the FEM Model), the AFV Model goes through two iterations; first, estimating sales volume using the previous year's volume-dependent prices, then re-estimating prices and consequent sales. The first step in the calculation involves the evaluation of Stage 3, in which market shares of one type of alternative vehicle, Electric Vehicles and associated hybrids, are determined. These results are then passed to Stage 2, in which market shares for all alternative vehicles are estimated. The average characteristics of alternative vehicles are subsequently passed to Stage 1, where the final mix of alternative and conventional vehicles is calculated.

[10] The number of dummy variables required in subdividing the population is one less than the number of groups so that if 5 family size groups were included in the module 4 dummy variables would be required.

An additional constraint is included at each stage of the market share calculation which incorporates commercial availability of the alternative-fuel technology. The aggregate probability function assumes that all technologies are fully developed and available to the consumer at the present time. This assumption does not hold true for most of the alternative-fuel technologies, which at the present time still remain in development stages. Therefore, an upper limit constraint is placed on the market share penetration of alternative vehicle sales corresponding to the expected development and commercial availability of alternative fuel vehicles. This constraint applies to the early years and is gradually reduced through the forecasting period, via a logistic curve for each technology. The equations associated with each stage of the model are presented below, in order of execution.

The Alternative Fuel Vehicle Model flowchart is presented in Figure 3A-3 below. More detailed sketches of AFV calculations are presented at the end of Section 3A.

Figure 3A-3. Alternative Vehicle Model



STAGE 3

Stage 3 of the AFV module determines the market share of each of the four EV technologies considered in the model. These market shares are used to characterize a prototypic EV when all alternative vehicles are considered in Stage 2. The steps involved in Stage 3 are described below.

1) Map vehicle range and price for cars and light trucks from six to three size classes, combining domestic and imported vehicles. For each AFV technology:

$$LDVRANGE_{ISC} = \frac{\sum_{OSC} \sum_{K=1}^{2} \left[FEMRNG_{K,OSC} \cdot LDVSHRR_{OSC} \right]}{2 \cdot \sum_{OSC} LDVSHRR_{OSC}}$$

and **(80)**

$$LDVPRICERANGE_{ISC} = \frac{\sum_{OSC} \sum_{K=1}^{2} \left[FEMPRIRNG_{K,OSC} \cdot LDVSHRR_{OSC} \right]}{2 \cdot \sum_{OSC} LDVSHRR_{OSC}}$$

where:

LDVRANGE = Aggregate vehicle range for reduced size class *ISC,* for each technology

LDVPRICE = Aggregate vehicle price for reduced size class *ISC*, for each technology

FEMRNG = Vehicle range, from the FEM Model, by size class, *OSC*, and origin, *K*

FEMPRI = Vehicle price, from the FEM Model, by size class, *OSC*, and origin, *K*

LDVSHRR = Vehicle sales shares, by size class, represented in the code by PASSHRR for cars, and LTSHRR for light trucks

K = Index indicating 1) domestic, or 2) import

OSC, *ISC* = Index indicating expanded or corresponding reduced size class:
For cars: *ISC* = 1, *OSC* = 1, 2, 3, 6; *ISC* = 2, *OSC* = 4; *ISC* = 3, *OSC* = 5
For light trucks: *ISC* = 1, *OSC* = 1, 3; *ISC* = 2, *OSC* = 2, 5; *ISC* = 3, *OSC* = 4, 6

The factor of 2 in the denominator reflects the fact that sales shares are counted twice for each size class: once for domestic and once for imported vehicles.

2) Map vehicle fuel economy for cars and light trucks from six to three size classes, combining domestic and imported vehicles. For each AFV technology:

$$LDVMPG_{ISC} = \left[\frac{\sum_{OSC} \sum_{K=1}^{2} \left(\frac{LDVSHRR_{OSC}}{FEMMPG_{K,OSC}} \right)}{2 \cdot \sum_{OSC} LDVSHRR_{OSC}} \right]^{-1} \quad \textbf{(81)}$$

where:

LDVMPG = Aggregate vehicle fuel economy for reduced size class *ISC*, for each technology, represented in the code as CARMPG for cars, and TRKMPG for light trucks

FEMMPG = Vehicle fuel economy, from the FEM Model, by size class, *OSC*, and origin, *K*

3) Calculate the weighted average fuel price for each EV technology, by region.

$$AFCOST_{EVTECH,REG} = \frac{\sum_{FUEL} (RFP_{FUEL,REG} \cdot FAVAIL_{FUEL,REG})}{\sum_{FUEL} FAVAIL_{FUEL,REG}} \quad \textbf{(82)}$$

where:

AFCOST = Electric vehicle fuel price, in 1990$ / MMBTU

RFP = Price of each fuel used by the corresponding EV technology

FAVAIL = Relative availability of the corresponding fuel

EVTECH = Index referring the electric vehicle technology

FUEL = Index referring to fuel used by technology *EVTECH*

4) Calculate EV operating costs, by region.

$$COPCOST_{EVTECH,ISC,REG} = \frac{AFCOST_{EVTECH,REG}}{LDVMPG_{EVTECH,ISC}} \quad \textbf{(83)}$$

where:

COPCOST = Fuel operating costs for each technology, in 1990 cents per mile

5) Determine fuel availability relative to gasoline, $FAVAIL_{EVTECH,REG}$, using the highest value associated with any of the fuels used in electric hybrids.

$$FAVAIL_{EVTECH,REG} = MAX (FAVAIL_{FUEL,REG}) \quad \textbf{(84)}$$

6) Calculate the logit function inputs from the attributes and coefficients, by region.

$$EVECT_{EVTECH,REG} = EXP\ [\ BETACONST_{EVTECH} + \beta_1\ VPRICE_{EVTECH} + \beta_2\ COPCOST_{EVTECH,REG} + \beta_3\ VRANGE_{EVTECH} + \beta_4\ VRANGE^2_{EVTECH} + \beta_5\ VEMISS_{EVTECH} + \beta_6\ VEMISS^2_{EVTECH} + \beta_7\ FAVAIL_{EVTECH,REG} + \beta_8\ FAVAIL^2_{EVTECH,REG}\ ] \tag{85}$$

where:

BETACONST = Constant associated with each EV technology
VPRICE = Price of each EV technology in 1990$
VRANGE = Vehicle range of the considered technology
VEMISS = Emissions levels relative to gasoline ICE's: In the current model, emissions are not considered significant inputs. β_5 and β_6 are therefore set to zero.

7) Calculate EV market shares, by region.

$$APSHR33_{EVTECH,REG} = \frac{EVECT_{EVTECH,REG} \cdot COMAVAIL_{EVTECH}}{\sum_{EVTECH=1}^{4} (\ EVECT_{EVTECH,REG} \cdot COMAVAIL_{EVTECH}\ )} \tag{86}$$

where:

APSHR33 = Relative market shares of each EV technology
COMAVAIL = Commercial availability of each technology

8) Calculate average market shares across Census regions:

$$APSHR33_{EVTECH} = \frac{1}{9} \sum_{REG=1}^{9} APSHR33_{EVTECH,REG} \tag{87}$$

9) Determine the characteristics of a prototypical EV technology by weighting the individual technologies' characteristics by their respective market shares.

$$\Psi_{EV} = \sum_{EVTECH=1}^{4} \Psi_{EVTECH} \cdot APSHR33_{EVTECH} \tag{88}$$

where Ψ_{EV} denotes the average attributes of the EV technologies: vehicle price, efficiency, relative emissions, range, commercial availability, and alternative-specific constant. A similar procedure is used to characterize regional attributes such as fuel price and availability, and operating costs. These attributes are used as inputs in the Stage 2 subroutine.

STAGE 2

Stage 2 determines the relative market shares among the set of alternative vehicles. The result of this step is a prototypic AFV whose characteristics are determined by the market share-weighted attributes of all 11 alternative vehicle types. The sequence of calculations replicates those conducted in Stage 3, and is presented below.

10) Calculate the weighted average fuel price for each AFV technology, by region.

$$AFCOST_{AFVTECH,REG} = \frac{\sum_{FUEL} (RFP_{FUEL,REG} \cdot FAVAIL_{FUEL,REG})}{\sum_{FUEL} FAVAIL_{FUEL,REG}} \quad \textbf{(89)}$$

where:

AFCOST = Alternative vehicle fuel price, in 1990$ / MMBTU
AFVTECH = Index referring to AFV technology

11) Calculate AFV operating costs, by region.

$$COPCOST_{AFVTECH,REG,OSC} = \frac{AFCOST_{AFVTECH,REG}}{LDVMPG_{AFVTECH,OSC}} \quad \textbf{(90)}$$

where:

COPCOST = Fuel operating costs for each technology, in 1990$ per mile

12) Determine fuel availability relative to gasoline, $FAVAIL_{AFVTECH,REG}$, which is set to the highest value associated with the group of fuels used in multi-fuel vehicles.

$$FAVAIL_{AFVTECH,REG} = MAX \; (FAVAIL_{FUEL,REG}) \quad \textbf{(91)}$$

13) Calculate the logit function inputs from the attributes and coefficients, by region.

$$\begin{aligned} AFVECT_{AFVTECH,REG} = EXP \; [& BETACONST_{AFVTECH} + \beta_1 VPRICE_{AFVTECH} + \beta_2 COPCOST_{AFVTECH,REG} \\ & + \beta_3 VRANGE_{AFVTECH} + \beta_4 VRANGE^2_{AFVTECH} + \beta_5 VEMISS_{AFVTECH} \\ & + \beta_6 VEMISS^2_{AFVTECH} + \beta_7 FAVAIL_{AFVTECH,REG} + \beta_8 FAVAIL^2_{AFVTECH,REG} \;] \end{aligned} \quad \textbf{(92)}$$

where:

BETACONST = Constant associated with each AFV technology
VPRICE = Price of each AFV technology in 1990$
VRANGE = Vehicle range of the considered technology
VEMISS = Emissions levels relative to gasoline ICE's

14) Calculate AFV market shares, by region.

$$APSHR22_{AFVTECH,REG} = \frac{AFVECT_{AFVTECH,REG} \cdot COMAVAIL_{AFVTECH}}{\sum_{AFVTECH=1}^{11} (AFVECT_{AFVTECH,REG} \cdot COMAVAIL_{AFVTECH})} \quad \textbf{(93)}$$

where:

APSHR22 = Relative market shares of each AFV technology
COMAVAIL = Commercial availability of each technology

15) Determine average characteristics of AFV's for each region, for use in Stage 1.

$$\Psi_{AFV,REG} = \sum_{AFVTECH=1}^{11} \Psi_{AFVTECH,REG} \cdot AFVMSH_{AFVTECH,REG} \quad \textbf{(94)}$$

STAGE 1

Stage 1 determines the final mix of conventional and alternative technologies, using the share-weighted average characteristics of AFV's determined in Stage 2. Three technologies are considered in this stage: gasoline, diesel, and alternatives.

16) Calculate the logit function inputs from the attributes and coefficients, by region.

$$\begin{aligned} VECT_{TECH,REG} = EXP\,[\,& BETACONST_{TECH} + \beta_1\,VPRICE_{TECH} + \beta_2\,COPCOST_{TECH,REG} \\ & + \beta_3\,VRANGE_{TECH} + \beta_4\,VRANGE^2_{TECH} + \beta_5\,VEMISS_{TECH} \quad \textbf{(95)} \\ & + \beta_6\,VEMISS^2_{TECH} + \beta_7\,FAVAIL_{TECH,REG} + \beta_8\,FAVAIL^2_{TECH,REG}\,] \end{aligned}$$

where:

BETACONST = Constant associated with each technology
VPRICE = Price of each technology in 1990$
VRANGE = Vehicle range of the considered technology

VEMISS = Emissions levels relative to gasoline ICE's
TECH = Index referring to the three major vehicle technologies: gasoline, diesel & alternative

17) Calculate market shares, by region.

$$APSHR11_{TECH,REG} = \frac{VECT_{TECH,REG} \cdot COMAVAIL_{TECH}}{\sum_{TECH} (VECT_{TECH,REG} \cdot COMAVAIL_{TECH})} \quad (96)$$

where:

APSHR11 = Relative market shares of each technology
COMAVAIL = Commercial availability of each technology

The final step is to combine the market shares of the preceding three stages to produce absolute market shares of each of the sixteen technologies addressed in this model. The absolute regional market shares of gasoline and diesel vehicles remain unchanged from those calculated in Stage 1, the AFV market shares from Stage 2 are adjusted by the total alternative market share from Stage 1, and the EV market shares from Stage 3 are modified by the adjusted electric vehicle market share. These values are placed in $APSHR44_{IT,REG}$, where *IT* represents the expanded sixteen technologies.

For gasoline and diesel vehicles (TECH = 1,2):

$$APSHR44_{IT,REG} = APSHR33_{TECH,REG} \quad (97)$$

For non-electric AFV's (TECH = 3, AFVTECH ≠ 9):

$$APSHR44_{IT,REG} = APSHR33_{AFV} * APSHR22_{AFVTECH} \quad (98)$$

For electric AFV's (TECH = 3, AFVTECH = 9):

$$APSHR44_{IT,REG} = APSHR33_{AFV} * APSHR22_{EV} * APSHR11_{EVTECH} \quad (99)$$

Regional sales of new cars and light trucks may then be calculated, disaggregated by six size classes and by technology:

$$NCSTECH_{IT,REG,SC} = APSHR_{IT,REG,SC} * NCS_{REG,SC} \quad (100)$$

and:

$$NLTECH_{IT,REG,SC} = APSHR_{IT,REG,SC} * NLTS_{REG,SC} \quad \textbf{(101)}$$

where:

NCSTECH = Regional new car sales, by size class and technology
NLTECH = Regional new light truck sales, by size class and technology
APSHR = Absolute regional market shares of each vehicle technology
NCS = Regional new car sales, from the Regional Sales Model
NLTS = Regional new light truck sales, from the Regional Sales Model

On the first iteration of this model, the vehicle sales by technology type are passed back to the FEM Model to re-estimate the sales-dependent vehicle prices, and the revised prices are passed back to the AFV Model. Following the second iteration, these values are passed to the LDV Stock Module, in which the average attributes of the fleet of private light-duty vehicles are determined.

Figure 3A-4. Fuel Economy Model 1: Economic Market Share Calculation

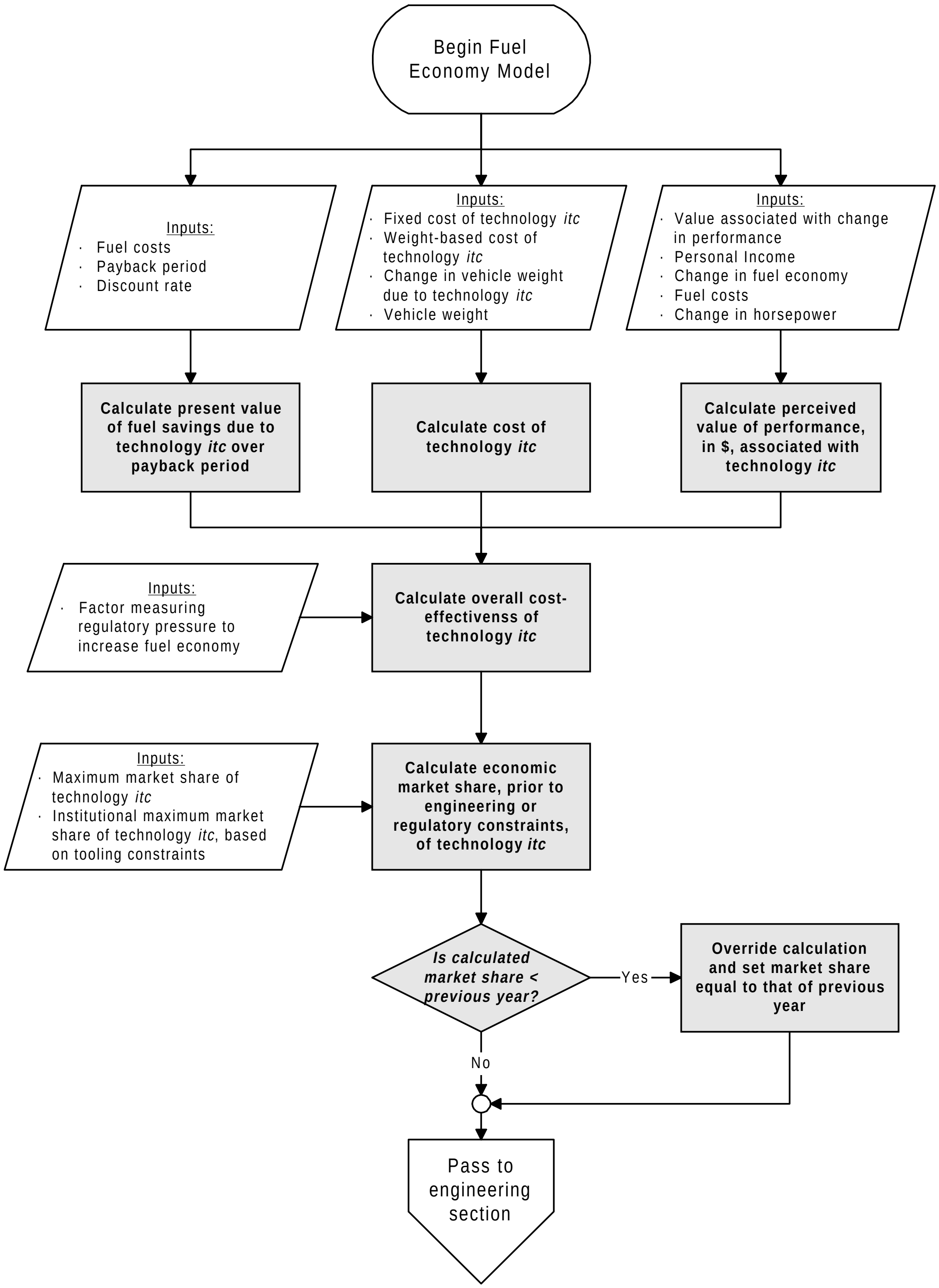


Figure 3A-5. Fuel Economy Model 2: Engineering Notes

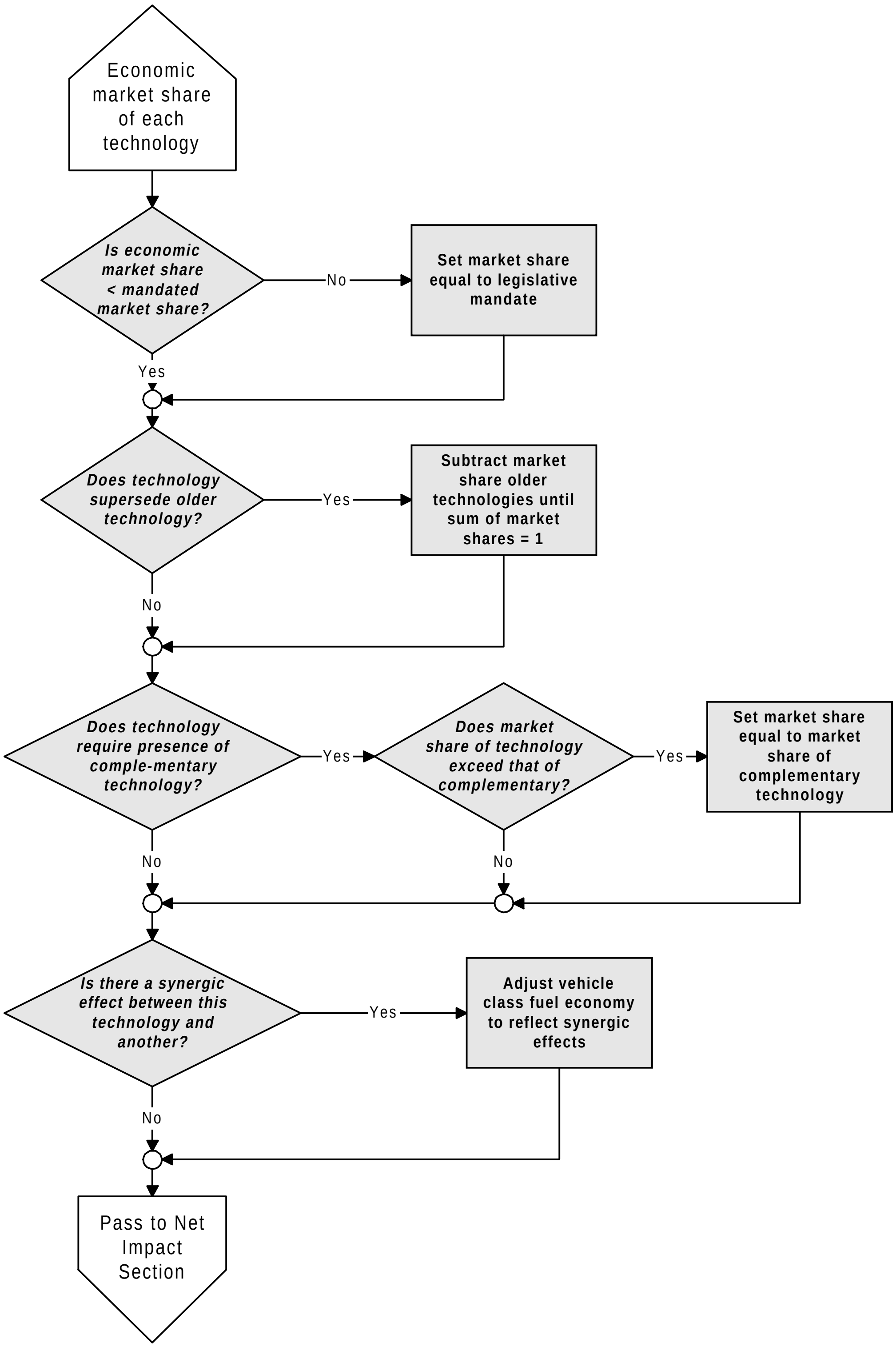


Figure 3A-6. Fuel Economy Model 3: Weight and Horsepower Calculations

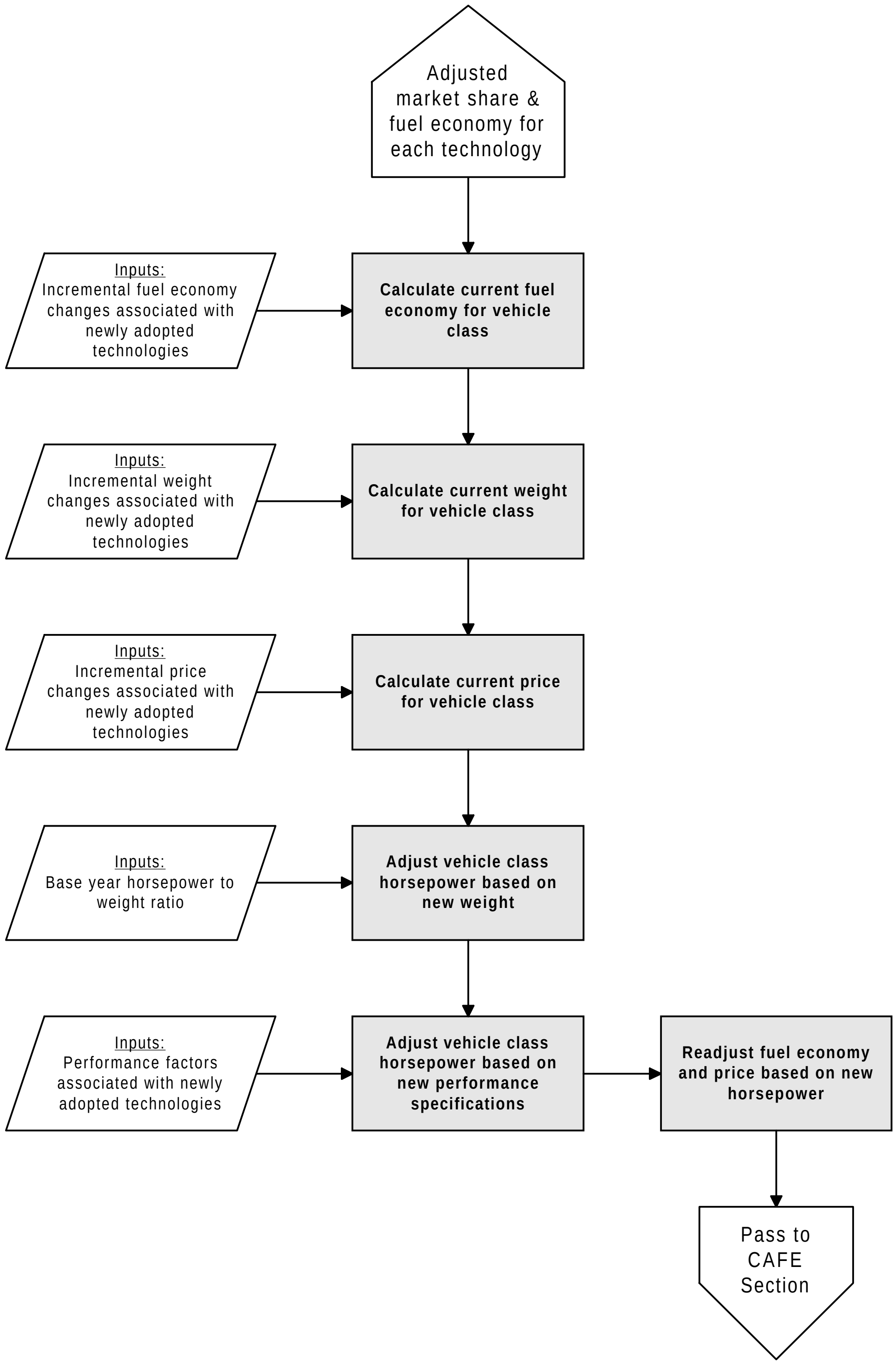


Figure 3A-7. Fuel Economy Model 4: CAFE Calculations

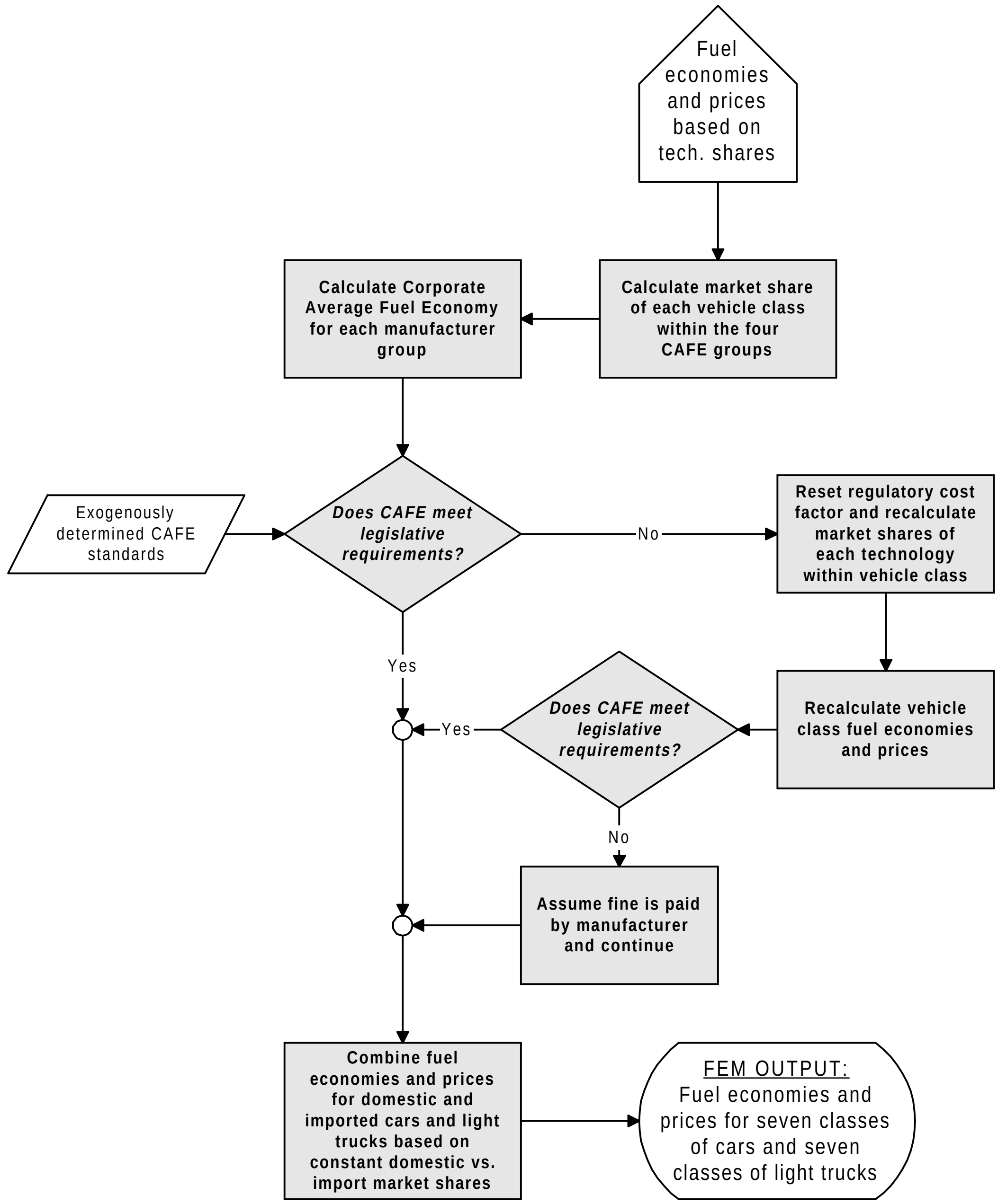


Figure 3A-8. Alternative Fuel Vehicle Model Stage 3

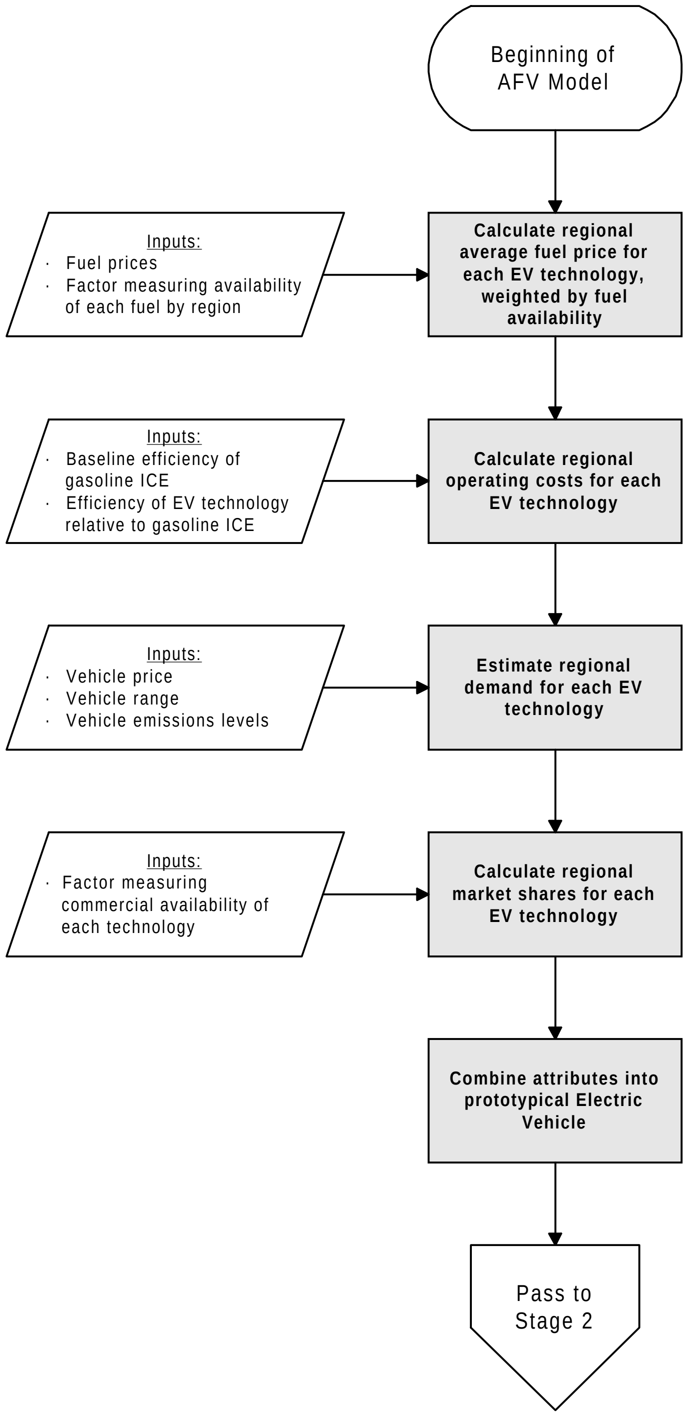


Figure 3A-9. Alternative Fuel Vehicle Model Stage 2

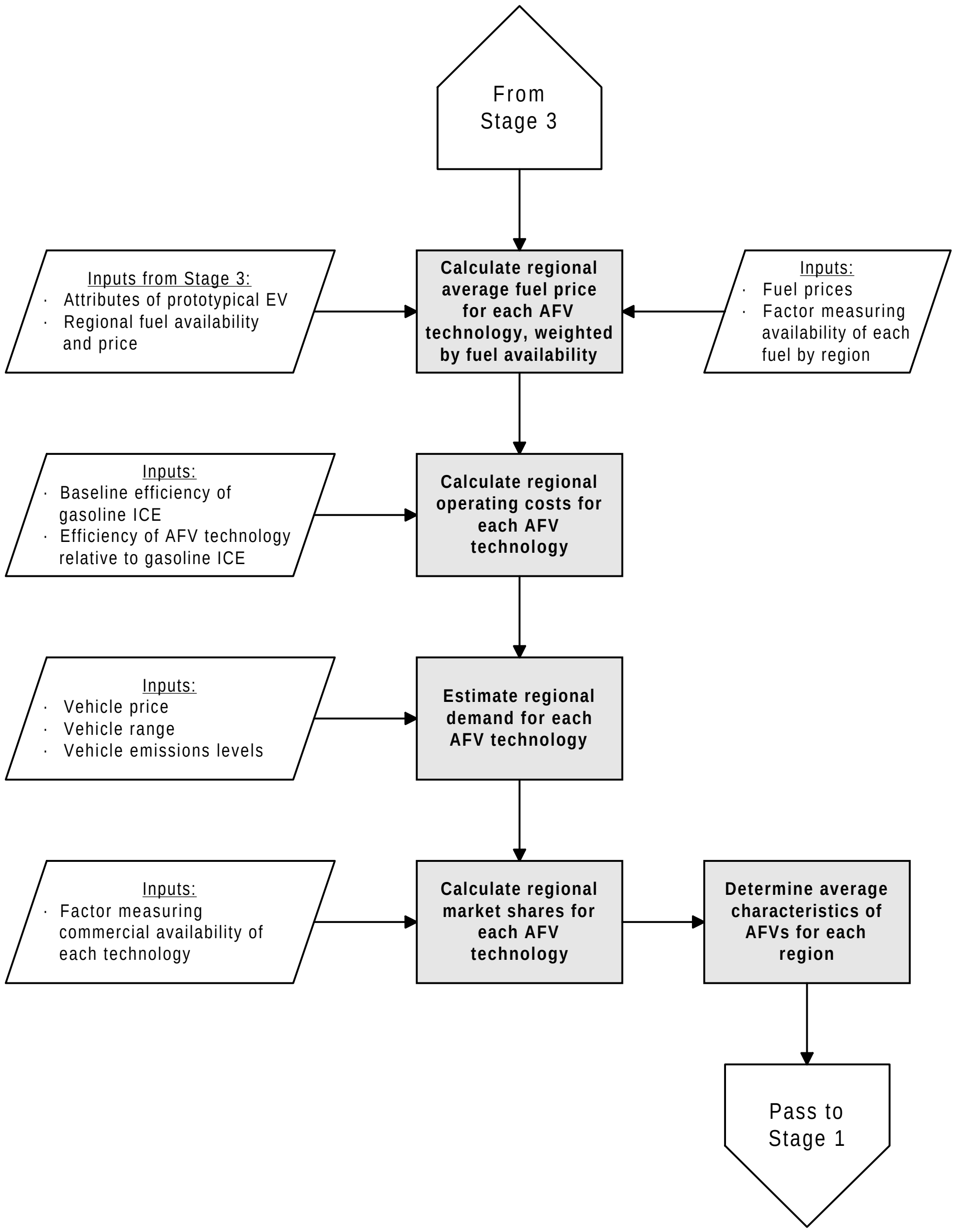
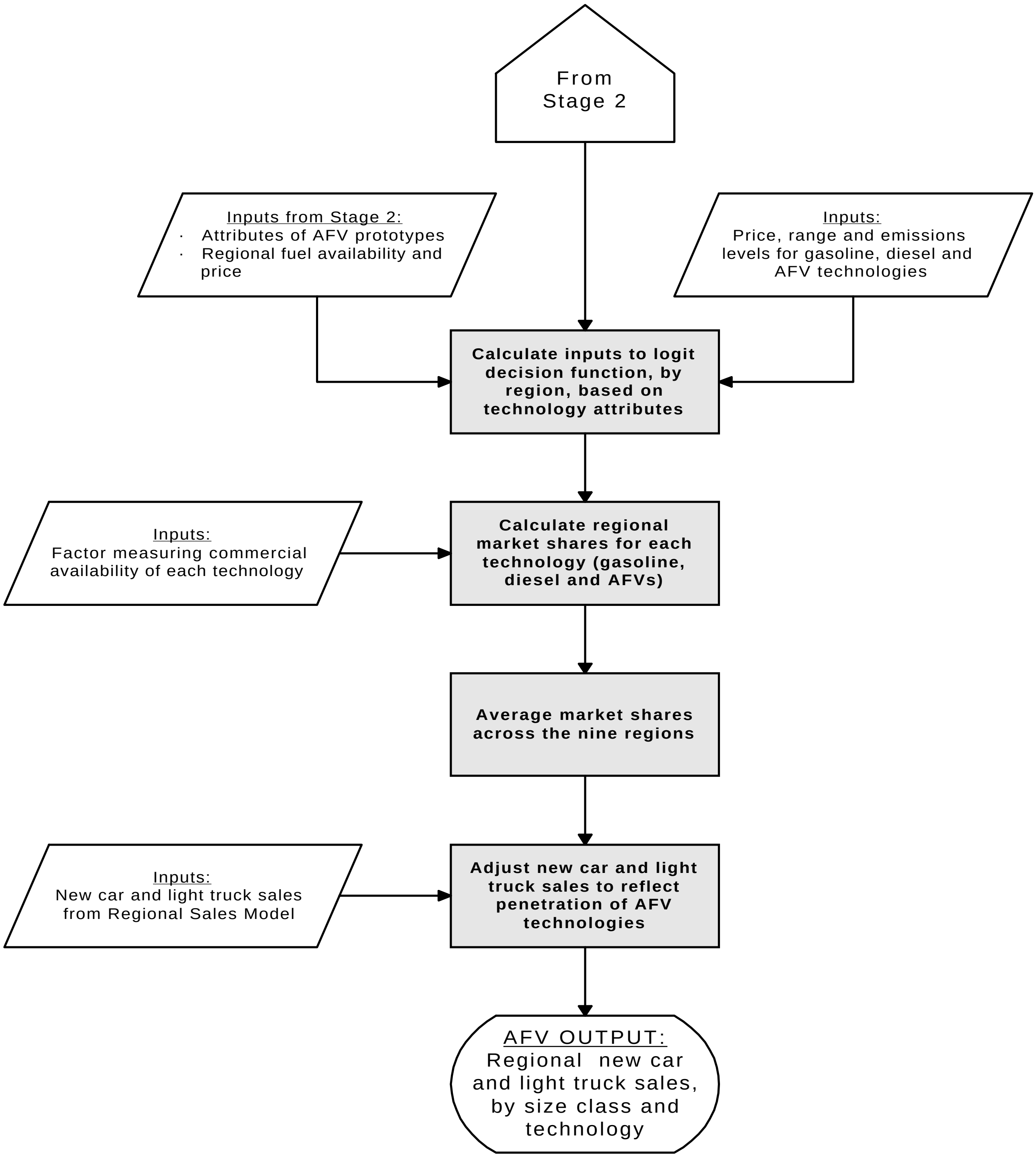


Figure 3A-10. Alternative Fuel Vehicle Model Stage 1



3B. 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 3B-1 below. More detailed sketches of LDV Stock calculations are presented at the end of Section 3B.

3B-1. LDV Stock Accounting Model

RATIONALE

The existing stock model is perhaps the most important transportation sector model, since by far the largest portion of transportation energy consumption is accounted for by light duty vehicles that are at least a year old. The LDV Stock Accounting Module takes the results of the LDV Module, i.e., the number and characteristics of newly purchased cars and light trucks, and integrates those into the existing stock of vehicles, taking into account vehicle retirements and vehicles which are transferred from fleets to private ownership. The result is a snapshot of the "average" car for each region.

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

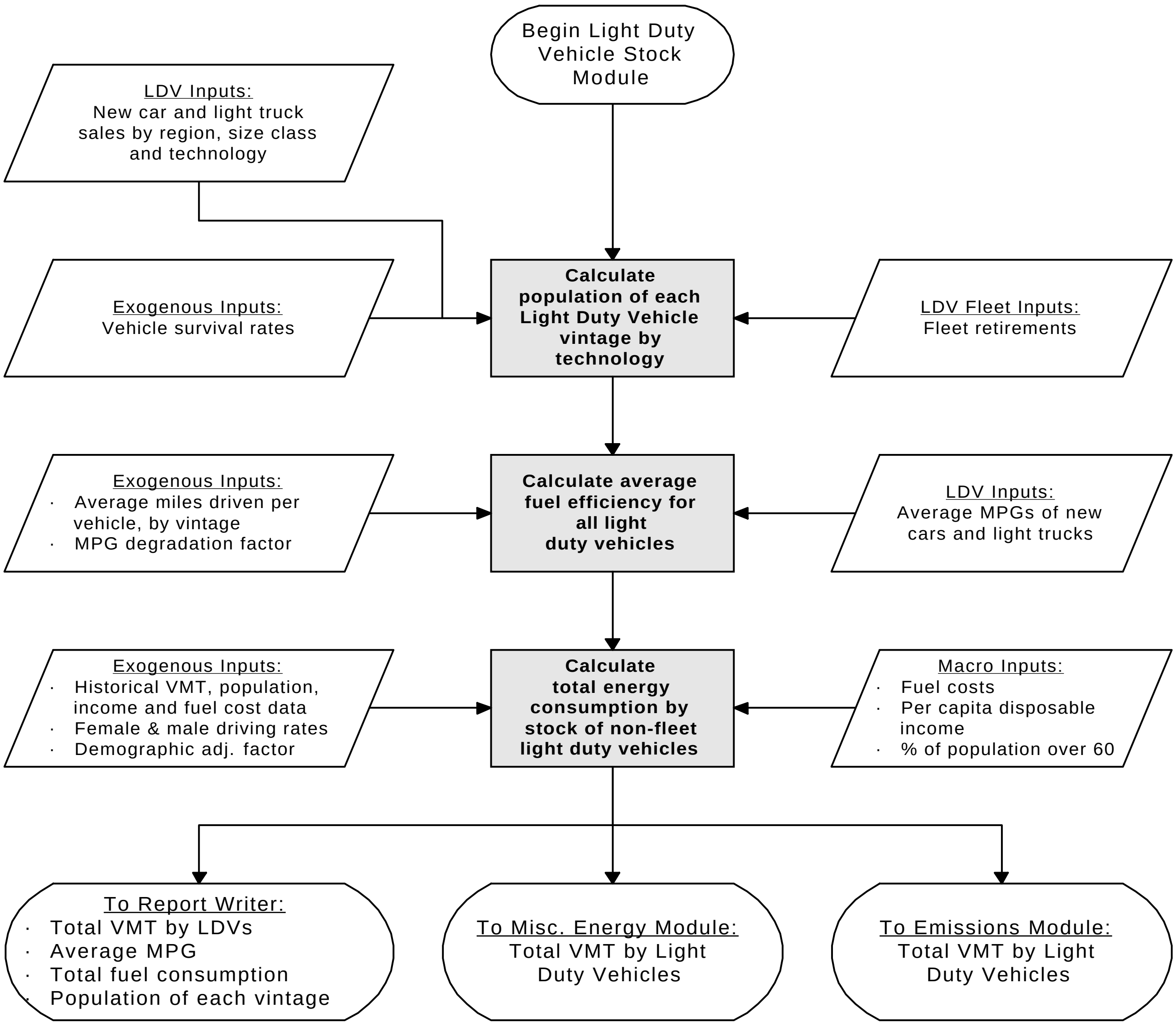
ALTERNATIVE SPECIFICATIONS

No alternative models were considered.

MODEL STRUCTURE

The flowchart for the LDV Stock Module is presented below in Figure 3B-1. More detailed flowcharts are presented at the end of this section.

Figure 3B-1. Light Duty Vehicle Stock Module



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

$$TECHNCS_{IT} = \sum_{SC=1}^{6} \sum_{REG=1}^{9} NCSTECH_{IT,REG,SC}$$

and: **(102)**

$$TECHNLT_{IT} = \sum_{SC=1}^{6} \sum_{REG=1}^{9} NLTECH_{IT,REG,SC}$$

where:

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

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

$$PASSTK_{IT,VINT,T} = PASSTK_{IT,VINT-1,T-1} * SSURVP_{VINT-1}$$

and: **(103)**

$$LTSTK_{IT,VINT,T} = LTSTK_{IT,VINT-1,T-1} * SSURVLT_{VINT-1}$$

where:

PASSTK = Surviving automobile stock, by technology and vintage
LTSTK = Surviving light truck stock, by technology and vintage
SSURVP = Fraction of a given vintage's automobiles which survive
SSURVLT = Fraction of a given vintage's light trucks which survive
VINT = Index referring to vintage, or age of vehicle

The model encompasses ten vintages, with the tenth being an aggregation of all vehicles 10 years old or older. SSURVP and SSURVLT thus each contain ten values measuring the percentage of vehicles of each vintage which survive into the next year. These values are taken from the ORNL Transportation Energy Data Book, which lists scrappage and survival rates for 25 vintages. Survival rates for vintages 10 through 25 were simply averaged to collapse ORNL's 25 vintages into the 10 used by the Transportation Model.

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

$$PASSTK_{IT,TVINT} = PASSTK_{IT,TVINT} + OLDFSTK_{CAR,TYPE,ITECH,TVINT}$$

and: **(104)**

$$LTSTK_{IT,TVINT} = LTSTK_{IT,TVINT} + OLDFSTK_{TRUCK,TYPE,ITECH,TVINT}$$

where:

OLTFSTK = Number of fleet vehicles rolled over into corresponding private categories
TVINT = Transition vintage: vintage at which vehicles of a given type are transferred
TYPE = Type of fleet vehicle: Business, Government, or Utility
ITECH = Index for the six fleet vehicle technologies: mapped to corresponding *IT* index

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

$$STKCAR_T = \sum_{VINT=1}^{10} \sum_{IT=1}^{16} PASSTK_{IT,VINT,T}$$

and: **(105)**

$$STKTR_T = \sum_{VINT=1}^{10} \sum_{IT=1}^{16} LTSTK_{IT,VINT,T}$$

where:

STKCAR = Total stock of non-fleet automobiles in year *T*
STKTR = Total stock of non-fleet light trucks in year *T*

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

$$VSPLDV_{IT,T} = \frac{\sum_{VINT=1}^{10} \left(PASSTK_{IT,VINT,T} + LTSTK_{IT,VINT,T}\right)}{STKCAR_T + STKTR_T} \qquad (106)$$

where:

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

The above variables are then passed to the subroutine TMPGSTK 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. The Alternative Fuel Vehicle Model generates efficiency estimates for fifteen non-gasoline technologies in three size classes, with no distinction made between cars and light trucks. Because conventional truck efficiencies are generally lower than automobiles in the corresponding size class, a series of ratios is first calculated in order to adjust downwards the AFV efficiency estimates of light trucks:

$$RATIO_{ASC,T} = \frac{AMPGT_{ASC,T}}{AMPGC_{ASC,T}} \tag{107}$$

where:

AMPGT = The average MPG of trucks, in three size classes
AMPGC = The average MPG of cars, in three size classes
ASC = The three AFV size classes, onto which the six primary size classes are mapped

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

$$MPGC_{IT,T} = \left[\sum_{ASC=1}^{3} \frac{MSHC_{IT,ASC,T}}{NAMPG_{IT,ASC,T}} \right]^{-1}$$

and: **(108)**

$$MPGT_{IT,T} = \left[\sum_{ASC=1}^{3} \frac{MSHLT_{IT,ASC,T}}{NAMPG_{IT,ASC,T} * RATIO_{ASC,T}} \right]^{-1}$$

where:

MPGC = New car fuel efficiency, by engine technology
MPGT = New light truck fuel efficiency, by engine technology
MSHC = The share of cars of size class *ASC* and technology *IT* in total car sales, from the AFV model
MSHLT = The share of light trucks of size class *ASC* and technology *IT* in total light truck sales
NAMPG = New AFV fuel efficiency, from the AFV model

For conventional technologies, when *IT* refers to gasoline ICE's, the calculation is similar, but over six size classes:

$$MPGC_{IT,T} = \left[\sum_{SC=1}^{6} \frac{MSHC_{IT,SC,T}}{NCMPG_{SC,T}} \right]^{-1}$$

and: **(109)**

$$MPGT_{IT,T} = \left[\sum_{SC=1}^{6} \frac{MSHLT_{IT,SC,T}}{NLTMPG_{SC,T}} \right]^{-1}$$

where:

NCMPG = New car MPG, from the FEM model
NLTMPG = New light truck MPG, from the FEM model

The average fuel efficiency across all technologies is then calculated for cars and trucks, and the result sent to the report writer:

$$ANCMPG_{T} = \left[\sum_{IT=1}^{16} \frac{APSHRNC_{IT,T}}{MPGC_{IT,T}} \right]$$

and: **(110)**

$$ANTMPG_{T} = \left[\sum_{IT=1}^{16} \frac{APSHRNT_{IT,T}}{MPGT_{IT,T}} \right]$$

where:

ANCMPG = Average new car MPG
ANTMPG = Average new light truck MPG
APSHRNC = Absolute market share of new cars, by technology, from the AFV model
APSHRNT = Absolute market share of new light trucks, by technology, from the AFV model

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

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

[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.

$$TOTMICT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} PASSTK_{IT,IV,T} * PVMT_{IV}$$

and: **(111)**

$$TOTMITT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} LTSTK_{IT,IV,T} * LVMT_{IV}$$

where:

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

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

$$CMPGT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} \frac{PASSTK_{IT,IV,T} * PVMT_{IV}}{CMPGSTK_{IT,IV,T} * CDF_T}$$

and: **(112)**

$$TMPGT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} \frac{LTSTK_{IT,IV,T} * LVMT_{IV}}{TTMPGSTK_{IT,IV,T} * LTDF_T}$$

where:

CMPGT = Automobile stock MPG
TMPGT = Light truck stock MPG
CMPGSTK = Automobile stock MPG, by vintage and technology
TTMPGSTK = Light truck stock MPG, by vintage and technology
CDF = Automobile fuel efficiency degradation factor
LTDF = Light truck fuel efficiency degradation factor

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

$$SCMPG_T = \frac{TOTMICT_T}{CMPGT_T}$$

and: **(113)**

$$STMPG_T = \frac{TOTMITT_T}{TMPGT_T}$$

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

$$MPGFLT = \frac{TOTMICT_T + TOTMITT_T}{CMPGT_T + TMPGT_T} \qquad \textbf{(114)}$$

where:

SCMPG = Stock MPG for automobiles
STMPG = Stock MPG for light trucks
MPGFLT = Stock MPG for all light duty vehicles

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

3B-2. VMT Model

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

RATIONALE

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

The predecessor VMT forecasting model was developed following an assessment of the alternative models described below. While both fleet-based and driver-based systems have appealing characteristics and are useful under certain modeling conditions, the latter of these approaches was considered to be most appropriate to the needs of the model. This is because the fleet-based approach relies to a greater degree on the continuation of past trends, and cannot explicitly address many of the underlying factors that may lead to shifts in VMT growth patterns in the future, while a driver-based approach allows explicit modeling of the factors that may "bend the curve", such as the aging of the population.

A driver-based approach takes the following form:

$$VMT_{Total} = \left(\frac{VMT}{Licensed\ Driver}\right)\left(\frac{Licensed\ Drivers}{Driving\ Age\ Population}\right)(Driving\ Age\ Population)$$

Forecasting two of the three terms of this equation is relatively straightforward. A forecast of the driving-age population is provided by the Census Bureau,[13] and licensure rates for most segments of the population are rapidly approaching unity. Therefore the principal task is to accurately forecast VMT per driver.

[13] *Projections of the Population of the United States, by Age, Sex, and Race: 1988 to 2080,* U.S. Department of Commerce, Bureau of the Census, Current Population Reports Series P-25, No. 1018 (Jan. 1989).

The functional form chosen to forecast VMT per driver in the *1992 Annual Energy Outlook (AEO92)* is an incremental modification of the econometric model used in the *AEO91*. Due to the limited (20 year) forecast period, it was convenient and defensible to consider society's demographic structure to be relatively static and uninfluential over trends which may be effectively characterized in the aggregate by economic variables. In a longer term forecast, however, projections of economic variables and the population's responses to them become more ambiguous, whereas the effects of gradual demographic change are expected to become more pronounced. This revised model, presented below, has been considered an interim step in the development of a longer term model which is more sensitive to structural change:

$$LnVMTPC = \alpha + \beta_1 (LnCPM) + \beta_2 (LnYPC) + \beta_3 (Ln(N_{20}/N_{65}))$$

where:

VMTPC = VMT per driving age population.
CPM = Average fuel cost per mile of driving, expressed in 1982 dollars.
YPC = Income per capita, expressed in 1982 dollars.
N_{20}, N_{65} = The population between the ages of 20-29 and older than 65, respectively.

This model replaced a previous VMT forecasting model in which fuel price and disposable income were the only factors influencing the growth of VMT. One consequence of that formulation was that per capita driving rates were forecast to grow without moderation—an issue that the inclusion of the demographic parameter was designed to address.

This specification was based on the notion that the rate of growth of per capita VMT should decline over time, as the population ages. The use of the ratio of the number of twenty to twenty nine year-olds to the number of those over the typical retirement age of sixty-five was an attempt to characterize the changing demographic structure of society. This ratio has been forecast to decline over the forecast period, and served to moderate the growth of VMT without constraining its trend to an *a priori* limit. In summary, this model placed a moderate demographic constraint on VMT growth, while using the same price and income regressors as were employed in the 1991 AEO. This constraint lowered the near-term VMT forecast without resorting to the artifice of imposing *ad hoc* limits to growth. This model, however, was somewhat compromised by the rudimentary demographic influence and by the absence of effects rising from changing female driving patterns. The VMT model implemented in NEMS has been designed to address these concerns.

ALTERNATIVE SPECIFICATIONS

The projection of VMT is rarely an end in itself; levels of personal travel demand are generally used as an intermediate step in the estimation of various factors which are influenced by driving levels. The following pages briefly describe several VMT forecasting methods currently being used by various agencies, and were considered in the development of the NEMS VMT forecasting model. The form that each model takes is a reflection of the concerns of the commissioning agency, the purpose to which the model is to be put, the time scale of the forecast, the availability of adequate data, and the preconceptions of the model designers.

The models described below are representative of the following three basic forecasting approaches typically used to project VMT. The *fleet-based* approach, which uses estimates of the distances driven by each vehicle, disaggregated by vintage, and linear projections of vehicle stock to project total VMT in a given year, is useful in predicting fuel consumption and pollutant emissions. Secondly, the *demographic* approach combines estimates of distances driven by each driver, disaggregated by age, and age-stratified population projections to determine VMT. This is a simple method which relies on projections made from readily available data, but which may be affected by overlooked economic or regional factors. Finally, the *economic* approach uses estimates of vehicle operating cost and other economic parameters such as personal income as predictive variables. Such approaches are commonly used for national-level forecasting, and have a high explanatory power. However, their reliance on forecasts of economic variables and the neglect of potential saturation effects renders such models relatively unstable in the mid- to long-term.

A fourth approach to VMT forecasting, *trip generation*, is a site-specific method which involves forecasting the number of trips taken, and predicting destinations, travel modes, and routes. This is a data intensive approach which is typically used on a local or regional level to predict road congestion and demand for mass transit, and was not considered to be commensurate with the requirements of NEMS.

<u>FHWA/Faucett VMT Forecasting Model:</u> FHWA, and DOT in general, uses this model designed by Jack Faucett Associates. The model is a generalized difference equation, using a log-linear econometric form, which consolidates the previous models used by the Department of Transportation. It is designed for both short and long range forecasting of VMT and vehicle stock on a national level for five categories of vehicle: personal use vehicles and four separate truck categories. The growth rate for VMT is estimated to be constrained by fuel price increases, forecast to begin in 1987 and continue at an increasing rate; and a tapering off in the expected rate of increase in the number of driver licenses per thousand population.

The forecasting model for personal-use vehicles used by FHWA takes the following form:

$$
\begin{aligned}
LVMTPUPC_t = \alpha &+ \rho LVMTPUPC_{t-1} + \beta_1 (LPIPC_t - \rho LPIPC_{t-1}) \\
&+ \beta_2 (LTCXDP_t - \rho LTCXDP_{t-1}) \\
&+ \beta_3 (LDLPK_t - \rho LDLPK_{t-1}) \\
&+ \beta_4 (FSD_t - \rho FSD_{t-1})
\end{aligned}
$$

where:

LVMTPUPC = Log of personal-use VMT per capita
LPIPC = Log of personal income per capita
LTCXDP = Log of vehicle operating cost index deflated by CPI[14]
LDLPK = Log of number of driver licenses per thousand population
FSD = Fuel shortage dummy[15]
ρ = The lag factor, set to 0.6017

The primary constraint in an econometric approach is the increasing uncertainty of price and macroeconomic projections in the mid- to long-term. The sensitivity of the model to fluctuations in these variables serves to increase the uncertainty of the projection towards the end of the forecast period.

MOBILE4 Fuel Consumption Model (EPA): While most models used by EPA concentrate on the local or regional level, its fuel consumption model makes forecasts of nationwide VMT. The MOBILE4 Fuel Consumption Model (M4FC) is used by EPA's Office of Mobile Sources in conjunction with its MOBILE4 Emissions Model to estimate individual states' degree of attainment of ambient air standards. M4FC is a fleet-based model which uses linear projections of vehicle stocks by type, subsequently estimating miles per year according to type and vintage. There are few demographic influences in the model. VMT in this model is estimated using vehicle stock projections, age distributions, and mileage accumulation rates as follows:[16]

$$
VMT_{TOTAL} = \sum_{Age} \left(\frac{VMT}{Vehicle} \right)_{Age} * (\%\ of\ Vehicles)_{Age} * (Total\ Vehicles)
$$

[14] The operating cost index comprises a weighted average of fuel costs, fuel efficiency forecasts, maintenance costs, the purchase price of new vehicles, and an assumed forecast of real increases in the cost of insurance.

[15] The fuel shortage dummy is set to zero, but is included to test, at the option of the user, the impact of an abnormal disruption in fuel supplies.

[16] Information on the MOBILE3 and MOBILE4 Fuel Consumption Models have been obtained through conversations with Phil Lorang and Mark Wolcott of EPA's Emissions Control Division, and from *Forecasting Vehicle Miles Traveled and Other Variables That Affect Mobile-source Emissions*, prepared for EPA by RCG/Hagler, Bailly, Inc., 8/18/88.

Although a stock-based model can provide a more robust extended forecast than one based solely on econometric methods, there remain concerns about such a model's sensitivity to deviations from vehicle purchase and scrappage-rate assumptions. These assumptions are predicated on expectations concerning consumer behavior and technological innovation, which are not easily projectable. The M4FC model is a revision of an earlier model, M3FC, and incorporates factors which attempt to reflect society's evolving driving patterns, assuming, somewhat optimistically, the eventual congruence of male and female driving characteristics.

The Consumer Automotive Response Model (CAR): This transportation model, which is used by the EPA Policy Office, may be distinguished from that used by the Office of Mobile Sources by its ultimate purpose. While the MOBILE4 model uses a fleet-based approach to estimate emissions of specific pollutants, the model used by the policy office takes an econometric approach to forecast the effects of various policy options such as the impact of a gas tax on VMT, and consequently, on criterion pollutant emissions.

The CAR model is a discrete-choice, logit model which is based on Kenneth Train's Consumer Choice Model which was originally prepared for the California Energy Commission. It comprises a system of submodels which separately forecast vehicle ownership and stock characteristics, and miles traveled in each vehicle at the household level. The personal travel portion of Train's model forecasts VMT in four categories: intra- and inter-city work and non-work travel, using the following log-linear econometric form:

$$Log(VMT) = \beta Z$$

where β and Z are vectors of parameters and explanatory variables, respectively.[17] These explanatory variables include logarithms of the household income and size; the operating cost of each vehicle, in cents per mile; the number of workers in the household; the number of transit trips per capita in the area in question; and several dummy variables identifying the urban density and geographic region of the household. The operating cost of each vehicle is further considered to be an endogenous variable, as it is implicitly defined by each household's purchase decision. This parameter is therefore determined by a variety of exogenous demographic variables such as the age, sex, and education level of the household head; the regional gas price and the commuting distance.

This model represents a rather detailed merging of econometric and demographic approaches to forecasting. It is a relatively complex model, involving the independent forecasting of a large number of exogenous variables. The descriptive ability of the original Consumer Choice model does not

[17] From K. Train, *Qualitative Choice Analysis: Theory, Econometrics, and an Application to Automobile Demand,* 1986, Chapter 8.

appear to be enhanced by its level of detail, however, as the R-squared of 0.114 for the one-vehicle household submodel does not explain a significant level of variation in the data.[18] A demographic model which is sensitive to economic conditions, but at a lower level of complexity may provide the basis for a credible long-term VMT forecast.

Transportation Energy and Emissions Modeling System (TEEMS): Developed by Argonne National Laboratory, TEEMS is a series of disaggregate models, linked to produce forecasts of transportation activity and energy demand. The models cover both freight and passenger transport, with personal and fleet vehicles being separately addressed.

This is a combination demographic and stock model, based on forecasts of distributions of household characteristics. It is based on Kenneth Train's Consumer Choice Model, and depends on changes in the distribution of the sample of households, not on average characteristics. In the section which determines an estimate of personal travel, a matrix is constructed using data from the 1983 Nationwide Personal Transportation Study (NPTS), which is then adjusted to represent 1985 conditions.[19] The VMT estimate is calculated as follows:

$$VMT_{Total} = \sum_{Cell=1}^{N} \left(\frac{VMT}{Vehicle} \right)_{Cell} \left(\frac{Vehicles}{Household} \right)_{Cell} \left(Households \right)_{Cell}$$

The survey sample is stratified into cells according to the following six household attributes:

1. Location (three categories)
2. Income (four categories)
3. Age of Householder (four categories)
4. Household Size (four categories)
5. Number of Drivers (four categories)
6. Number of Vehicles (four categories)

Distributions of households by demographic attribute are independently forecast, and the occupancy of each cell in the future is estimated. This model contains elements of all three of the considered model types, but is primarily a stock model with a pronounced demographic influence. The stratified approach to forecasting is useful, in that it provides for the consideration of selected discrete

[18] K. Train, *op. cit.*, p. 165.

[19] For a detailed description of TEEMS, see: Mintz, M.M., and Vyas, A.D., *Forecast of Transportation Energy Demand Through the Year 2010*, Argonne National Laboratory Report, ANL/ESD-9, April 1991.

characteristics, permitting an evaluation based on particular, quantifiable attributes.

Two dangers of this approach lie in specifying a broader stratification scheme than can be supported by the available sample, resulting in underpopulated levels; and the potential for the disproportionate influence of extreme data. As mentioned above, this model's reliance on vehicle purchase and scrappage projections, as well as its assumption of a static distribution of VMT per vehicle may have to be revised in order to use the model for forecasts extending several decades. This model also requires the independent forecast of a large number of exogenous inputs, consequently increasing the likelihood of significant impacts from the propagation of errors.

FHWA Spreadsheet Forecast: This model was developed on a spreadsheet system for the Federal Highway Administration. It was used by FHWA in 1987 to produce a series of forecasts of automobile and light truck VMT through the year 2000. It represents the base case in a series of forecasts produced by FHWA in 1987.[20] This is a straightforward demographic model, using disaggregated population data to project VMT. For inputs it relies on data from the 1969, 1977, and 1983 NPTS data bases, and population projections from the Census Bureau. The model also forecasts the total number of drivers, the VMT per driver, and the fraction of the driving age population with driver licenses from 1985 to 2020. These figures are also dependent on assumptions of a static distribution of driver licenses across the various age groups. The model forecasts total VMT by sex as follows:

$$VMT_{TOTAL} = \sum_{AGE} \left(\frac{VMT}{Capita} \right)_{AGE} * \ (Population)_{AGE}$$

This model has the benefit of simplicity, relying on very few inputs. Two of these, population and licensure rates, can be considered robustly forecastable. The "most likely" case of the model, however, assumes unlimited VMT per capita growth at constant rates, and a female/male driving ratio of 60 percent, both of which are subject to question. The incorporation of economic dependencies in such a demographic model could provide opportunities for analysis of the impact of various policy initiatives on VMT.

MODEL STRUCTURE

The primary concern in forecasting VMT per licensed driver in the mid to long term (out to 2030) is to address those effects that are liable to alter historical growth trends, i.e. factors likely to "bend

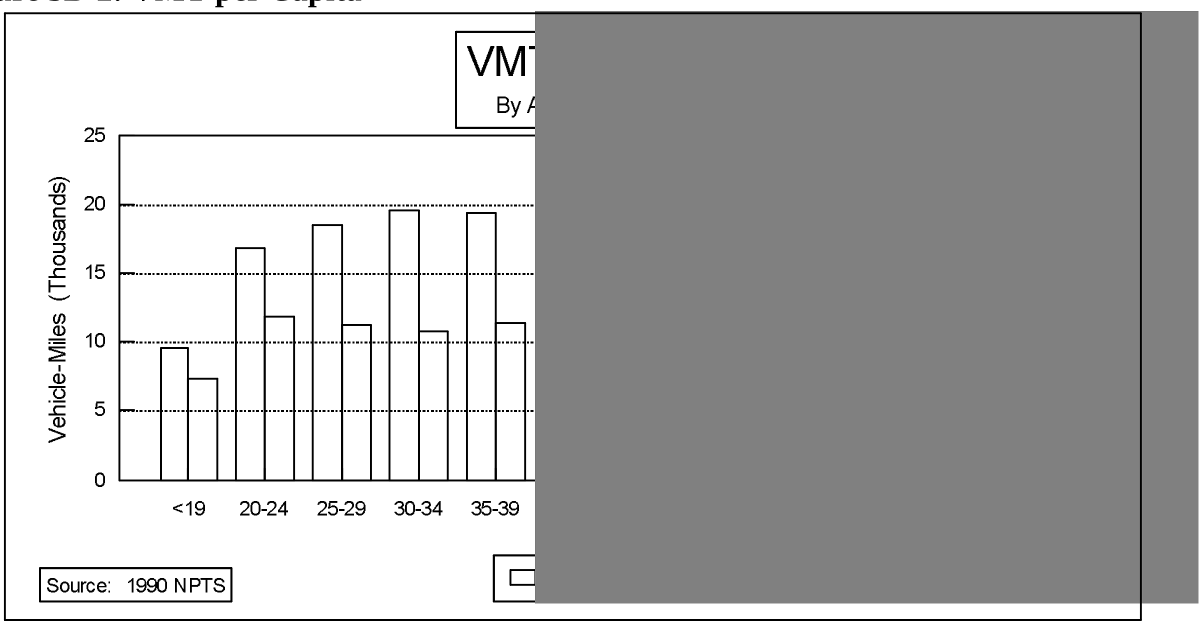
[20] The Future National Highway Program: 1991 and Beyond, Working Paper No. 2, *Trends and Forecasts of Highway Passenger Travel*, FHWA, 12/87.

the curve". Central among these are demographic and geographic effects. The discussion here will focus on demographic effects; regional effects may be equally important, but are beyond the scope of this effort. The two factors considered to have the greatest potential to affect future VMT trends in a significant manner are the aging of the population and the growth of female driving rates relative to male driving rates. These are discussed in turn below.

Population Aging

VMT per licensed driver varies considerably by age group and sex. The mean VMT per driver by age group and sex is shown in Figure 1. At the high end of this range are males 30 to 34 years of age, who on average drive close to 20 thousand miles per year. At the low end are females over seventy years of age who drive less than 4 thousand miles per year. Considering men and women together, the highest driving group is that of age 35-39, at 15,446 miles per year, while the lowest group is 70 and over, at 6,264 miles per year. This variation is significant because the average age of Americans is forecast to increase markedly in the coming decades.

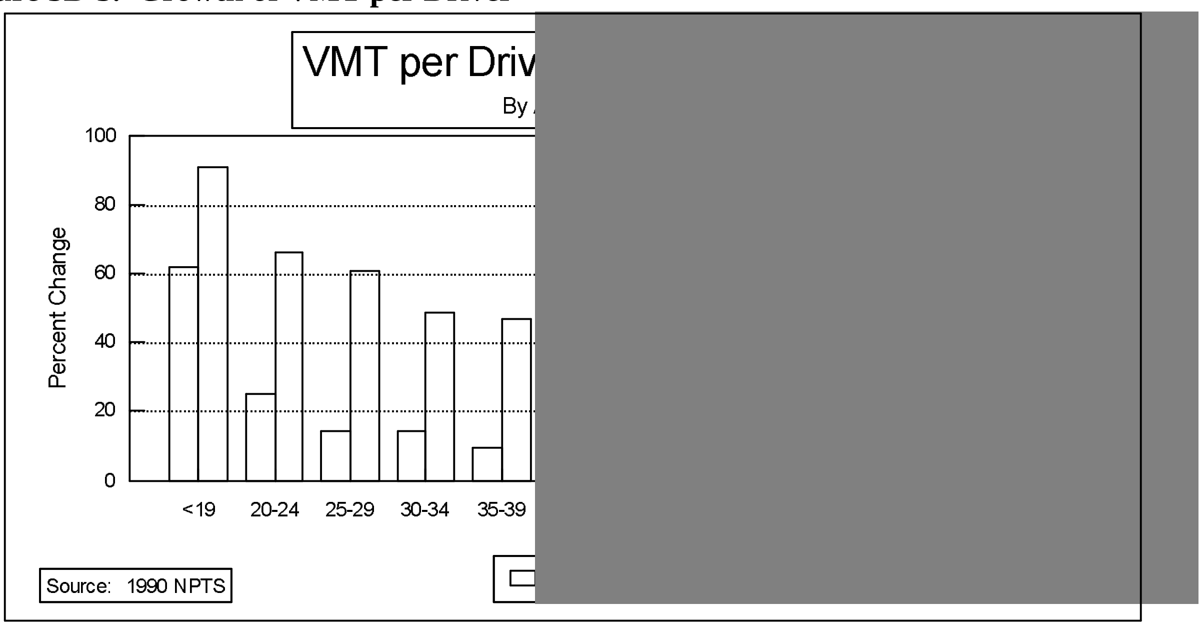
Figure 3B-2: VMT per Capita



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

The effect of the aging trend on travel could be substantial, but it is difficult to know the precise manner in which it will affect overall VMT. If one assumes that in 30 years, 65 year olds will drive about the same amount as current 65 year olds, then assessing the effect of population aging on VMT would be a matter of simple accounting. For example, total VMT in 2030 can be calculated simply by multiplying the number of drivers that will be in each age group in 2030 (Census forecast) by the current average VMT in each age group and then summing VMT across all age groups.

Figure 3B-3. Growth of VMT per Driver



Unfortunately, one cannot be confident that the 65 year old of tomorrow will continue to behave as he or she does today. As individuals age, their levels of driving will probably continue to decline, particularly following retirement, as it has in the past. But it is unlikely to decline to the levels of current retirees, as those currently over 65 years old did not grow up in a society as dependant on the automobile as did the current 35 year olds. Additionally, retirees of the future may have substantially greater wealth, better health, and/or a greater desire for mobility than do current ones. Indeed, the 1990 preliminary NPTS estimates indicate that the estimated VMT per year for drivers greater than 70 years old has increased by nearly 50% over the 1983 estimate.[21]

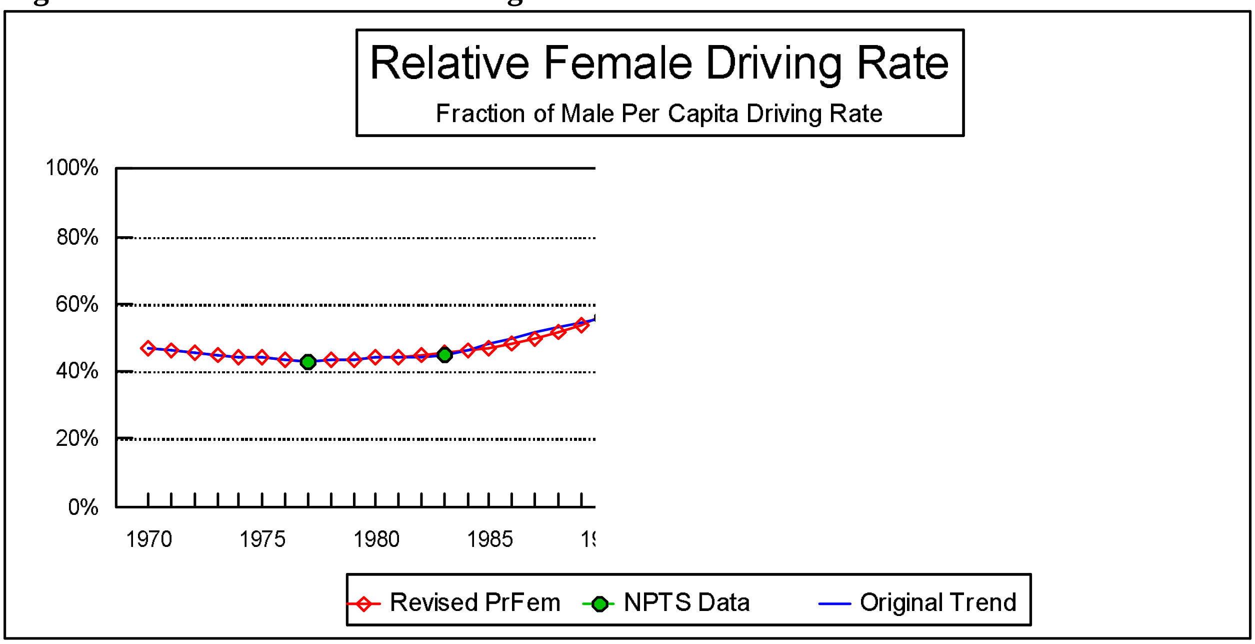
[21] Preliminary estimate: 6264 miles per person per year, 70 years and older, NPTS Driver's Annual Estimate, Table 15.

Growth in Female Driving Rates

Another important issue is the VMT gap between males and females, and how this will change in the future. Females have historically driven far fewer miles per year, on average, than males, but they have been closing the gap rapidly in recent years. Evidence of this is provided in Figure 2, which indicates that women between the ages of 20 and 45 dramatically increased their driving rates relative to their male counterparts. According to the 1969, 1977, and 1983 NPTS results, the per capita female/male driving ratio has generally hovered around 45 percent. The 1990 NPTS data suggest a significant deviation from this trend, with women's average VMT approaching 60 percent of men's. This may be at least partly attributable to the increased participation of women in the labor force.

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

Figure 3B-4. Relative Female Driving Rate



The trend line represents a logistic curve, anchored at the 1977 NPTS value, reaching 50 percent in 1994 (T_{50}), and achieving 99 percent parity in 2010 (T_{99}). Or, in equation form:

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

where: **(115)**

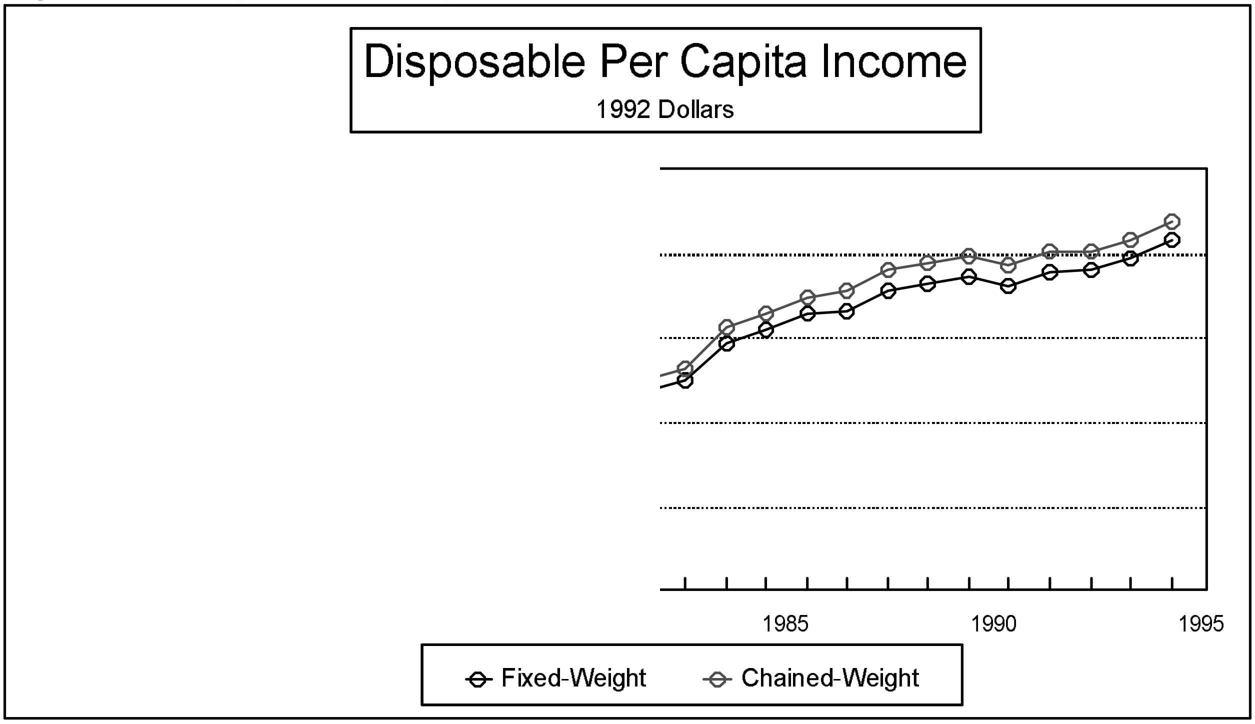
$$k = \frac{Ln(.01)}{(T_{99} - T_{50})}$$

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

Updating Data Inputs

Since the last revision of the VMT model, two more years of vehicle stock, VMT, and fuel consumption data have been made available from FHWA, and the income variable from the Macroeconomic Model has been revised. All macro inputs are now being calculated based on a chain-weighted average, replacing the fixed-weight methodology previously used. This results in a modest change in disposable income per capita, as depicted below.

Figure 3B-5. Disposable Per Capita Income



These new data sets permit the re-estimation of the generalized difference equation adopted for the NEMS VMT forecasting model:

$$VMTPD_T - \rho VMTPD_{T-1} = \alpha(1-\rho) + \sum_{N=1}^{3} \beta_N (X_{N,T} - \rho X_{N,T-1}) \qquad \textbf{(116)}$$

where VMTPD is the per capita driving demand for the driving age population, and $X_{N=1,..,3}$ represent the input variables.

Of greater significance is the revision of the historical VMT and stock inputs provided by FHWA. In the past FHWA's estimate of the number and driving patterns of 2-axle, 4-tire trucks has been interpreted as representing that of Light Duty Trucks, defined as having a weight of less than 8,500 pounds, and thus properly within the purview of the LDV Module. This assumption, however, has been only a first approximation, as FHWA does not classify these trucks by weight. In an attempt to further refine the model, a new category of truck has been defined: Light Commercial Trucks (LCT), which comprise all single-unit trucks in the 8,500 to 10,000 pound range. The travel demands of these trucks are now modeled separately, based on aggregate measures of industrial output from the Macro Model. In order to avoid double-counting, the 2-axle, 4-tire strata of these LCT's, previously included in the LDV model, must be subtracted from the data inputs. Details of the stratification and estimation of LCT demand are provided in a subsequent section, which contains historical data estimates between 1990 and 1995. Estimates of LCT travel prior to 1990 are obtained by indexing the 1990 estimate to GDP growth trends from 1969 to 1990. The original and revised data are tabulated in Appendix E.

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

In the first stage of this model, a generalized difference equation is used to estimate the unadjusted VMT per capita:[22]

$$\begin{aligned} VMTPC_T &= \rho\, VMTPC_{T-1} + 4.521\,(1-\rho) - 7.50\,(CPM92_T - \rho\, CPM92_{T-1}) \\ &\quad + 3.6x10^{-4}\,(YPC92_T - \rho\, YPC92_{T-1}) + 8.36\,(PrFem_T - \rho\, PrFem_{T-1}) \end{aligned} \qquad \textbf{(117)}$$

where:

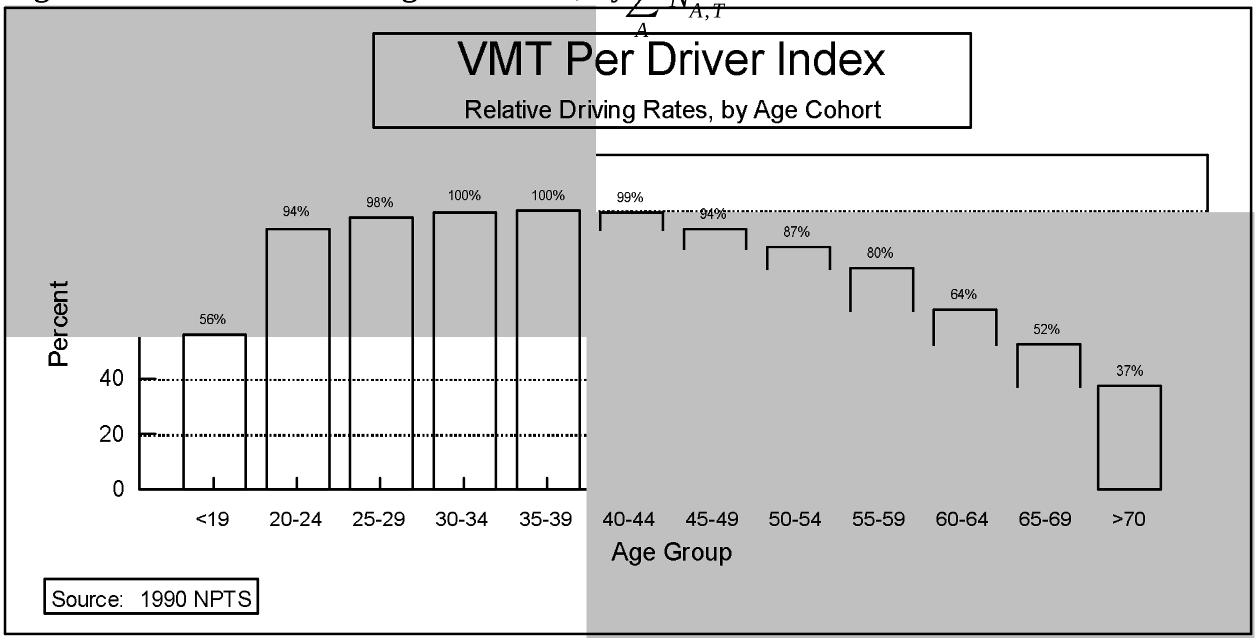
VMTPC = the vehicle miles traveled per capita
CPM97 = the fuel cost of driving a mile, expressed in 1992 dollars.
YPC92 = the disposable personal income per capita, expressed in 1992 dollars.
PrFem = the ratio of per capita female driving to per capita male driving.
ρ = the lag factor, estimated using the Cochrane-Orcutt iterative procedure to be 0.736.

The unadjusted forecast is subsequently modified by a demographic adjustment factor (DAF), which is based on the age-specific driving rates reported in the 1990 NPTS. The Demographic Adjustment Factor is based on the idea that the average VMTPD can be represented as a weighted average of the age-specific VMTPD's, as follows:

[22] VMT per capita should be understood mean VMT per population 16 years and older. "Per capita" is used for simplicity. Its use in other variables refers to the total US population.

$$VMTPD_T = \frac{\sum_A VMTPD_{A,T} \cdot N_{A,T}}{\sum_A N_{A,T}} \qquad \textbf{(118)}$$

Figure 3B-6. Relative Driving Rate Index, by Cohort



The VMTPD of each age cohort can be expressed as the product of a relative index and the maximum VMTPD in the population:

$$VMTPD_T = VMTPD_{Max,T} \cdot \frac{\sum_A VMTPDI_{A,T} \cdot N_{A,T}}{\sum_A N_{A,T}} \qquad \textbf{(119)}$$

where VMTPDI represents the travel index, depicted in the following figure:

The DAF used in the earlier version of this model is an index which represents the effect of changes in the age distribution of the population over the forecast period, assuming that relative driving rates remain unchanged. That is to say, if, as was reported in the 1990 NPTS, VMT per driver in the oldest age cohort is 37 percent of the maximum VMT per driver in the overall distribution, this ratio would remain unchanged over time. The DAF is a population-weighted index of these relative driving rates, expressed as follows:

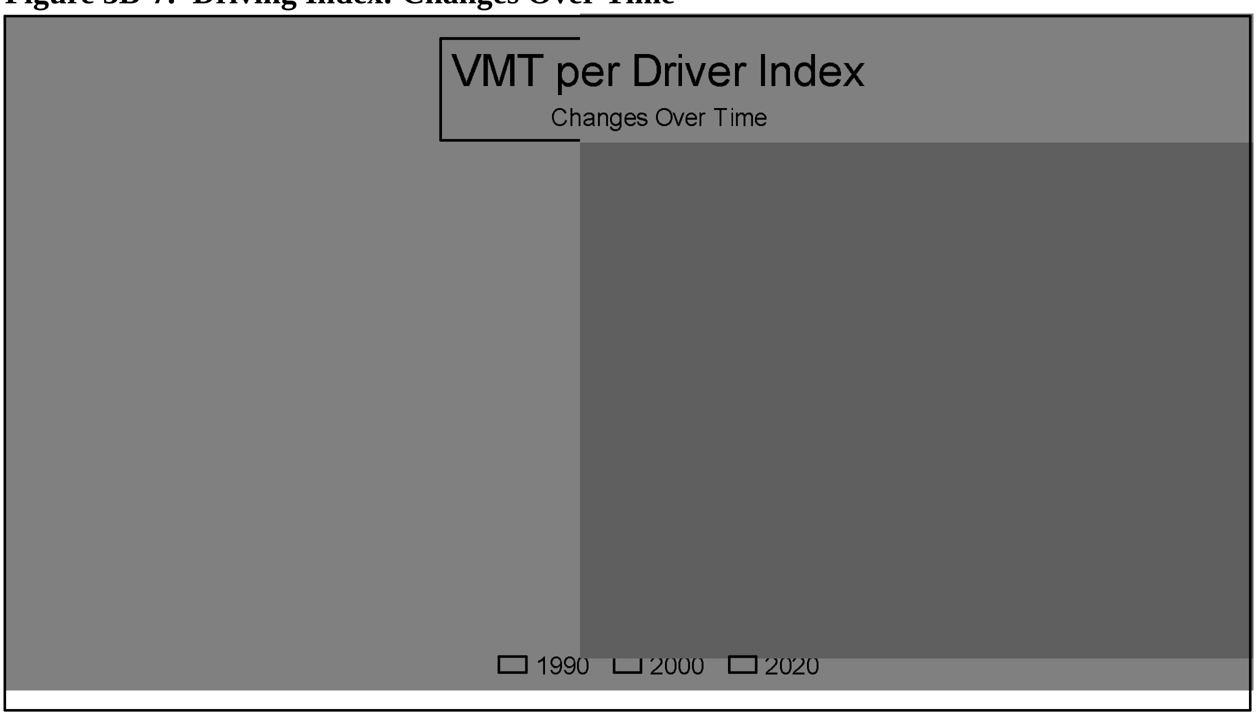
$$DAF_T = \frac{\sum_A VMTPDI_{A,T} \cdot N_{A,T}}{\sum_A N_{A.T}} \qquad \textbf{(120)}$$

It has been suggested that this formulation underestimates the consequences of population aging, as drivers moving into the older age categories are likely to retain some of their earlier driving habits. In order to account for this shift, the VMTPDI is re-estimated to include a time dimension, under the *ad hoc* assumption that the difference between each age cohort's VMTPDI and 1.0 will be reduced over the forecast period as follows: the VMTPDI for drivers in the 16-19 age group will reduce the gap by 33 percent; all age groups until the >70 group will converge 50 percent of the way to unity. Drivers older than 70 are further disaggregated into four groups: 70-74, 75-79, 80-84, and >=85. Their indices are tied to that of the next younger group as follows:

$$\begin{aligned} VMTPDI_{70,T} &= 0.9 \cdot VMTPDI_{65,T} \\ VMTPDI_{75,T} &= 0.5 \cdot VMTPDI_{70,T} \\ VMTPDI_{80,T} &= 0.5 \cdot VMTPDI_{75,T} \\ VMTPDI_{85,T} &= 0.25 \cdot VMTPDI_{80,T} \end{aligned} \qquad \textbf{(121)}$$

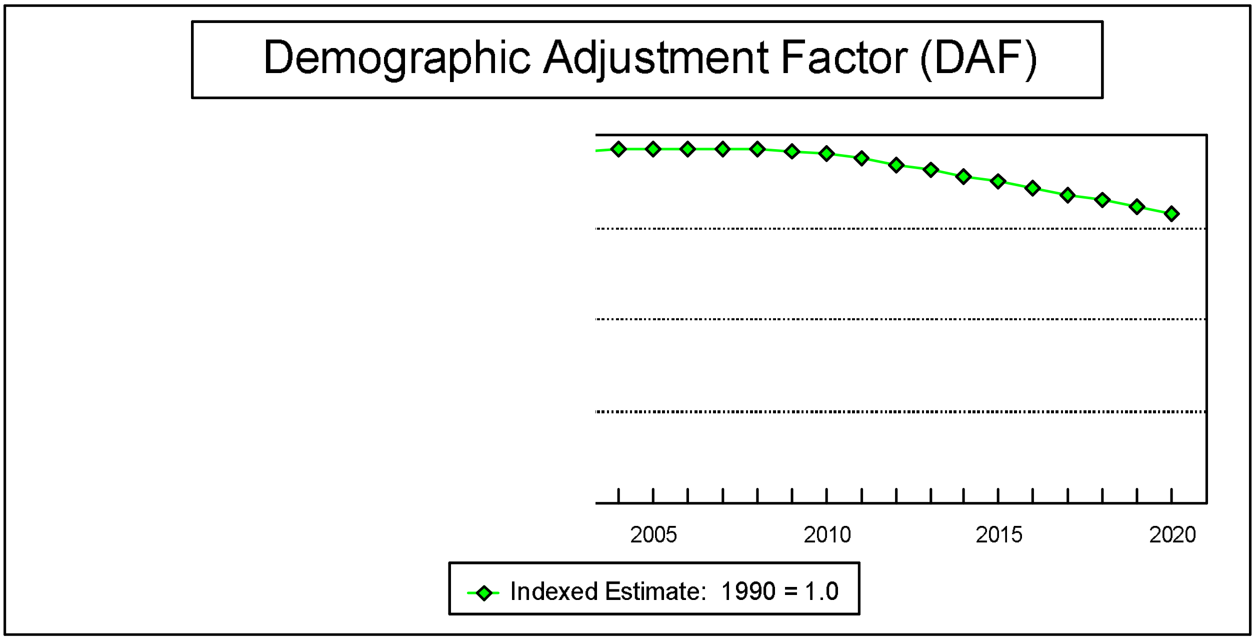
These factors have been chosen to most closely approximate the historical values of the VMTPDI for the >=70 age group, when population weights are applied. The resulting distribution of relative driving rates is depicted below.

Figure 3B-7. Driving Index: Changes Over Time



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

Figure 3B-8. Demographic Adjustment Factor



When applied to the VMT model, the DAF represented above is itself indexed to 1990, and is thus no longer bounded by 1.0.

The DAF is applied to historical VMTPD figures prior to the regression analysis described above. This permits a more consistent baseline comparison, by positing driving rates under a constant 1990 demographic distribution. The estimated results are subsequently re-transformed using the DAF, bringing them back in line with observed values.

Coefficient Estimation

Using the updated data sets described above and, as before, using the Cochrane-Orcutt iterative procedure, the generalized difference equation is estimated, resulting in the following coefficients:

TABLE 2: Generalized Difference Equation Output

Parameter	ρ	α	CPM92	YPC92	PrFem	Adj. R-Sq
Coefficient	0.736	4.521	-0.101	2.64e-04	1.805	0.855
T-Stat			*-4.0*	*4.0*	*1.8*	

In producing the estimated coefficients for this model, historical VMTPD figures were first adjusted using the indexed DAF to impute driving rates under a 1990 demographic distribution. The unadjusted VMTPD produced by the difference equation therefore represents an estimate of driving patterns under the assumption that age distributions and relative driving rates remain static. This variable, which is a weighted average across age cohorts, can be expressed by the following identity:

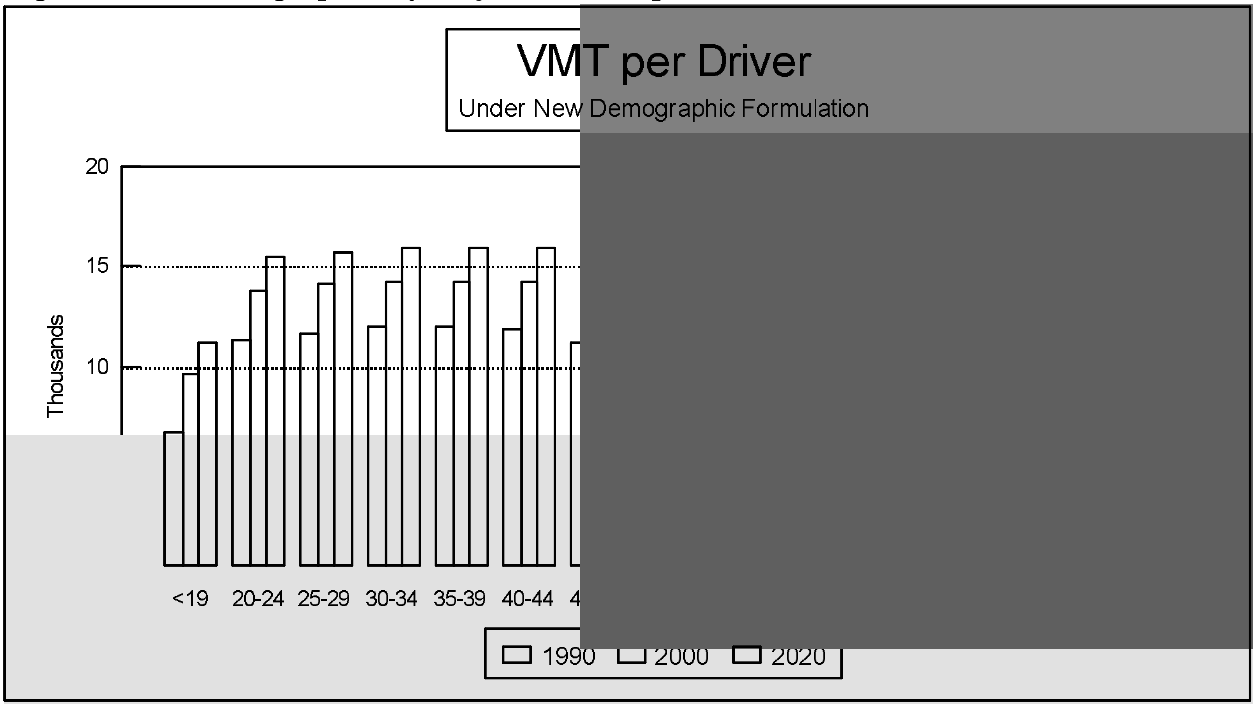
$$VMTPD_T \equiv VMTPDMAX_T \cdot DAF_{1990} \qquad \textbf{(122)}$$

In order to account for demographic shifts, it is necessary to multiply the VMTPD by the indexed DAF, as follows:

$$\begin{aligned} VMTPD_T^{/} &= VMTPD_T \cdot \left[\frac{DAF_T}{DAF_{1990}}\right] \\ &= VMTPDMAX_T \cdot DAF_{1990} \cdot \left[\frac{DAF_T}{DAF_{1990}}\right] \qquad \textbf{(123)} \\ &= VMTPDMAX_T \cdot DAF_T \end{aligned}$$

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

Figure 3B-9. Demographically-Adjusted VMT per Driver



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

3C. LDV Fleet Module

The Light Duty Vehicle Fleet Module generates estimates of the stock of cars and trucks used in business, government, and utility fleets, and subsequently estimates travel demand, fuel efficiency, and energy consumption by these fleet vehicles prior to their transition to the private sector at predetermined vintages. The LDV Fleet Module has also been amended to include a characterization of Light Commercial Trucks (LCT's), which are used in business and trade, and are not classifiable under either the LDV model or the Highway Freight Model.

3C-1. LDV Fleet Module

RATIONALE

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

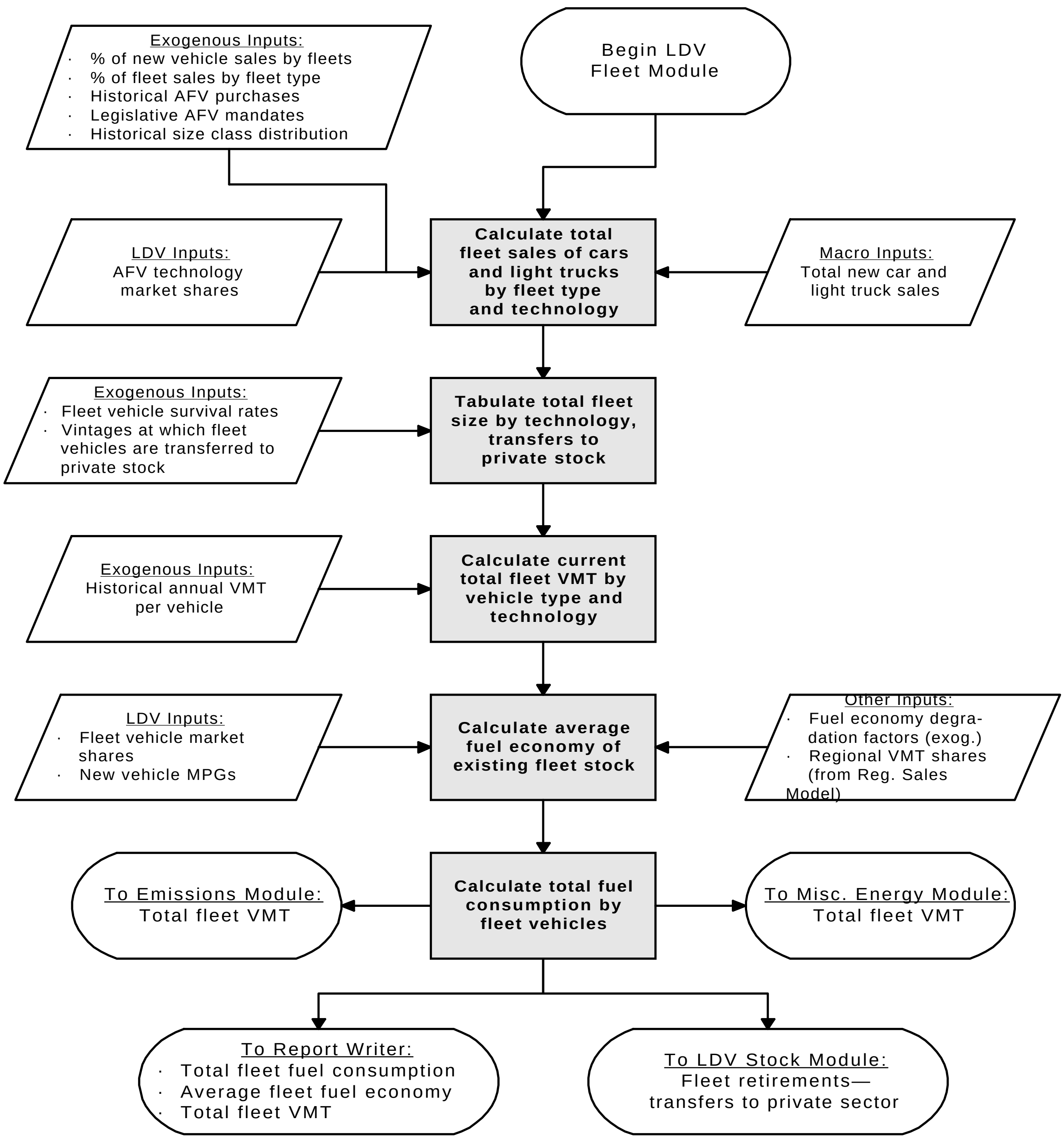
ALTERNATIVE SPECIFICATIONS

No alternative specifications were considered.

MODEL STRUCTURE

In a departure from the conventions of other modules, this model uses the same variable names for cars and light trucks; they are distinguished by the value of an index designating vehicle type. Vehicles are also distinguished by the type of fleet to which they are assigned; business, government, and utility fleets are assumed to have different operating characteristics and retirement rates. This model consists of three stages: determine total vehicle purchases, surviving fleet stocks and travel demand, calculate the fuel efficiency of fleet vehicles, and estimate the consequent fuel consumption. The flowchart for the Light Duty Vehicle Fleet Module is presented below in Figure 3C-1. Additional flowcharts outlining major LDV Fleet calculations in more detail are presented at the end of this section.

Figure 3C-1. Light Duty Vehicle Fleet Module



Calculate Fleet Stocks and VMT

Calculate fleet acquisitions of cars and light trucks:

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

and: **(124)**

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

where:

FLTSAL = Sales to fleets by vehicle and fleet type
FLTCRAT = Fraction of total car sales attributed to fleets
FLTTRAT = Fraction of total truck sales attributed to fleets
SQTRCARS = Total automobile sales in a given year
SQDTRUCKSL = Total light truck sales in a given year
FLTCSHR = Fraction of fleet cars purchased by a given fleet type
FLTTSHR = Fraction of fleet trucks purchased by a given fleet type
IT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

For cars only: separate the business fleet sales into "covered" and "uncovered" strata, reflecting the fact that EPACT regulations do not extend to privately owned or leased fleet vehicles. This separation is based on an extrapolation of historical trends in business fleets, using an assumed upper limit. Details on this, and other derivations are provided in the Appendix.

$$BFLTFRAC_{T-1971} = BFLTFRAC_{MIN} + (BFLTFRAC_{MAX} - BFLTFRAC_{MIN}) \cdot EXP^{(K_2 \cdot (T-1971))} \quad \textbf{(125)}$$

and:

$$BUSCOV_T = FLTSAL_{IT=1,ITY=1,T} \cdot BFLTFRAC_T \quad \textbf{(126)}$$

where:

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

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

$$FLTPCT_{VT=1,ITY=1,3,IFS=3} = k_3 \left[\frac{1}{Ln(50)} \right] \tag{127}$$

For light trucks:

$$FLTPCT_{VT=2,ITY=1,3,IFS=3} = (50)^{k_{2,ITY}} \tag{128}$$

where:

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

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

For cars:

$$FLTSALX_{IT=1,ITY=1,T} = BUSCOV_T \cdot FLTPCT_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$
$$and \tag{129}$$
$$FLTSALX_{IT=1,ITY\neq 1,T} = FLTSAL_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$

For light trucks:

$$FLTSALX_{IT=2,ITY=1,3,T} = FLTSAL_{IT,ITY,T} \cdot FLTPCT_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$
$$and \tag{130}$$
$$FLTSALX_{IT=2,ITY=2,T} = FLTSAL_{IT,ITY,T} \cdot CTLREFUEL_{ITY} \cdot MSA_{ITY} \cdot FLT20_{ITY}$$

where:

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

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

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

$$FLTALTE_{IT,ITY,T} = FLTSALX_{IT,ITY,T} \cdot EPACT3_{ITY,T,T} \tag{131}$$

where:

FLTALTE = AFV sales to fleets under EPACT mandates

EPACT3 = Sales-weighted aggregation of EPACT purchase requirements, reflecting impacts on three fleet types. See the Appendix for further details.

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

$$FLTALTH_{IT,ITY,T} = FLTSAL_{IT,ITY,T} \cdot FLTQAPSHR1_{ITY} \tag{132}$$

where:

FLTALTH = Fleet AFV purchases, using constant historical shares.

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

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

$$FLTALT_{IT,ITY,T} = MAX\left[FLTALTE_{IT,ITY,T}\ ,\ FLTALTH_{IT,ITY,T}\right] \tag{133}$$

where:

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

FLTAPSHR1 = Fraction of each fleets' purchases which are AFV's, from historical data

EPACT = Legislative mandates for AFV purchases, by fleet type

The difference between total and AFV sales represents conventional sales:

$$FLTCONV_{IT,ITY,T} = FLTSAL_{IT,ITY,T} - FLTALT_{IT,ITY,T} \tag{134}$$

where:

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

Fleet purchases are subsequently divided by size class:

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

and: **(135)**

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

where:

FLTSLSCA = Fleet purchases of AFV's, by size class
FLTSLSCC = Fleet purchases of conventional vehicles, by size class
FLTSSHR = Percentage of fleet vehicles in each size class, from historical data
IS = Index of size classes: 1 = small, 2 = medium, 3 = large

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

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

$$FLTECHSAL_{IT,ITY\neq 1,IS,ITECH} = FLTSLSCA_{IT,ITY\neq 1,IS} * FLTECHSHR_{ITECH,ITY} \tag{136}$$

and:

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

where:

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

Sales are then summed across size classes:

$$FLTECH_{IT,ITY,ITECH} = \sum_{IS=1}^{3} FLTECHSAL_{IVT,ITY,IS,ITECH} \tag{137}$$

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

$$FLTSTKVN_{IT,ITY,ITECH,IVINT,T} = FLTSTKVN_{IT,ITY,ITECH,IVINT-1,T-1} * SURVFLTT_{VT,IVINT-1}$$
$$\textit{and:} \qquad (138)$$
$$FLTSTKVN_{IT,ITY,ITECH,IVINT=1,T} = FLTECH_{IT,ITY,ITECH,T}$$

where:

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

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

$$OLDFSTK_{IT,ITY,ITECH,IVINT,T} = FLTSTKVN_{IVT,ITY,ITECH,IVINT,T} \qquad (139)$$

where:

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

The variable OLDFSTK is subsequently sent to the LDV Stock Model to augment the fleet of private vehicles. The vintages at which these transitions are made are dependent on the type of vehicle and the type of fleet, as shown below.

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

Total surviving vehicles are then summed across vintages:

$$TFLTECHSTK_{IT,ITY,ITECH,T} = \sum_{IVIN=1}^{6} FLTSTKVN_{IVT,ITY,ITECH,IVIN,T} \tag{140}$$

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:

$$VFSTKPF_{IT,ITY,ITECH,T} = \frac{TFLTECHSTK_{IT,ITY,ITECH,T}}{\sum_{IT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} TFLTECHSTK_{IT,ITY,ITECH,T}} \tag{141}$$

where:

VFSTKPF = Share of fleet stock by vehicle type and technology

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

$$FLTVMT_T = \sum_{IT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \left(TFLTECHSTK_{IT,ITY,ITECH,T} * FLTVMTYR_{IT,ITY,T} \right) \tag{142}$$

where:

FLTVMT = Total VMT driven by fleet vehicles

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

Total VMT is then disaggregated by vehicle type and technology:

$$FLTVMTECH_{IT,ITY,ITECH,T} = FLTVMT_T * VFSTKPF_{IVT,ITY,ITECH,T} \tag{143}$$

where:

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

Calculate Fleet Stock MPG

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

$$FLTMPG_{IT=1,ITY,ITECH} = \left[\sum_{ASC=1}^{3} \frac{FMSHC_{ITY,ITECH,ASC}}{NAMPG_{ITS,ASC}} \right]^{-1}$$

and: **(144)**

$$FLTMPG_{IT=2,ITY,ITECH} = \left[\sum_{ASC=1}^{3} \frac{FMSHLT_{ITY,ITECH,ASC}}{NAMPG_{ITS,ASC} * RATIO_{ASC}} \right]^{-1}$$

where:

FLTMPG = New fleet vehicle fuel efficiency, by fleet type and engine technology
FMSHC = The market share of fleet cars, from the AFV model
FMSHLT = The market share of fleet light trucks, from the AFV model
NAMPG = New AFV fuel efficiency, from the AFV model
ITS = Index which matches technologies in the AFV model to corresponding *ITECH*

For conventional technologies, when *ITECH* refers to gasoline ICE's, the calculation is similar. FEM estimates of fuel economy for the six vehicle size classes are averaged into three classes to correspond to the output of the fleet model, and new fleet vehicle fuel economy is calculated as follows:

$$FLTMPG_{IT=1,ITY,ITECH} = \left[\sum_{ASC=1}^{3} \frac{FMSHC_{ITY,ITECH,ASC}}{FEC3SC_{ASC}} \right]^{-1}$$

and: **(145)**

$$FLTMPG_{IT=2,ITY,ITECH} = \left[\sum_{ASC=1}^{3} \frac{FMSHLT_{ITY,ITECH,ASC}}{FET3SC_{ASC}} \right]^{-1}$$

where:

FEC3SC = New car MPG, in three size classes, from the FEM model
FET3SC = New light truck MPG, in three size classes, from the FEM model

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:

$$MPGFSTK_{IT,ITY,ITECH,IVIN,T} = MPGFSTK_{IVT,ITY,ITECH,IVIN-1,T-1}$$

and: **(146)**

$$MPGFSTK_{IVY,ITY,ITECH,IVIN=1,T} = FLTMPG_{IT,ITY,ITECH,T}$$

where:

MPGFSTK = Fleet MPG by vehicle and fleet type, technology, and vintage

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

$$MPGFLTSTK_{IT,ITY,ITECH} = \left[\sum_{IVINT=1}^{MAXVINT} \frac{\left(\dfrac{FLTSKTVN_{IT,ITY,ITECH,IVINT}}{MPGFSTK_{IT,ITY,ITECH,IVINT} * VDF_{VT}} \right)}{\left(TFLTECHSTK_{IT,ITY,ITECH} \right)} \right]^{-1} \quad \textbf{(147)}$$

where:

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

MAXVINT = Maximum *IVIN* index associated with a given vehicle and fleet type

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

$$FLTTOTMPG_{IVT,T} = \left[\sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \frac{VFSTKPF_{IT,ITY,ITECH,T}}{MPGFLTSTK_{IVT,ITY,ITECH,T}} \right]^{-1} \quad \textbf{(148)}$$

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:

$$FLTLDVC_{IT,ITY,ITECH,T} = \frac{FLTVMTECH_{IT,ITY,ITECH,T}}{MPGFLTSTK_{IVT,ITY,ITECH,T}} \quad \textbf{(149)}$$

where:

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

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

$$FLTFCBTU_{IT,ITECH,T} = \sum_{ITY=1}^{3} FLTLDVC_{IVT,ITY,ITECH,T} * QBTU_{ITECH} \qquad \textbf{(150)}$$

where:

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

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

$$FLTFCBTUR_{IR,ITECH,T} = \sum_{IT=1}^{2} FLTFCBTU_{IVT,ITECH,T} * RSHR_{IR,T} \qquad \textbf{(151)}$$

where:

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

3C-2. LIGHT COMMERCIAL TRUCK MODEL

RATIONALE

As it was originally structured, the NEMS Transportation Model addressed trucks in two separate modules according to their presumed primary use: light duty trucks (LDT's), defined as 2-axle, 4-tire trucks with a gross vehicle weight (GVW) of less than 8,500 pounds, assumed to be used principally for personal transport and described within the Light Duty Vehicle Mode; and medium and heavy duty trucks, with GVW's of over 10,000 pounds, addressed in the Highway Module of the Freight Transport Model. While this accounted for the overwhelming majority of trucks on the road, there was one obvious gap in coverage. Trucks with a GVW of between 8,500 and 10,000 pounds were not explicitly characterized in the Transportation Model, but were represented through the use of estimated adjustments to the results of the freight model. The purpose of this section is to characterize the stock and driving patterns of these light commercial trucks (LCT's) within the NEMS structure.

ALTERNATIVE SPECIFICATIONS

No alternative specifications were considered.

MODEL STRUCTURE

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

Figure 3C-2. Distribution of FHWA Single-Unit Truck Stocks

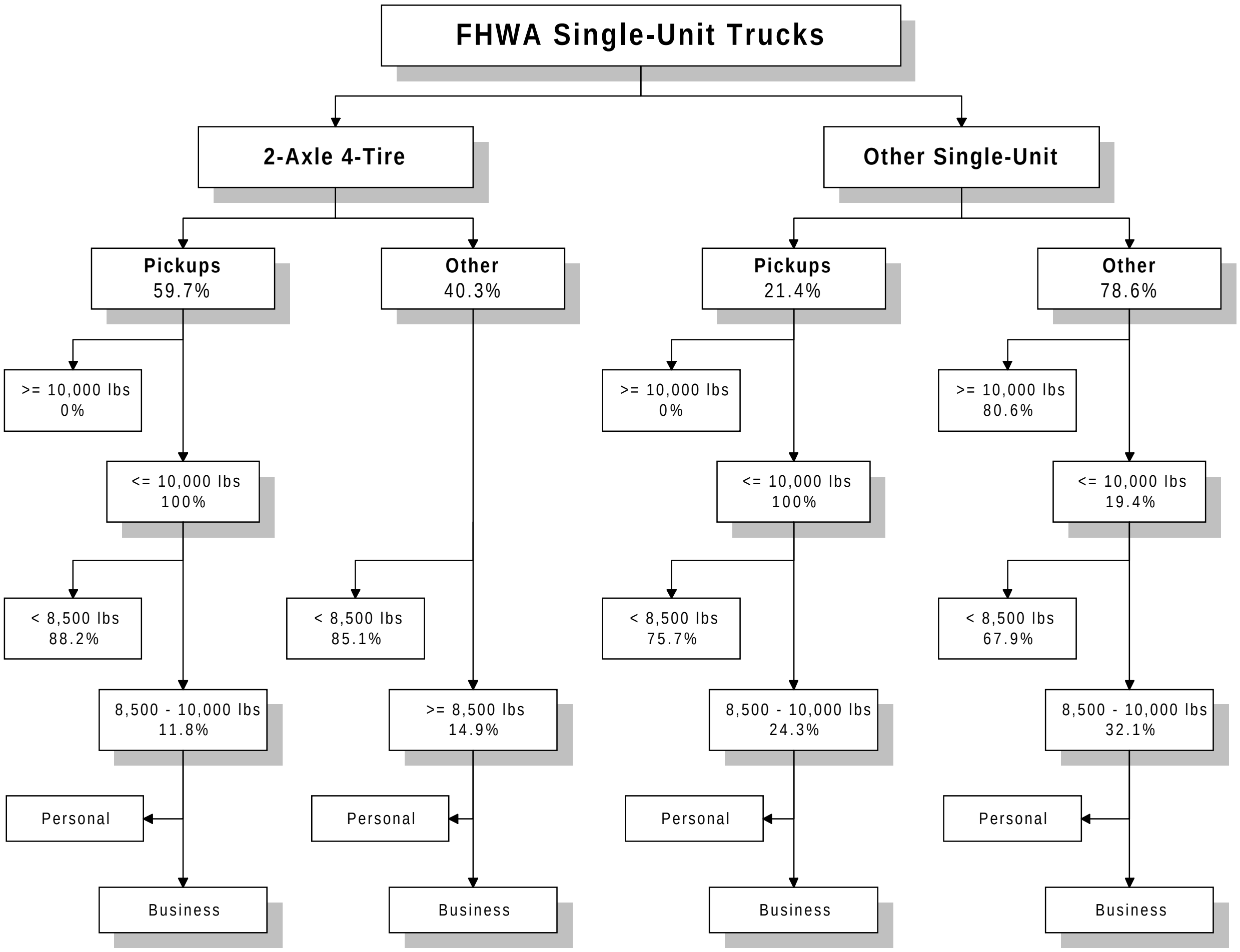
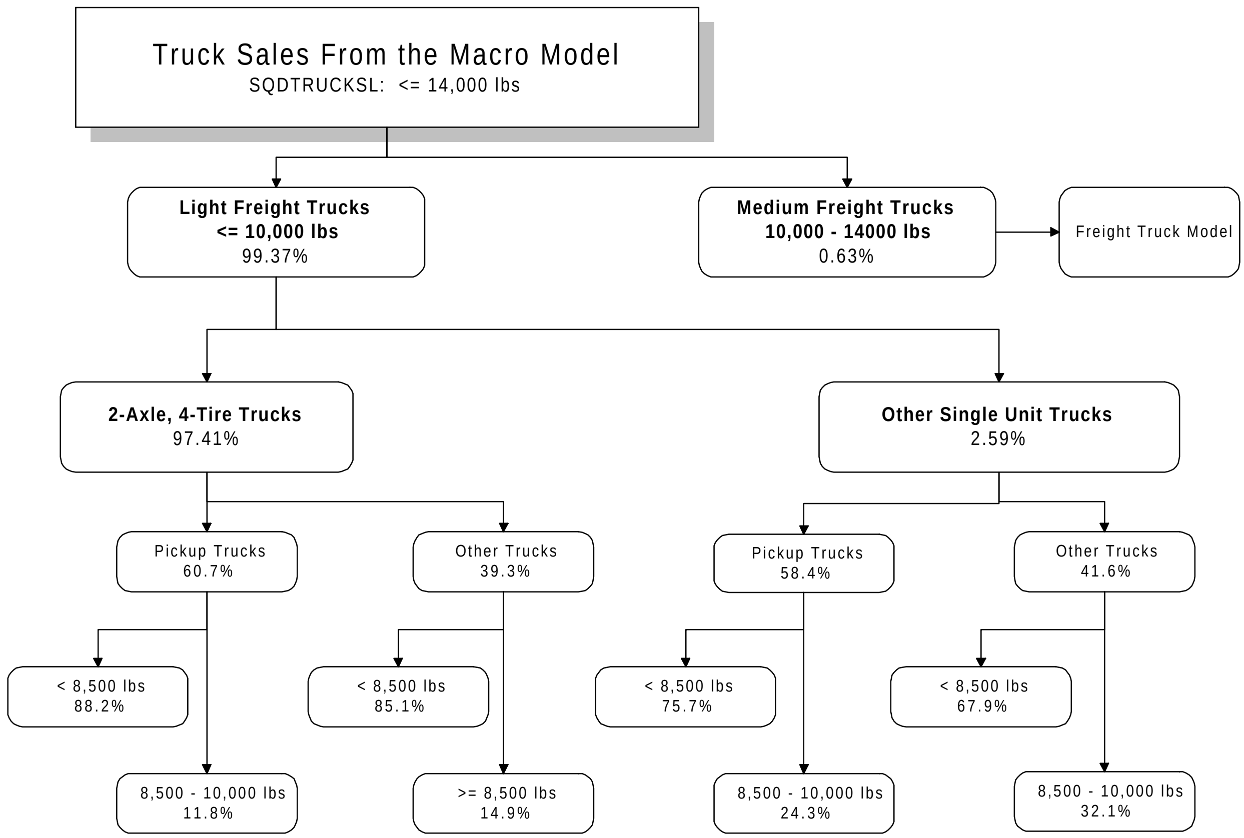


Figure 3C-3: Distribution of Light Truck Sales



LCT Model Equations

1) Calculate LCT sales:

$$LT\_CLTT_N = MC\_SQDTRUCKSL_N * LT10K * 1e^6 \tag{152}$$

where:

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

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

$$CLTSAL2A4T_N = LT\_CLTT_N * LT2A4 \quad and \quad CLTSALOSU_N = LT\_CLTT_N * LTOSU \tag{153}$$

where:

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

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

$$CLTSAL2A4TS_{istyl,N} = CLTSAL2A4T_N * LT2A4CLT_{istyl} \quad and \quad CLTSALOSUS_{istyl,N} = CLTSALOSU_N * LTOSUCLT_{istyl} \tag{154}$$

where:

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

4) Allocate sales among the aggegate major-use groups:

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

$$and \qquad \textbf{(155)}$$

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

where:

CLTSICSHR = Share of LCT sales allocated to each major-use group, by truck type and style

is = Index of truck type: 1 = 2-axle, 4-tire; 2 = other single-unit truck

isic = Index of major use group: 1 = Agriculture; 2 = Mining; 3 = Construction; 4 = Trade; 5 = Utilities; 6 = Personal

5) Update LCT stocks to reflect survival curve and sales:

$$CLTSTK_{is,istyl,isic,N} = CLTSTK_{is,istyl,isic,N-1} * SURVCLT_{is} + CLTSAL_{is,istyl,isic,N} \qquad \textbf{(156)}$$

where:

CLTSTK = Light commercial truck stock

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

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

$$CLTVMT_{is,istyl,isic,N} = CLTVMT_{is,istyl,isic,N-1} * \left[\frac{CLTSIC_{isic,N}}{CLTSIC_{isic,N-1}} \right] \qquad \textbf{(157)}$$

where:

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

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

$$NCLTMPG_{is,istyl,isic,N} = NCLTMPG_{is,istyl,isic,N-1} * \left[\frac{MPGT_N}{MPGT_{N-1}} \right] \qquad \textbf{(158)}$$

where:

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

8) Incorporate new LCT estimates into existing stock:

$$CLTMPG_{is,istyl,isic,N} = \left[\frac{\left\{ \left(\frac{CLTSTK_{is,istyl,isic,N-1} * SURVCLT_{is}}{CLTMPG_{is,istyl,isic,N-1}} \right) + \left(\frac{CLTSAL_{is,istyl,isic,N-1}}{NCLTMPG_{is,istyl,isic,N-1}} \right) * LTDFRFG_N \right\}}{CLTSTK_{is,istyl,isic,N}} \right]^{-1} \quad \textbf{(159)}$$

where:

CLTMPG = Stock MPG of light commercial trucks, by truck type and style

LTDFRFG = Scaling factor, associated with the increased use of reformulated gasoline

9) Calculate aggregate sales-weighted new LCT MPG:

$$NCLTMPGT_N = \left[\sum_{is} \sum_{istyl} \sum_{isic} \left\{ \frac{\left(\frac{CLTSAL_{is,istyl,isic,N}}{\sum_{is} \sum_{istyl} \sum_{isic} CLTSAL_{is,istyl,isic,N}} \right)}{NCLTMPG_{is,istyl,isic,N}} \right\} \right]^{-1} \quad \textbf{(160)}$$

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

$$CLTMPGT_N = \left[\sum_{is} \sum_{istyl} \sum_{isic} \left\{ \frac{\left(\frac{CLTVMT_{is,istyl,isic,N}}{\sum_{is} \sum_{istyl} \sum_{isic} CLTVMT_{is,istyl,isic,N} * 1e^{9}} \right)}{CLTMPG_{is,istyl,isic,N}} \right\} \right]^{-1} \quad \textbf{(161)}$$

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

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

$$and \quad \textbf{(162)}$$

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

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

$$CLTBTUT_N = \sum_{is} \sum_{istyl} \sum_{isic} CLTBTU_{is,istyl,isic,N} \quad \textbf{(163)}$$

Figure 3C-4: LDV Fleet Module 1: Process New Fleet Acquisitions

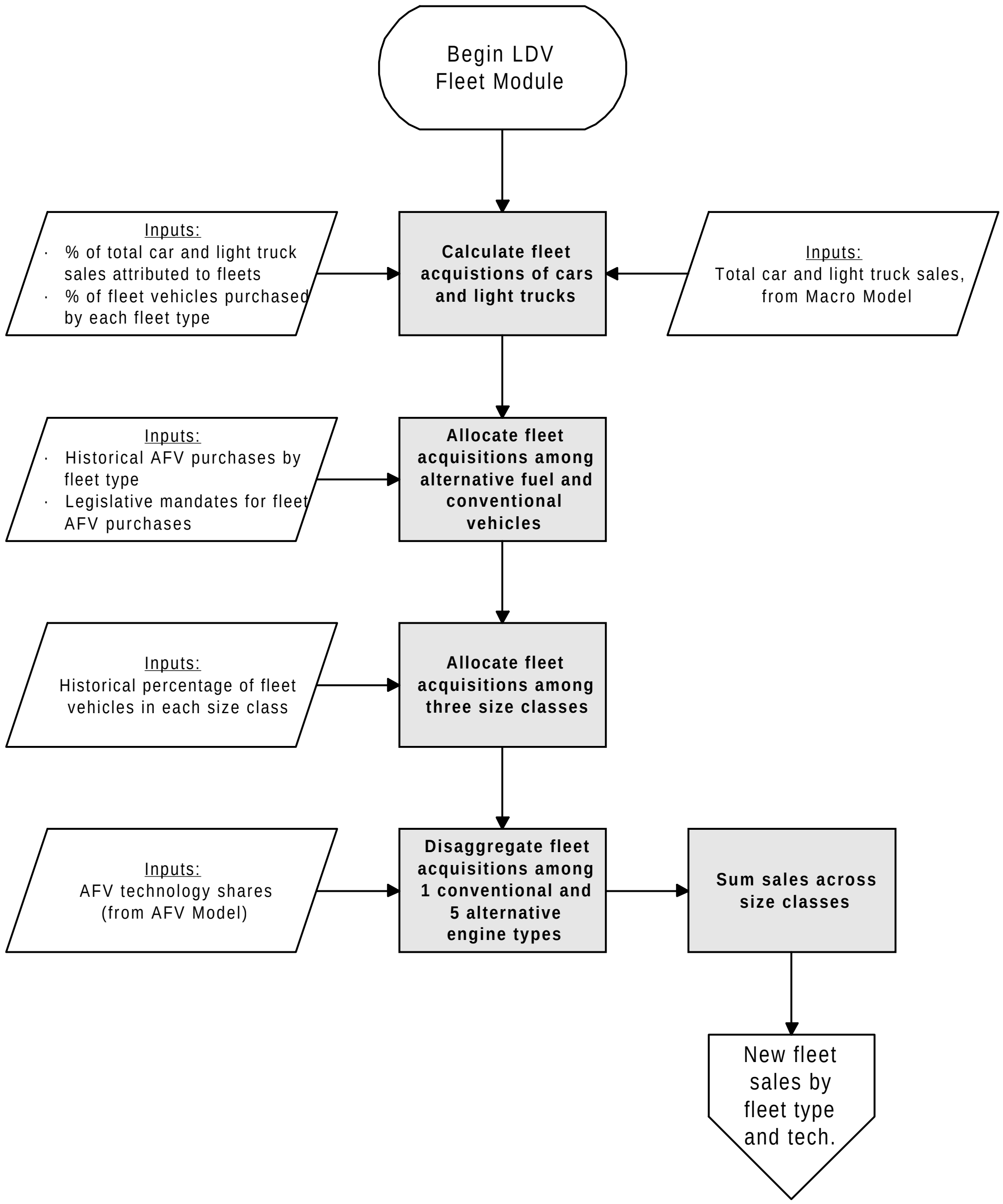


Figure 3C-5. LDV Fleet Module 2: Determine Characteristics of Existing Fleets

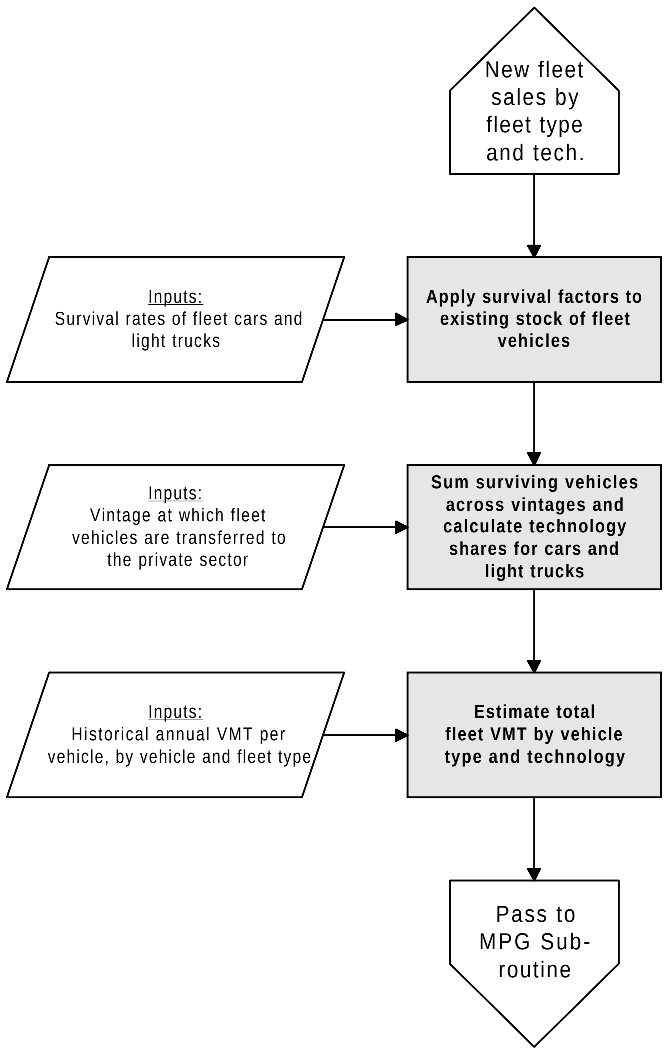
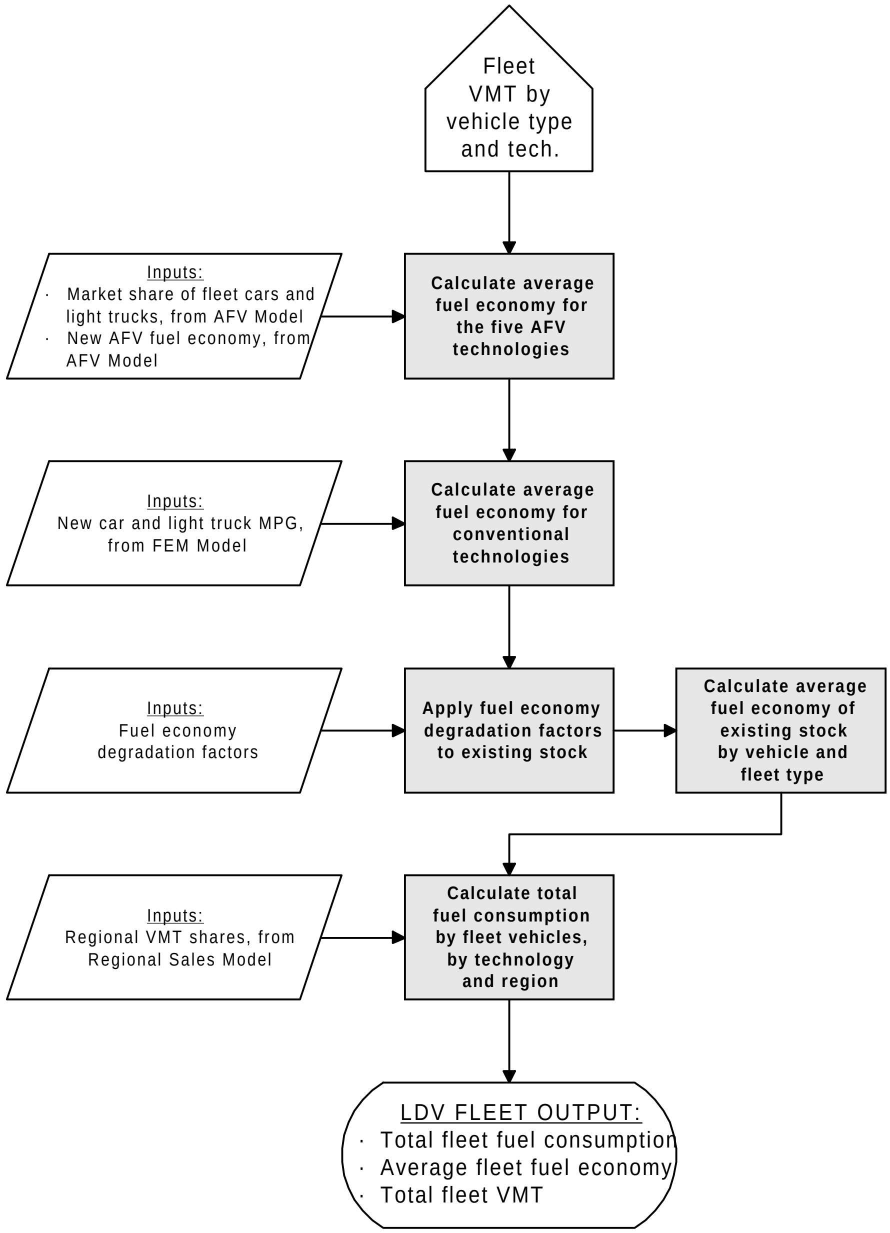


Figure 3C-6. LDV Fleet Module 3: Determine Fleet Fuel Economy and Consumption



3D. Air Travel Module

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

3D-1. Air Travel Demand Model

RATIONALE

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

Structural changes in the airline industry over the past decade have made it difficult to develop long-term forecasts of travel demand. The opening-up of routes, the implementation of the "hubbing" system, the use of competitive pricing, and the growth of a dedicated air freight system are just some of the consequences of a deregulated market. The commercial aviation system is still in a state of flux, having yet to settle down to the level of long-run equilibrium necessary for the application of conventional forecasting methodologies. Today, aviation forecasting experts are emphasizing the role of "judgement" in planning for the future—an implicit acknowledgement of the limitations of a purely quantitative methodology.[23] It is with this in mind that a policy-sensitive approach to forecasting air travel demand has been developed.

In order to increase the sensitivity of the forecast to economic and demographic parameters, a disaggregate model, incorporating separate treatment of business, personal, and international passenger travel has been implemented. Separate forecasts of domestic passenger and freight travel are generated, influenced by economic, demographic and fuel price factors, and are combined into an aggregate estimate of air travel demand. This model stands in contrast to its predecessor, used in producing the 1993 AEO, in which an aggregate demand for commercial passenger travel is first estimated using a constant-elasticity approach:

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[23] *Aviation Forecasting Methodology,* Transportation Research Circular No. 348, Transportation Research Board, Washington, D.C., 8/89, p. 8.

$$RPM_T = 1.2566 \cdot RPM_{1985} \left(\frac{Real\ \ GNP_T}{Real\ \ GNP_{1985}} \right)^{1.92} \left(\frac{TicketPrice_T}{TicketPrice_{1985}} \right)^{-0.413}$$

The RPMs thus generated are subsequently incremented by a fixed percentage representing demand by general aviation and dedicated air cargo aircraft, and a constant military demand. That model's lack of sensitivity to economic and demographic influences has necessitated the consequent revision.

The Air Travel Demand Model is based on several assumptions about personal behavior and the structure of the airline industry. Of greatest significance is the assumption that the deregulation of the industry has substantially altered the dynamics of passenger travel; model parameters have therefore been estimated using only post-deregulation data. It is further assumed that business and personal travel are motivated by different measures of economic conditions, and should be modeled separately. Finally, it is assumed that personal travel demand is influenced by demographic conditions, and forecasts of this demand should be adjusted to reflect the changing age and gender characteristics of the U.S. population. The design of this model, and its underlying assumptions have been influenced by several literature sources and alternative model specifications which are described below.

ALTERNATIVE SPECIFICATIONS

Several alternative models of air travel demand have been considered in the development of this model: the Air Transport Energy Use Model (ATEM), developed by Oak Ridge National Laboratories (ORNL); the Transportation Energy and Emissions Modeling System (TEEMS), developed by Argonne National Laboratory (ANL); the Data Resources Incorporated (DRI) economic model; and forecasts produced by the Federal Aviation Administration (FAA). Each model contributed to the understanding of the dynamics of passenger travel and the assumptions underlying the forecast.

The emphasis of the ATEM model is on estimates of commercial passenger and freight aircraft stocks, and most closely corresponds to the AEO predecessor model.[24] RPM and RTM are estimated by separate models, both of which are functions of GNP and the cost of flying, represented

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[24] Greene, D.L., et. al., *Air Transport Energy Use Model*, Center for Transportation Analysis, Oak Ridge National Laboratory, 4/91, Draft.

by the yield.[25] The yield is considered solely as a function of fuel price, whose contribution to total costs remains a fixed percentage. ATEM employs a modified constant elasticity specification as follows:

$$RPM_t = RPM_0 \cdot Pop \cdot GNPPC^{\beta_1(t)} \cdot Yield^{\beta_2(t)}$$

and:

$$RTM_t = RTM_0 \cdot GNP^{\beta_1(t)} \cdot Yield^{\beta_2(t)}$$

where RPM_0 and RTM_0 represent base year values, and the remaining variables are all indexed to their respective base year values. The elasticities, $ß_1$ and $ß_2$, are specified by the user for each decade of the forecast. This approach was not considered suitable for inclusion in NEMS due to the limited variable inputs, thereby decreasing sensitivity to economic and demographic conditions, and the reliance on user specification of elasticities.

TEEMS directly estimates domestic RPM and energy demand using a linear formulation. RPM values are considered to be functions of disposable personal income (DPI) and changes in jet fuel price (JP), while energy use is subsequently determined using exogenous projections of aircraft efficiency.[26] The travel demand equation is as follows:

$$RPM = .212\,(DPI) - .12\,(JP) - 262.344$$

where the coefficients have been estimated using a regression on 1970-1988 data. In determining consequent fuel consumption, TEEMS assumes an annual aircraft efficiency improvement of 1.5 percent over the next twenty years. This factor is the result of TEEMS' exogenous assessment of expected technology improvements as well as the mandated retirement of older aircraft to comply with noise regulations. Air cargo is projected as part of a separate freight demand model, within which a share of air ton-miles is allocated to dedicated cargo aircraft. Again, the limited reliance on variable inputs precludes the direct incorporation of this model in NEMS.

In the DRI model, air travel demand is influenced by the yield, or revenue per passenger-mile, whose

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[25] "Yield" is a commonly used term in the airline industry, and refers to the revenue per passenger-mile. It is used in most analyses as a normalized representation of ticket price.

[26] Argonne National Laboratory, *Forecast of Transportation Energy Demand Through the Year 2010*, ANL/ESD-9, 4/91.

algorithm is the same for both passengers and cargo:[27]

$$Yield = Yield_{T-1} \left[.65 \left(\frac{Fuel\ Cost_T}{Fuel\ Cost_{T-1}} \right) + .35 \left(\frac{GNP_T}{GNP_{T-1}} \right) \right]$$

Revenue passenger and cargo ton miles are subsequently calculated:

$$RPM = Exp^{5.78} \cdot Yield^{-.372} \cdot \left(\frac{DPI}{Pop}\right)^{3.33}$$

and:

$$RTM = Exp^{-.38} \cdot Yield^{-.12} \cdot GNP^{1.23}$$

Revenue passenger miles are then converted into pound-miles, using an average weight for passengers and baggage, and the demand for kerosene-type jet fuel is finally estimated as follows:

$$Fuel\ Demand = Exp^{-3.13} \cdot RTM_p^{.37} \cdot RTM_c^{.31} \cdot (Real\ Fuel\ Price)^{-.14}$$

where the subscripts p and c refer to passengers and cargo, respectively. While the above models of RTM and RPM have more variable inputs than those models described previously, there seems to be no compelling reason to retain the constant elasticity specification in the development of the Air Travel Demand Model.

The primary function of the Federal Aviation Administration model is to forecast "workload measures", such as instrument operations at towered airports.[28] Such forecasts are used to estimate appropriate staffing levels, and new capital expenditures. The approach is a mixture of econometrics and intuition, using forecasts of secondary measures such as RPM, load-factors, and yields as process inputs.

Total operating cost and aircraft efficiency measures are first used to predict yields; these are then combined with GNP estimates to forecast total RPM and, subsequently, enplanements. Future

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[27] Model description obtained through personal communication with Mary Novak of DRI.

[28] Mayer, C.J., 1989. "Federal Aviation Administration Methodology," pp.9-29, in *Aviation Forecasting Methodology*, Transportation Research Circular Number 348, Transportation Research Board, National Research Council, Washington, D.C.

airport operations are then estimated using predictions about load factors,[29] aircraft size, and trip length. Many of the key variables used in the estimation are the result of intuitive judgements of aircraft manufacturers and airlines.

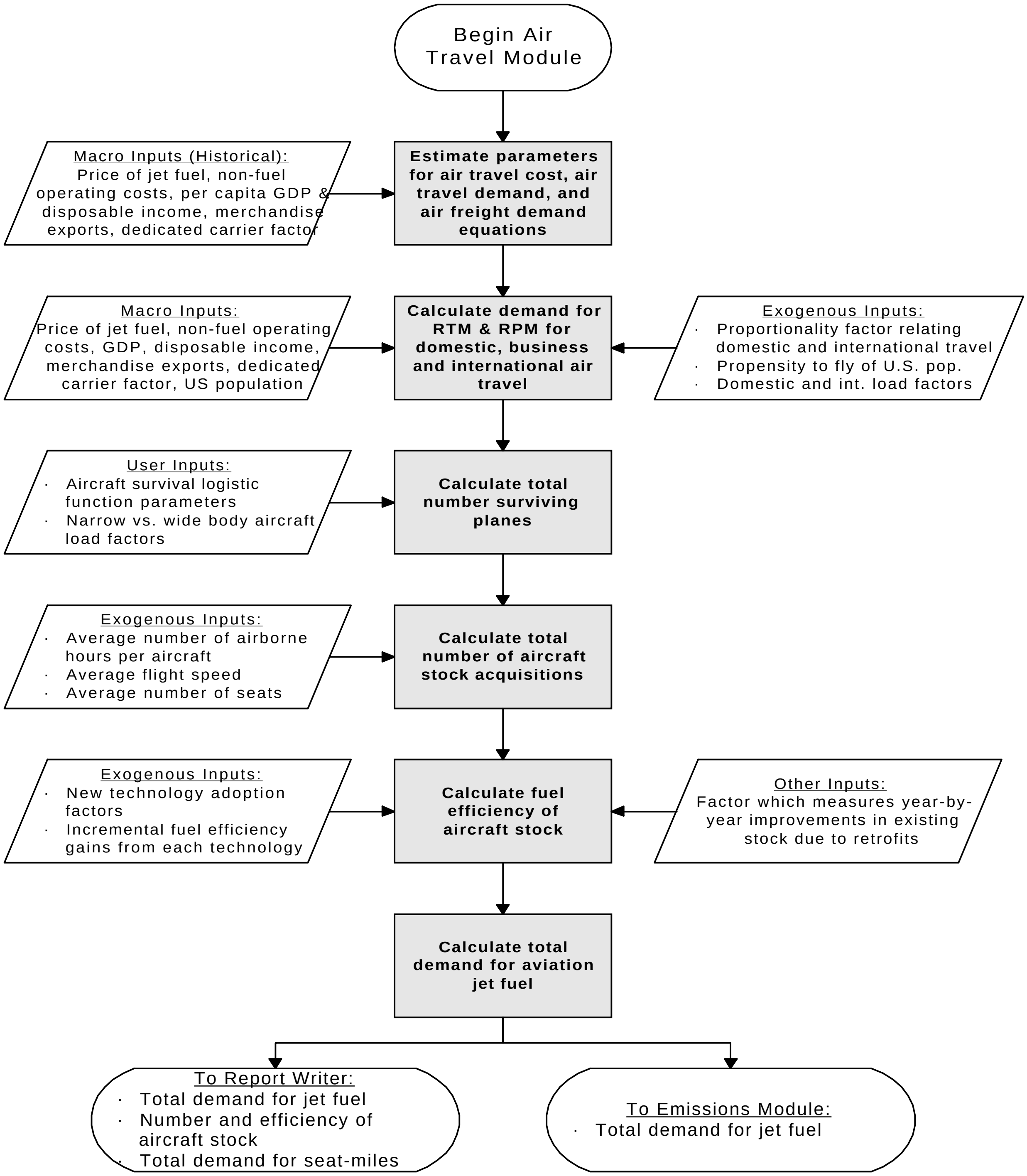
In considering the effect of deregulation on forecasting efforts, it is noted that the demand equation used to forecast RPM produces significantly different coefficients for pre- and post-deregulation data. Estimated price and income elasticities are significantly larger (in absolute value) in the post-deregulation era, reflecting structural changes in the airline industry. For example, the growth of the hub-and-spoke system has substantially increased the availability and convenience of air travel to many areas not previously served by major airlines. It is this dichotomy which has motivated the decision to restrict parameter estimation to the post-deregulation period.

MODEL STRUCTURE

The Air Travel Demand Model, as implemented in NEMS, is a series of linear equations estimated over the period 1979-1990. As noted above, it is assumed that domestic business and personal travel are motivated by different economic measures, and that personal travel is further affected by the demographic makeup of the United States. Key model relationships are presented below, in order of their appearance. Where numbers appear in place of variable names, parameters have been estimated statistically from historical trends. Descriptive statistics for all estimated parameters are provided in Appendix E, Tables E-4 through E-8. Also presented below in Figure 3D-1 is the flowchart for the Air Travel Module. At the end of this section are additional flowcharts which depict the calculations in the Air Travel Demand and Aircraft Fleet Efficiency models in more detail.

[29] The "load factor" is the ratio of revenue passenger-miles to available seat-miles; it provides an estimate of the average occupancy rate of passenger aircraft.

Figure 3D-1. Air Travel Module



1) Calculate the cost of flying:

$$YIELD = 9.73 + .794\,PJF \tag{164}$$

where:

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

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

Business:

$$RPMBPC = 89.70 + .029\,\frac{TMC\_GDP}{TMC\_POPAFO} - 16.04\,YIELD \tag{165}$$

Personal:

$$RPMPPC = -481.84 + .083\,\frac{TMC\_YD}{TMC\_POPAFO} - 18.68\,YIELD \tag{166}$$

International:

$$RPMIPC = PCTINT \cdot (RPMBPC + RPMPPC) \tag{167}$$

where:

TMC_GDP = Gross domestic product, in 1987 dollars.
TMC_YD = Per capita disposable personal income, in 1987 dollars.
TMC_POPAFO = U.S. population
PCTINT = Proportionality factor relating international to domestic travel levels[30]

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

$$RTM = \left(-14{,}556 + 19.81\,TMC\_EXDN92 + 3.49\,TMC\_GDP\right) \cdot DFRT \tag{168}$$

where:

TMC_EXDN92 = Value of merchandise exports, in 1992 dollars, from the Macro Model
DFRT = Fraction of freight ton-miles transported by dedicated carriers[31]

[30] This factor is an extrapolation of historic trends, and is tabulated in Appendix A, Table A-4.

[31] DFRT is obtained from an asymptotic extrapolation of past trends, and is tabulated in Appendix A, Table A-4.

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

$$RPMP = RPMPPC \cdot TMC\_POPAFO \cdot DI \tag{169}$$

$$RPMD = RPMB + RPMP \tag{170}$$

$$RPMI = RPMIPC \cdot TMC\_POPAFO \tag{171}$$

$$RPMB = RPMBPC \cdot TMC\_POPAFO \tag{172}$$

where:

RPMB = Revenue passenger miles for business travel
RPMP = Revenue passenger miles for personal travel
RPMI = Revenue passenger miles for international travel
RPMD = Revenue passenger miles for all domestic travel
TMC_POPAFO = Total U.S. population
DI = Demographic index, reflecting the public's propensity to fly[32]

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

$$ASMDEMD = \left(\frac{RPMD}{LFDOM} \right) + \left(\frac{RPMI}{LFINTER} \right) + (RTM \cdot EQSM) \tag{173}$$

where:

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

3D-2. Aircraft Fleet Efficiency Model

[32] The Demographic Index is derived in Appendix F, Attachment 6.

RATIONALE

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

In the model currently used to produce the 1993 Annual Energy Outlook (AEO), stock efficiency increases at a constant rate, with no explicit dependence on those parameters which would most affect it. This equation is an adaptation of the "best available technology" scenario proposed by ORNL in its analysis of aircraft efficiency:[33]

$$GPM_t = .0230 \cdot (1 - .0137)^{(t - 1985)}$$

where GPM_t represents the gallons per available seat mile in a given year. Given a forecast horizon of 2030, the 1.37 percent annual rate of improvement assumed in the current model leads to an approximate halving of aircraft energy intensity. The above equation assumes a consistent and uniform replacement of older aircraft with newer, more efficient units. Since, in fact, very few aircraft that have actually been retired in the last decade, this assumption seems inappropriate for a comprehensive air transportation modeling system.

The intent of this component of the NEMS Transportation Model is to provide a more intuitive, quantitative approach for estimating aircraft fleet energy efficiency. To this end, the model estimates surviving aircraft stocks and average characteristics at a level of disaggregation which is supportable by available data, and projects the fuel efficiencies of new acquisitions under different sets of economic and technological scenarios. The resulting fleet average efficiencies are returned to the Air Travel Demand Module of TERF to support the forecast of commercial passenger and freight carriers' jet fuel consumption to the year 2030.

Although the air model estimates fuel use from all types of aircraft, only commercial aircraft efficiencies are explicitly modeled. Efficiencies of general aviation aircraft and military planes are not addressed. General aviation fuel use is directly estimated; jet fuel consumption is considered to be a fixed percentage of commercial aircraft demand, and aviation gasoline demand is projected

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[33] *Energy Efficiency Improvement Potential of Commercial Aircraft to 2010,* David Greene, Energy Division, Oak Ridge National Laboratory, Draft Report, October, 1989.

using a time-dependent extrapolation. Military jet fuel use—both naphtha and kerosene based fuel—is estimated in another Module using forecasts of military budget trends.

ALTERNATIVE SPECIFICATIONS

In developing this methodology, two alternative approaches to the estimation of aircraft stocks and fleet efficiency have been considered: Oak Ridge National Laboratory's Air Transport Energy Use Model (ATEM), and an air transportation sub-module, being developed by Energy and Environmental Analysis, Inc. (EEA) for use by DOE's Office of Policy, Planning and Analysis in the Integrated Dynamic Energy Analysis Simulation model (IDEAS). While both employ the conventional methodology of matching new capacity acquisition with expected travel demand, each takes a different approach to the trade-off of flexibility and simplicity. The approach proposed in this component will incorporate aspects of each.

ATEM is a comprehensive effort to describe aircraft stock and efficiency changes.[34] This is a detailed stock vintaging model in which all aircraft are grouped into classes according to their market segment and size. The result is six classes, each described by their trip length and maximum passenger capacity. Passenger travel demand is distributed among the classes, approximating the previous year's distribution, and surviving aircraft capacity is subsequently determined, following the retirement of stock which has reached a uniform, user-specified retirement age. If aircraft supply exceeds travel demand in any class, excess capacity is permanently retired.

Excess travel demand in any class is met by the purchase of specific aircraft models with known operating characteristics and configurations, or generic models incorporating the most efficient new technologies available in a given year. As a default, all active aircraft models in a class would receive an equal market share of new purchases.[35] Using this model, the number of aircraft of every model is always known, as are their operating characteristics, configurations, and utilization rates. This is a very detailed and flexible model which can incorporate a wide variety of assumptions about future trends, but is therefore somewhat unwieldy, requiring an amount of computer time which is inappropriate for use within NEMS.

Efficiency improvements are assumed to come from retrofitting existing aircraft with new technologies, the choice of which is partially dependent on fuel prices, and the incorporation of

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[34] Rathi, A., Peterson, B., and Greene, D., *Air Transport Energy Use Model*, Oak Ridge National Laboratory, April 1991, Draft.

[35] *Ibid.*, pp. 2-9 — 2-14.

increasingly efficient technologies in newly acquired aircraft.[36] ATEM links the operating efficiency of existing aircraft to fuel prices, using an elasticity of -0.04, and a constant efficiency improvement of .03 percent per year.

In contrast, the commercial airline sector of the IDEAS model avoids this level of detail in favor of a simple aircraft vintaging model.[37] This model uses four age classes (0-10 years, 11-20 years, 21-30 years, and > 30 years), making no distinction between aircraft sizes or flight characteristics. This model assumes that average utilization rates and fuel efficiencies vary by aircraft age, and uses these characteristics to estimate the average fuel consumption per passenger mile of the fleet. The advantage of this approach is its ability to provide a quick overall estimate of trends, but its lack of policy levers, such as the effect of increased airport congestion or higher fuel prices, limits its usefulness in exploring the impact of various scenarios. The approach proposed in this report will represent a middle ground between these models—reducing the computation needs of ATEM without entirely sacrificing the ability to respond to economic, technological, or policy issues.

MODEL STRUCTURE

Total fleet efficiency is based on separate estimates of the stock and efficiency of the two types of aircraft considered by the model—narrow body and wide body.[38] The development of the hub and spoke system has made airlines inclined to invest in smaller aircraft in recent years, but increasing airport congestion provides the impetus for investments in larger craft. In 1990, narrow body aircraft accounted for approximately 56 percent of total available seat-miles, and wide body aircraft accounted for the remaining 44 percent. In this model, while the base case maintains the status quo, the share of total passengers and freight conveyed by each of these aircraft types may be altered by the user.

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

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[36] Greene, D.L., *Energy Efficiency Improvement Potential of Commercial Aircraft to 2010,* Oak Ridge National Laboratory, ORNL-6622, June 1990.

[37] Personal communication with Mike Sloane, Energy and Environmental Analysis, Inc.

[38] Narrow body aircraft, such as the Boeing 727, have seating for approximately 120-150 passengers, and are characterized by two banks of seats separated by a center aisle. Wide body aircraft, such as the Boeing 747, carry from 200-500 passengers in three banks of seats

Stock Estimation

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

$$SMFRAC_{NARROW,T} = \left[\left(\frac{SMDEMD_{NARROW,T-1}}{SMDEMD_{T-1}}\right) + \delta \cdot \left(\frac{SMDEMD_{WIDE,T-1}}{SMDEMD_{T-1}}\right)\right] \quad ; \quad \delta \geq 0$$

$$= \left[\left(\frac{SMDEMD_{NARROW,T-1}}{SMDEMD_{T-1}}\right) \cdot (1+\delta)\right] \quad ; \quad \delta < 0 \qquad \textbf{(174)}$$

and

$$SMFRAC_{WIDE,T} = 1 - SMFRAC_{NARROW,T}$$

where:

SMFRAC = Seat mile fraction, by type.
SMDEMD = Total seat-mile demand, by type, in year T.

This specification represents the shifting of a fraction of passenger load from one aircraft type to another, at a rate, δ, which is zero in the base case, but may be exogenously set. It is believed that the most probable value for this factor is negative—increasing the wide body market share—due, in addition to airport congestion, to the growth in the long-haul market, coupled with the longer range and lower seat-mile cost of wide body aircraft.[39]

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

$$SMDEMD_{TYPE,T} = SMFRAC_{TYPE,T} \cdot SMDEMD_{T} \qquad \textbf{(175)}$$

The number of surviving aircraft of each type are subsequently estimated. Because of the relatively small size of the U.S. commercial fleet--slightly over five thousand aircraft--it is important to provide an accurate portrayal of the age distribution of airplanes. This distribution determines the number of aircraft retired from service each year, and consequently has a strong influence over the number of new aircraft acquired to fulfill the demand for air travel. The rate of new aircraft acquisition

[39] Personal communication with David Sepanen, Boeing Commercial Airplane Group, 9/23/92.

significantly affects the average energy intensity of the fleet, and, subsequently, the forecast of energy demand. This model differs from other stock models in that retirements are not assumed to take place abruptly once the aircraft have reached a specified age. Instead, a logistic survival function estimates the fraction of originally delivered aircraft which survive after a given number of years. The sum across years gives an estimate of surviving stocks of each type of plane:

$$NSURV_{TYPE,T} = \sum_{VINT=0}^{n} NPCHSE_{TYPE,T-VINT} \cdot f(VINT) \quad (176)$$

where:

NSURV = Number of surviving planes in year T
NPCHSE = Number of planes originally purchased in the corresponding vintage year
VINT = The vintage, or number of years the aircraft have been in service

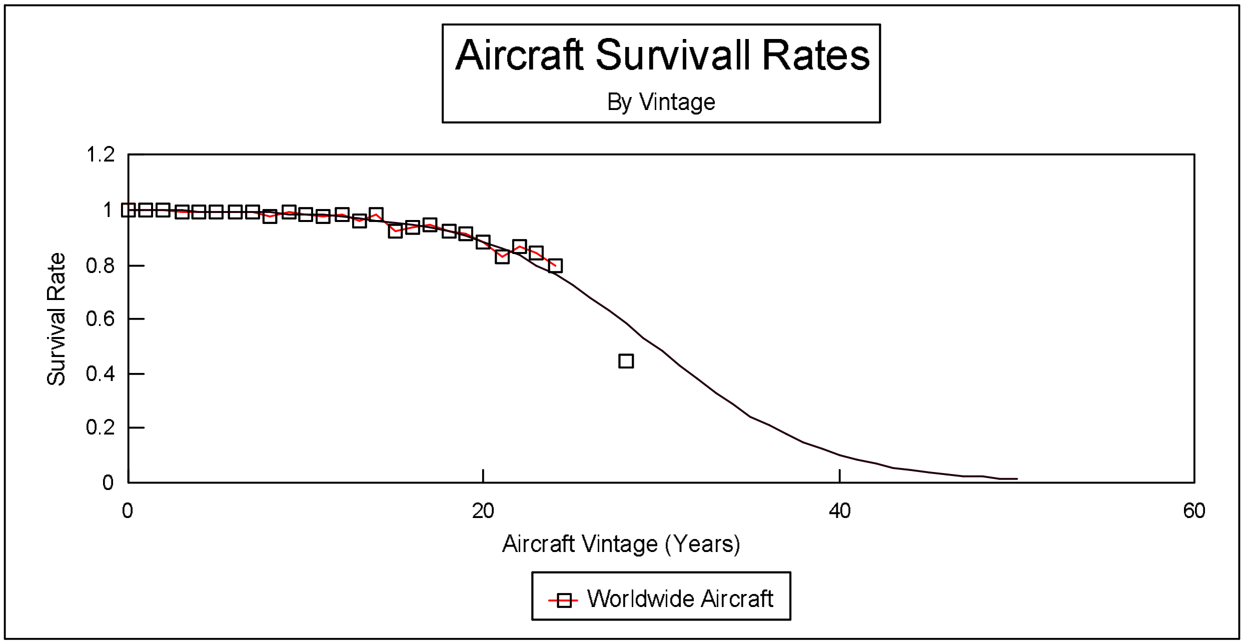
It should be noted that, due to the international nature of the market for aircraft, constructing a survival algorithm using only domestic deliveries and stocks is not feasible. This is because aircraft of different vintages are regularly bought and sold on the international market, and the surviving domestic stock of a given vintage may exceed the number of aircraft of that vintage which had originally been domestically delivered. The problem is mitigated by assuming that the scrappage rate of aircraft on a worldwide basis also characterizes that of domestic aircraft. Data on global aircraft purcases and survival rates are tabulated in the Appendix, and have been used to construct the vintage survival function. The survival function, f(VINT), is expressed as follows:

$$f(VINT) = \left[\frac{1}{1 + Exp(0.209 \cdot VINT - 6.2)} \right] \quad (177)$$

This function is graphically displayed in the figure below.

After the survival function has been specified, it is used in conjunction with the 1992 U.S. inventory of aircraft to generate a baseline of implied deliveries of narrow-body and wide-body aircraft. These implied deliveries represent the number of aircraft of each vintage which, upon application of the survival function, match the Boeing estimates of surviving planes. These figures are tabulated in the Appendix, along with the actual recorded domestic deliveries for the purpose of comparison.

Figure 3D-2. Aircraft Survival Rates



Having established the number of surviving aircraft by type, the available aircraft capacity is calculated. Total available seat miles are estimated using average aircraft characteristics: utilization rates, cruising speed, and seats per aircraft. Surviving aircraft capacity (SMSURV) is calculated as follows:

$$SMSURV_{TYPE,T} = NSURV_{TYPE,T} \cdot ASMP_{TYPE,T}$$

Where **(178)**

$$ASMP_{TYPE,T} = AIRHRS_{TYPE,T} \cdot AVSPD_{TYPE,T} \cdot SEATS_{TYPE,T}$$

where:

SMSURV = Surviving aircraft capacity
NSURV = The number of surviving aircraft, by type
ASMP = The available seat-miles per plane, by type
AIRHRS = The average number of airborne hours per aircraft
AVSPD = The average flight speed
SEATS = The average number of seats per aircraft

These average aircraft characteristics will be either set to default values, or will follow an assumed trend. Tables of these values are provided in Appendix A, Table A-4.

Surviving aircraft capacity is then compared with the travel demand estimates described above. The difference represents the additional capacity required to meet demand. Determining the number of aircraft of each type to add to the fleet is a matter of reorganizing the above equation:

$$NPCHSE_{TYPE,T} = \left[\frac{SMDEMD_{TYPE,T} - SMSURV_{TYPE,T}}{ASMP_{TYPE,T}}\right] \tag{179}$$

where:

NPCHSE = New purchases of aircraft to meet excess demand for travel

The resulting number of new aircraft is then added to surviving stock, and the data table is updated to reflect the newest vintage. This approach presumes that new aircraft are immediately available to meet demand. Actually, airlines' orders for planes are put in several years in advance of need based on estimates of air travel.

Fleet Efficiency

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

$$SMPG_{TYPE,T} = \left[\left(\frac{STKFRAC_{OLD,TYPE,T}}{(1 + \rho_{TYPE}) \cdot (SMPG_{OLD,TYPE,T})}\right) + \left(\frac{STKFRAC_{NEW.TYPE,T}}{SMPG_{NEW,TYPE,T}}\right)\right]^{-1} \tag{180}$$

where:

SMPG = Aircraft fuel efficiency in seat-miles per gallon

$STKFRAC_{OLD}$ = Fraction of seat-miles handled by existing stock

$STKFRAC_{NEW}$ = Fraction of seat-miles handled by newly acquired stock

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

For simplicity, it is assumed that load factors do not vary with the age of the plane; these shares are therefore assumed to be solely dependent on the respective number of planes, as follows:

$$STKFRAC_{OLD,TYPE,T} = \frac{NSURV_{TYPE,T}}{(NSURV_{TYPE,T} + NPCHSE_{TYPE,T})}$$

and

$$STKFRAC_{NEW,TYPE,T} = (1 - STKFRAC_{OLD,TYPE,T}) \tag{181}$$

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

Efficiency improvements of newly acquired aircraft are determined by technology choice which is, in turn, dependent on the year in question, the type of aircraft and the price of fuel. Appendix A, Table A-5, tabulates the technology choices and the expected efficiency improvements of aircraft incorporating those technologies. The model also sets a lower limit for efficiency gains by new aircraft, based on the assumption that new planes will be at least five percent more efficient than the stock efficiency of surviving aircraft. This provision is triggered if the incorporation of new technologies fail to sufficiently increase the efficiencies of new acquisitions.

In order to model a smooth transition from old to new technologies, the efficiencies of new aircraft acquisitions are based on several logistic functions which reflect the commercial viability of each technology. For each technology, a Technology Penetration Function is defined as follows:

$$Penetration_{TECH} = \frac{1}{1 + \exp^{-(PE+TE-6)}} \qquad \textbf{(182)}$$

where:

Penetration = The fraction of new aircraft incorporating a given technology
PE = The influence of fuel prices on technology penetration
TE = The influence of time on technology penetration

The two arguments, the price effect (*PE*) and the time effect (*TE*), are based on the assumption that the rate of technology incorporation is determined not only by the magnitude of a given technology's price advantage, but also by the length of time in which the technology has been commercially viable. *TE*, the time effect, is defined as a user-specified constant multiplied by the number of years following the trigger year in which the trigger price has been met or exceeded. This constant strongly influences the slope of the logistic curve and has been initially set to 0.7 to reflect historical trends in technology adoption. The larger this factor, the more abrupt the transition between zero and full implementation of the considered technology. The factor *-6* represents an *ad hoc* adjustment which anchors the logistic curve, thus ensuring that technologies are not incorporated prior to their commercial viability. The price effect, *PE*, is defined as follows (where 10 is a scaling factor):

$$PE = 10 \cdot \frac{[\,Fuel\ Price\ -\ Trigger\ Price\,]}{Fuel\ Price}$$

when

$$(0 < Trigger\ Price \leq Fuel\ Price) \qquad \textbf{(183)}$$

and

$$PE = 0 \quad , \quad \text{Otherwise}$$

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.

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

$$SMPG_T = \left[\sum_{TYPE=1}^{2} \left(\frac{SMFRAC_{TYPE,T}}{SMPG_{TYPE,T}} \right) \right]^{-1} \qquad \textbf{(184)}$$

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

Estimating Fuel Consumption

Estimating the demand for jet fuel is simply a matter of combining the output of these two models:

$$JFDEMD_T = \frac{SMDEMD_T}{SMPG_T} \qquad \textbf{(185)}$$

where:

JFDEMD = The total demand for aviation jet fuel.

This result is subsequently augmented by five percent to reflect the use of jet fuel in private planes.

3E. Freight Transport Module

RATIONALE

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

The freight model currently used for the AEO is an aggregate version of the Argonne National Laboratory freight model, FRATE. Forecasts are made for each of the four modes of freight transport: trucks, rail, ships, and air. In each case, travel forecasts are based on the industrial production of specific industries, travel growth in most cases being directly proportional to increases in value added. 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 is considered in the aggregate, no distinction is drawn between classes of carrier, such as trucks of different size.

The freight transport model developed for NEMS is an adaptation of the AEO model, providing flexibility for future developments, and incorporating another level of detail in the specification of modes. This is accomplished by stratifying the trucking sector according to size classes and developing a stock adjustment model for each size class and fuel type, and providing for similar stratification of the other modes, as needed. Parameters relating industrial output tonnage to changes in value added have been explicitly incorporated.

ALTERNATIVE SPECIFICATIONS

Argonne National Laboratory's Transportation Energy and Emissions Modeling System (TEEMS) provides the foundation for this component. This model links several disaggregate models to produce a forecast of transportation activity, energy use, and emissions. The freight sector model estimates future-year activity (ton-miles or vehicle-miles) and energy consumption by mode. Indices of sectoral output are supplied by a macroeconomic model. A mode choice model then computes ton-miles traveled by truck, rail, water, and air for 24 commodity sectors based on commodity characteristics, changes in fuel price, energy intensities, and modal operating characteristics. An accounting submodel uses modal energy intensities, load factors, and size/subactivity allocation factors to compute activity and energy consumption by fuel type for each freight mode.[40]

The FRATE model is highly disaggregate, incorporating a variety of commodity and mode-dependent characteristics used by a shipper to maximize utility. Forecasts are dependent on base year (1985) freight movement data, which have been obtained from several sources. The 1985 *One Percent Rail Waybill Sample*[41] and the Association of American Railroads' *Railroad Facts*[42] were used to estimate rail ton-miles of travel; *Waterborne Commerce of the United States*,[43] published by the U.S. Army Corps of Engineers, was used to estimate marine ton-miles of travel; truck vehicle-miles and ton-miles of travel were estimated using the *Truck Inventory and Use Survey*,[44] and growth indices of sectoral economic output from Data Resource Inc.'s macroeconomic model.[45] Truck energy consumption is projected using fuel economy in terms of miles per gallon and average load factors. Rail and marine energy intensities are computed using the total fuel sales by mode as published in the *Petroleum Marketing Monthly*.[46] The differences between energy intensities of various sectors have been held constant from 1977.

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[40] This summary is derived from *Forecast of Transportation Energy Demand Through the Year 2010*, Energy Systems Division, Argonne National Laboratory, ANL/ESD-9, April, 1991, p. 34, et. seq.

[41] *One Percent Waybill Sample*, Federal Railroad Administration, Washington, D.C., 1987.

[42] *Railroad Facts*, Association of American Railroads, Washington, D.C., 1987.

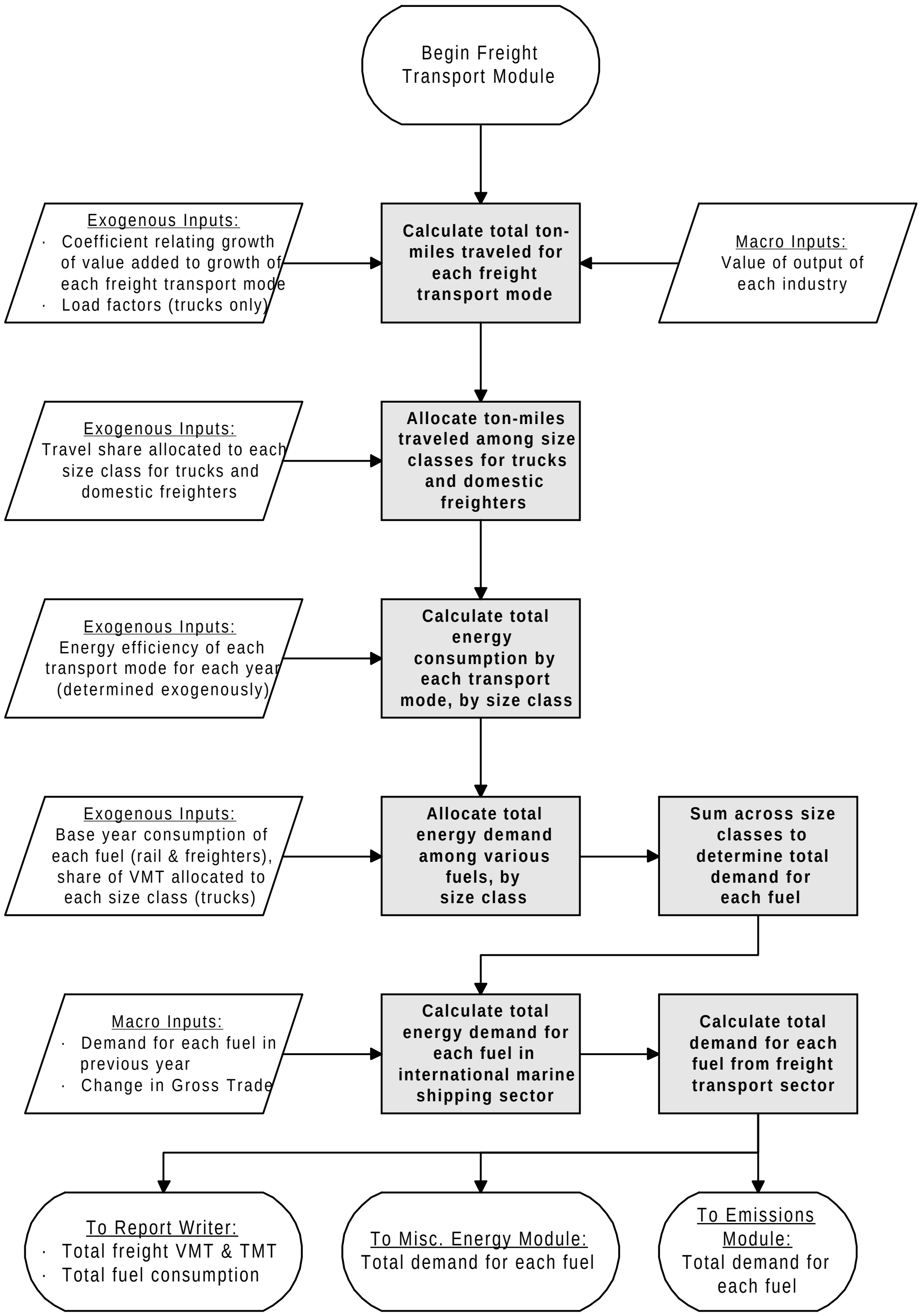
[43] *Waterborne Commerce of the United States*, U.S. Army Corps of Engineers, Water Resources Support Center, New Orleans, LA, 1987.

[44] *The 1982 Truck Inventory and Use Survey: Public Use Tape*, Bureau of the Census, U.S. Department of Commerce, Washington, D.C., 1984.

[45] *The DRI Annual Model of the U.S. Economy: PC Version*, Data Resources, Inc., Lexington, MA, 1986.

[46] *Petroleum Marketing Monthly*, Energy Information Administration, U.S. Department of Energy, Washington, D.C., 1986.

Figure 3E-1. Freight Transport Module



MODEL STRUCTURE

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

3E-1. Freight Truck Stock Adjustment Model

INTRODUCTION

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

ALTERNATIVE SPECIFICATIONS

Current NEMS Model: The freight model currently used for the AEO is an aggregate version of the Argonne National Laboratory freight model, FRATE. Forecasts are made for three modes of freight transport: trucks, rail, and ships. In each case, travel forecasts are based on the industrial production of specific industries, travel growth in most cases being directly proportional to increases in value added. 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. The proposed version of the Freight Truck Stock Adjustment Model will replace the average energy intensity with vintage, size class, sector and fuel technology-specific freight truck fuel economies.

Argonne National Laboratory—Transportation Energy and Emissions Modeling System: Argonne National Laboratory's Transportation Energy and Emissions Modeling System (TEEMS) links several disaggregate models to produce a forecast of transportation activity, energy use, and emissions. The freight sector model estimates future-year activity (in vehicle-miles) and energy consumption by sector. Indices of sectoral output are supplied by a macroeconomic model. A mode choice model then computes ton-miles traveled by truck, rail, water, and air for 24 commodity sectors based on commodity characteristics, changes in fuel price, energy intensities, and modal operating characteristics. The FRATE model is highly disaggregate, incorporating a variety of commodity and mode-dependent characteristics used by a shipper to maximize utility. Forecasts are dependent on base year (1985) freight movement data, which have been obtained from several sources. Truck vehicle-miles and ton-miles of travel are estimated using the Truck Inventory and Use Survey, and growth indices of sectoral economic output are obtained from Data Resource Inc.'s macroeconomic model. Vehicle miles are assigned to truck size groups based on commodity-specific allocation factors. Four size classes are defined by average laden weight. Fuel types are limited to gasoline and diesel. Energy requirements are computed using exogenous fuel economy baselines in combination with market penetration of fuel-saving technologies. Truck stocks within each size and fuel combination are computed on the basis of historical and projected vehicle utilization rates.

DRI/McGraw-Hill—Energy Review: Demand for motor fuels in the transportation sector is based on a vintage capital analysis of on-road vehicles. Consumers are assumed to determine the composition of the capital stock--in terms of both volume and technological characteristics--through their vehicle purchase decisions. The demand for travel, in conjunction with the number and type of vehicles in the stock, then determines the level of fuel consumption. Motor vehicles are divided into cars, light trucks, medium trucks (10,000-33,000 lbs. gross) and heavy trucks. The allocation of trucks among weight classes was changed for the 1994 version. FHWA's *Highway Statistics* categorizes trucks in three size classes: "two axle, four tire"; "other single unit"; and "combination trucks". DRI assumes that all two-axle, four-tire trucks belong in the light-duty truck category and all combination trucks belong in the heavy-duty category. However, the more than 4 million vehicles registered in the "other single unit" category include some light trucks and potentially some heavy trucks as well.

MODEL STRUCTURE

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

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

1. Estimate New Truck Fuel Economies

The first step in the FTSAM is to determine the characteristics the incoming class of truck purchases. Estimates of new medium and heavy truck fuel economies are generated endogenously and depend on the market penetration of specific fuel-saving technologies. Currently existing fuel-saving technologies are based on the *1992 Truck Inventory and Use Survey* [47]and include aerodynamic features, radial tires, "axle or drive ratio to maximize fuel economy", "fuel economy engine", and variable fan drives. 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 Argonne National Laboratory's *Transportation Energy Use Through the Year 2010,*[48] and include improved tires & lubricants, electronic engine controls, electronic transmission controls, advanced drag reduction, turbocompound diesel engines, and "heat engines/LE-55", a DOE/EERE technology. Placeholders allow for the introduction of five additional technologies. Future technologies enter the market at various times throughout the model run depending on the year in which they become commercially available and on the level of fuel prices relative to a "trigger price" at which the technology becomes economically viable. Because prices vary by fuel type, the market shares of fuel-saving technologies are specified separately for diesel, gasoline, LPG and CNG trucks.

Characterizations of existing and future fuel-saving technologies are documented in an earlier

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[47]*1992 Census of Transportation: Truck Inventory and Use Survey*, U.S. Department of Commerce, Bureau of the Census, TC92-T-52, May 1995.

[48]*Forecast of Transportation Energy Demand Through the Year 2010,* Argonne National Laboratory, energy Systems Division, ANL/ESD-9, April, 1991.

report.[49] Because future technologies are speculative, future technology characterizations can be modified by the user. However, existing characterizations are derived from historical data and should not be altered.

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

$$AVGPRC_{T,FUEL} = \frac{(PRICE_{T,FUEL} + PRICE_{T-1,FUEL} + PRICE_{T-2,FUEL})}{3} \tag{186}$$

where:

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

Whether a future technology enters the market during a particular year depends on the trigger price of that technology relative to the average price of each fuel over the past three years. If the technology has not yet entered market and the average price is greater than the technology's trigger price, the technology enters the market during the current year:

$$\begin{gathered} For\ TECH = 6,...,16 \\ If \quad AVGPRC_{T,FUEL} \geq TRIGPRC_{SC,FUEL,TECH} \\ INITYR_{SC,FUEL,TECH} = T \end{gathered} \tag{187}$$

where:

$TECH$	=	Index referring to fuel-saving technologies, where $TECH = 1,...,5$ refers to currently available technologies and $TECH = 6,...,16$ refers to future technologies
SC	=	Index referring to truck size class, where $SC = 2$ refers to medium trucks and $SC = 3$ refers to heavy trucks
INITYR	=	Year in which technology *TECH* enters market
TRIGPRC	=	Exogenously determined fuel price at which technology *TECH* becomes economically viable

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

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

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

and **(188)**

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

where:

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

These coefficients are then used during the remainder of the forecast period to determine that technology's market share. Technology market penetration depends on the level of fuel prices relative to the technology's trigger price. For each technology which has entered the market, and for existing technologies, the effect of fuel prices on market penetration is determined for the current year:

$$PREFF_{T,SC,FUEL,TECH} = 1 + PRCVAR_{SC,FUEL,TECH} \cdot \left[\frac{AVGPRC_{T,FUEL}}{TRIGPRC_{SC,FUEL,TECH}} - 1\right] \quad \textbf{(189)}$$

where:

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

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

$$For\ TECH = 1,...,5$$

$$TECH_{T,SC,FUEL,TECH} = \min \left\{ PREFF_{T,SC,FUEL,TECH} \cdot \left[BSHRT_{SC,TECH} + \left(ESHRT_{SC,FUEL,TECH} - BSHRT_{SC,TECH} \right) \cdot \left(1 - e^{CONST_{SC,TECH} + COEFT_{SC,TECH} \cdot T} \right) \right], 1 \right\} \quad \textbf{(190)}$$

$$For\ TECH = 6,.....,16$$

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

where:

TECHSHR = Market share of fuel-saving technology *TECH* for size class *SC* and fuel type *FUEL*
CONST = Exogenously determined market penetration curve parameter for existing technologies
COEFT = Market penetration curve parameter; exogenous for existing technologies, endogenous for future technologies
BSHRT = Exogenously determined market penetration curve parameter representing market share of existing technology *TECH* in 1992
ESHRT = Exogenously determined market penetration curve parameter representing final market share of technology *TECH* if fuel price were always equal to trigger price

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

$$TECHSHR_{T,SC,FUEL,TECH} = \left(1 - SPRSDEFF_{T,SC,FUEL,TECH} \right) \cdot TECHSHR_{T,SC,FUEL,TECH} \quad \textbf{(191)}$$

where:

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

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

$$MPGEFF_{T,SC,FUEL} = \prod_{TECH=1}^{16} \left(1 + MPGINCR_{SC,FUEL,TECH} \cdot TECHSHR_{T,SC,FUEL,TECH} \right) \quad \textbf{(192)}$$

where:

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

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

$$MPG_{T,SC,AGE=0,FUEL} = BASEMPG_{SC,FUEL} \cdot MPGEFF_{T,SC,FUEL} \tag{193}$$

where:

BASEMPG = Fuel economy of new medium and heavy trucks with no fuel-saving technologies

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

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

The first step in this process is to calculate the fuel cost per mile for trucks of each size class and fuel type:

$$FCOST_{T,SC,FUEL} = \frac{AVGPRC_{T,FUEL}}{MPG_{T,SC,FUEL}} \cdot HTRATE \tag{194}$$

where:

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

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

$$RCOST_{T,SC,FUEL} = 1 - \left[\frac{FCOST_{T,SC,FUEL}}{FCOST_{T,SC,FUEL=1}} - 1 \right] \cdot PRCDIFFVAR_{SC,FUEL} \quad \textbf{(195)}$$

where:

RCOST = Fuel cost per mile of diesel relative to LPG and CNG

PRCDIFFVAR = Exogenously determined parameter representing inherent variation in AFV market share due to difference in fuel prices

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

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

and **(196)**

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

where:

FLT = Index referring to fleet type, where *FLT* = 1 refers to trucks in fleets of nine or less and *FLT* = 2 refers to trucks in fleets of ten or more

COEFAFV = Endogenously determined logistic market penetration curve parameter

CYCAFV = Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration

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

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

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

$$MPATH_{T,SC,FUEL,FLT} = RCOST_{T,SC,FUEL} \cdot \left[BSHRF_{SC,FUEL,FLT} + \frac{ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT}}{1 + e^{COEFAFV_{SC,FUEL,FLT} \cdot (T - MYRAFV_{SC,FUEL,FLT})}} \right] \quad \textbf{(197)}$$

where:

BSHRF = Base year (1992) market share of each fuel type

ESHRF = Exogenously determined final market share of each fuel type

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

$$MPATH_{T,SC,FUEL=1,FLT} = BSHRF_{SC,FUEL,FLT} + \left[ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT}\right] \cdot \left(1 - e^{CONSD_{SC,FLT} + COEFT_{SC,FLT} \cdot T}\right) \quad \textbf{(198)}$$

where:

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

LPG and CNG trucks are already prominent in some sectors of the economy, most notably in the petroleum products sector. The market share of alternative fuel trucks is assumed never to dip below the historical level in each sector. The actual AFV market share is thus calculated as the maximum of historical and forecast shares:

$$FSHR_{T,SEC,SC,FUEL=3,4,FLT} = \max\left[BSEC_{SEC,SC,FUEL,FLT} \, , \, MPATH_{T,SC,FUEL,FLT}\right] \quad \textbf{(199)}$$

where:

BSEC = Exogenously determined base year (1992) share of alternative fuels in truck purchases

Because of the potential for any fuel type to exceed the user-specified "maximum" due to cost advantages over other technologies, market penetration must be capped at one hundred percent. Diesel market share is calculated as the forecast share of diesel in conventional truck sales multiplied by the share occupied by conventional trucks:

$$FSHR_{T,SEC,SC,FUEL=1,FLT} = \left(1 - \sum_{FUEL=3}^{4} FSHR_{T,SEC,SC,FUEL,FLT}\right) \cdot \left(\min\left[MPATH_{T,SC,FUEL,FLT} \cdot BSECD_{SEC,SC,FLT} \, , \, 1\right]\right) \quad \textbf{(200)}$$

where:

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

The remainder of truck purchases are assumed to be gasoline:

$$FSHR_{T,SEC,SC,FUEL=2,FLT} = 1 - \sum_{FUEL=1,3,4} FSHR_{T,SEC,SC,FUEL,FLT} \quad \textbf{(201)}$$

3. Determine Composition of Existing Truck Stock

Once the characteristics of the incoming class of new trucks are determined, the next step is to determine the composition of the stock of existing trucks. Scrappage rates are applied to the current truck population:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T-1,SEC,SC,AGE-1,FUEL,FLT} \cdot \left(1 - SCRAP_{SC,AGE-1}\right) \qquad \textbf{(202)}$$

where:

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

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

$$TRF1_{T,SEC,SC,AGE,FUEL} = TRFRATE_{SC,AGE} \cdot TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} \qquad \textbf{(203)}$$

where:

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

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

$$TRF2_{T,SEC,SC,AGE,FUEL=3,4} = FSHR_{T,SEC,SC,FUEL,FLT=1} \cdot TRFRATE_{SC,AGE} \cdot \sum_{FUEL=1}^{4} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} \qquad \textbf{(204)}$$

where:

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

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

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

$$and \qquad \textbf{(205)}$$

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

where:

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

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

$$TRFSHR_{T,SC,SEC} = \frac{\sum_{FUEL=1}^{4} \sum_{AGE=1}^{11} sUSUMTRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}}{\sum_{FUEL=1}^{4} \sum_{AGE=1}^{11} \sum_{SEC=1}^{12} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}} \qquad \textbf{(206)}$$

where:

TRFSHR = Share of fleet transfers which goes to each sector

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

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

$$and \qquad \textbf{(207)}$$

$$STK_{T,SEC,SC,AGE,FUEL,FLT=1} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} + TRFSHR_{T,SEC,SC} \cdot \sum_{SEC=1}^{12} TRF_{T,SEC,SC,AGE}$$

4. Calculate Purchases of New Trucks

Truck purchases are based on the operating characteristics of new and existing trucks, primarily the average annual vehicle mileage per truck, and on the demand for freight travel in the current year.

Annual vehicle mileage determines the ability of the existing stock to meet the VMT demand. VMT per truck has increased steadily since the early 1970s, and is forecast as an index in which 1992 is equal to one. The index is defined as a time-dependent exponential decay function for each size class with exogenously determined parameters:

$$VMTTREND_{T,SC} = \frac{BSHRV_{SC} + \left(ESHRV_{SC} - BSHRV_{SC}\right) \cdot \left(1 - e^{CONSV_{SC} + COEFV_{SC} \cdot T}\right)}{BSHRV_{SC} + \left(ESHRV_{SC} - BSHRV_{SC}\right) \cdot \left(1 - e^{CONSV_{SC} + COEFV_{SC} \cdot 1992}\right)} \qquad \textbf{(208)}$$

where:

VMTTREND = Index of average annual VMT per truck, where 1992 = 1
BSHRV = Exogenously determined VMT per vehicle increase factor representing minimum annual vehicle mileage
ESHRV = Exogenously determined VMT per vehicle increase factor representing maximum annual vehicle mileage
CONSV = Exogenously determined exponential VMT per vehicle increase factor
COEFV = Exogenously determined exponential VMT per vehicle increase factor

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

$$ANNVMT_{T,SEC,SC,AGE,FUEL} = ANNVMTBASE_{T,SEC,SC,AGE,FUEL} \cdot VMTTREND_{T,SC} \qquad \textbf{(209)}$$

where:

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

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

$$VMTOLD_{T,SEC} = \sum_{FLT=1}^{2} \sum_{FUEL=1}^{16} \sum_{AGE=1}^{11} \sum_{SC=1}^{3} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \cdot ANNVMT_{SEC,SC,AGE,FUEL} \qquad \textbf{(210)}$$

where:

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

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

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

$$and \tag{211}$$

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

where:

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

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

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

$$For\ T = 0$$

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

$$For\ T = 1-22 \tag{212}$$

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

where:

VMTDMD	=	Demand for freight travel by sector *SEC*, in year *T*

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

Truck purchases are based not on the actual VMT demand for a given year, for this cannot be known in advance by the decison-makers, but on the level of demand which is expected to occur at the time the trucks are delivered. Since industry practice is to order trucks six months in advance[50], the purchasing period for trucks delivered in year *T* extends from July 1 of year *T*-1 to June 30 of year *T*. Purchase orders are placed based on the expected freight shipping orders six months later. Expected shipping orders are based on two factors: the level of demand currently being experienced, or the perceived baseline demand, and the expected growth rate of VMT demand over the next six months.

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

$$PVMTGROWTH_{T,SEC} = 0.5 \cdot \left[\frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}} - 1 \right] + 0.5 \cdot \left[\frac{OUTPUT_{T-1,SEC}}{OUTPUT_{T-2,SEC}} - 1 \right] \qquad \textbf{(213)}$$

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

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

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

$$For\ T = 0$$

$$PVMTBASE_{T,SC} = 0.5 \cdot VMTDMDBASE_{SEC}$$

(214)

$$For\ T = 1-22$$

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

where:

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

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

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

$$and$$

(215)

$$VMTDMD_{T,SEC} = 0.25 \cdot VMTDMD_{T,SEC} + PVMTBASE_{T,SEC} \cdot \left(1 + PVMTGROWTH_{T,SEC}\right) \cdot FACTR_{SE}$$

where:

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

PVMTDMD = Perceived demand for freight travel in year *T*

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

$$PVMTUNMET_{T,SEC} = PVMTDMT_{T,SEC} - VMTOLD_{T,SEC} \quad \textbf{(216)}$$

where:

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

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

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

and **(217)**

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

where:

PVMT = Perceived demand for freight travel by new trucks of size class *SC* and fleet type *FLT* in sector *SEC*

VMTSCFAC = Exogenously determined parameter representing percentage of new truck sales which go to each size class *SC* in sector *SEC*

FLTSHR = Exogenous parameter representing percentage of new truck sales of each size class *SC* which go to fleets of ten or more in sector *SEC*

Market shares and VMT per vehicle for trucks of each fuel technology have been calculated above; these are used to calculate a fuel technology-weighted average annual VMT per vehicle of the current year's class of new fleet and non-fleet trucks:

$$PVN_{T,SEC,SC,FLT} = \sum_{FUEL=1}^{4} FSHR_{T,SEC,SC,FUEL,FLT} \cdot ANNVMT_{T,SEC,SC,AGE=0,FUEL} \quad \textbf{(218)}$$

where:

AGE = 0 refers to new trucks

PVN = Annual VMT per vehicle for new trucks in year *T*

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

$$TRKSTK_{T,SEC,SC,AGE=0,FUEL,FLT} = \left[\frac{PVMT_{T,SEC,SC,FLT}}{PVN_{T,SEC,SC,FLT}} \right] \cdot FSHR_{T,SEC,SC,FUEL,FLT} \quad \textbf{(219)}$$

5. Calculate Fuel Consumption

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

$$VMT_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \cdot ANNVMT_{T,SEC,SC,AGE,FUEL} \cdot \left[\frac{\sum_{SEC=1}^{12} VMTDMD_{T,SEC}}{\sum_{SEC=1}^{12} PVMTDMD_{T,SEC}} \right] \qquad \textbf{(220)}$$

where:

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

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

$$MPGDEGFAC_{T,SC} = \frac{1 - \left[\left(1 - MPGDEGFAC_{T,LDV}\right) \cdot \frac{URBANSHR_{SC}}{URBSHRLDV} \right]}{1 - \left[\left(1 - MPGDEGFAC_{T=0,LDV}\right) \cdot \frac{URBANSHR_{SC}}{URBSHRLDV} \right]} \qquad \textbf{(221)}$$

where:

$MPGDEGFAC_{LDV}$ = Fuel economy degradation factor, from LDV Module
MPGDEGFAC = Fuel economy degradation factor for freight trucks
URBANSHR = % of miles driven in urban areas by trucks of each size class in base year (1992)
URBSHRLDV = % of miles driven in urban areas by LDVs in base year (1992)

EPA does not rate heavy-duty trucks for fuel economy. Because historical values for medium and heavy trucks reflect on-road fuel economies, the fuel economy degradation factor must be indexed so that the value in 1992 is equal to one.

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

$$FUEL_{T,SEC,SC,AGE,FUEL,FLT} = \frac{VMT_{T,SEC,SC,AGE,FUEL,FLT}}{MPG_{T,SEC,SC,AGE,FUEL} \cdot MPGDEGFAC_{T,SC}} \qquad \textbf{(222)}$$

where:

FUEL = Total freight truck fuel consumption by sector, size class and fuel type in year *T*, in gallons of gasoline equivalent

$MPGDEGFAC_{T,SC}$ = Fuel economy degredation factor, overwritten in the code by 0.99.

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

$$TRIL_{T,SEC,SC,FUEL,FLT} = \sum_{AGE=0}^{11} FUEL_{T,SEC,SC,AGE,FUEL,FLT} \cdot HTRATE \cdot 10^{-6} \qquad \textbf{(223)}$$

where:

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

6. Roll Truck Population and Fuel Economy

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

$$MPG_{T+1,SC,SGE=10,FUEL} = \frac{\sum_{FLT=1}^{2} \sum_{AGE=10}^{11} \sum_{SEC=1}^{12} VMT_{T,SEC,SC,AGE,FUEL,FLT}}{\sum_{FLT=1}^{2} \sum_{AGE=10}^{11} \sum_{SEC=1}^{12} FUEL_{T,SEC,SC,AGE,FUEL,FLT}} \qquad \textbf{(224)}$$

where:

AGE = 10 refers to trucks in the tenth vintage, i.e., trucks which are ten years old during model run year *t*

AGE = 11 refers to trucks in the eleventh vintage, i.e., trucks which are eleven years old or older during model run year *t*

T+1 = refers to the next model run year

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

$$TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} + TRKSTK_{T,SEC,SC,AGE=11,FUEL,FLT} \qquad \textbf{(225)}$$

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

3E-2. Rail Freight Model

Rail forecasts represent a simplification of the freight trucking approach, in that only one class of freight rail and vehicle technology is considered. Projections of energy use by rail are driven by forecasts of ton-miles travelled for each of the industrial categories used in the trucking sector. The algorithm is virtually identical to the one used for trucks:

$$RTMT_T = \sum_{I=1}^{10} RTMT_{I,T_0} \cdot FACR_I \cdot \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_0}}\right] \qquad \textbf{(226)}$$

where:

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

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

$$TQRAILT_T = FERAIL_T \cdot RTMT_T \qquad \textbf{(227)}$$

where:

TQRAILT = Total energy consumption by freight trains
FERAIL = Rail energy efficiency

where rail efficiency gains resulting from technological development and increased system efficiency are based on an exogenous analysis of trends.

This aggregate energy demand is used to estimate the demand for the various fuels used for rail transport, adjusting the previous year's demand for a given fuel by the fractional increase in overall energy requirements:

$$TQRAIL_{FUEL,T} = TQRAIL_{FUEL,T-1} \cdot \left(\frac{TQRAILT_T}{TQRAILT_{T-1}} \right) \quad \textbf{(228)}$$

where:

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

This is based on the assumption that the relative shares of each fuel remains constant across the forecast horizon, and that there is little or no room for fuel substitution as prices vary.

Fuel consumption is then allocated to each region:

$$TQRAILR_{TECH,R,T} = TQRAIL_{C,TECH,T} \cdot SEDSHRDS_{C,TECH,T} \quad \textbf{(229)}$$

where:

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

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

3E-3. Waterborne Freight Model

Two classes of waterborne transit are considered in this component: domestic marine traffic and freighters conducting foreign trade. This is justified on the grounds that vessels which comprise freighter traffic on rivers and in coastal regions have different characteristics than those which ply international waters.

<u>Domestic Marine</u>

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

$$STMT_T = \sum_{I=1}^{10} STMT_{I,T_0} \cdot FACS_I \cdot \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_0}} \right] \quad \textbf{(230)}$$

where:

STMT = Total ton-miles of waterborne freight for industry I in year T

OUTPUT = Value of output of industry I, in base year dollars

FACS = Coefficient relating growth of value added with growth of shipping transport

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

$$STMT_{C,T} = TS_{C,T} \cdot STMT_T \tag{231}$$

where:

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

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

$$TS_C = \frac{STMT_C}{STMT_{Total}} \tag{232}$$

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

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

$$SFDT_T = FESHIP_T \cdot STMT_T \tag{233}$$

where:

SFDT = Domestic ship energy demand
FESHIP = Average fuel efficiency

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

$$SFD_{IF,T} = SFDT_T \cdot SFSHARE_{IF,T} \tag{234}$$

where:

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

The factor which allocates energy consumption among the three fuel types is based on 1990 AEO numbers and is held constant throughout the run period.

Total energy demand is then regionalized:

$$TQSHIPR_{IF,REG,T} = SFD_{IF,T} \cdot SEDSHR_{IF,REG,T} \qquad \textbf{(235)}$$

where:

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

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

International Marine

Fuel demand in international marine shipping is directly estimated, linking the level of international trade with the lagged consumption of the fuel in question:

$$ISFDT_T = ISFDT_{T-1} + \left[\frac{GROSST_T}{GROSST_{T-1}} - 1 \right] \cdot O.5 \cdot ISFDT_{T-1} \qquad \textbf{(236)}$$

where:

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

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

$$ISFD_{IF,T} = ISFDT_T \cdot ISFSHARE_{IF,T} \qquad \textbf{(237)}$$

where:

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

Regional fuel consumption is then calculated:

$$TQISHIPR_{IF,IR,T} = ISFD_{IF,T} \cdot SEDSHR_{IF,IR,T} \qquad \textbf{(238)}$$

where:

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

Figure 3E-2. Highway Freight Model

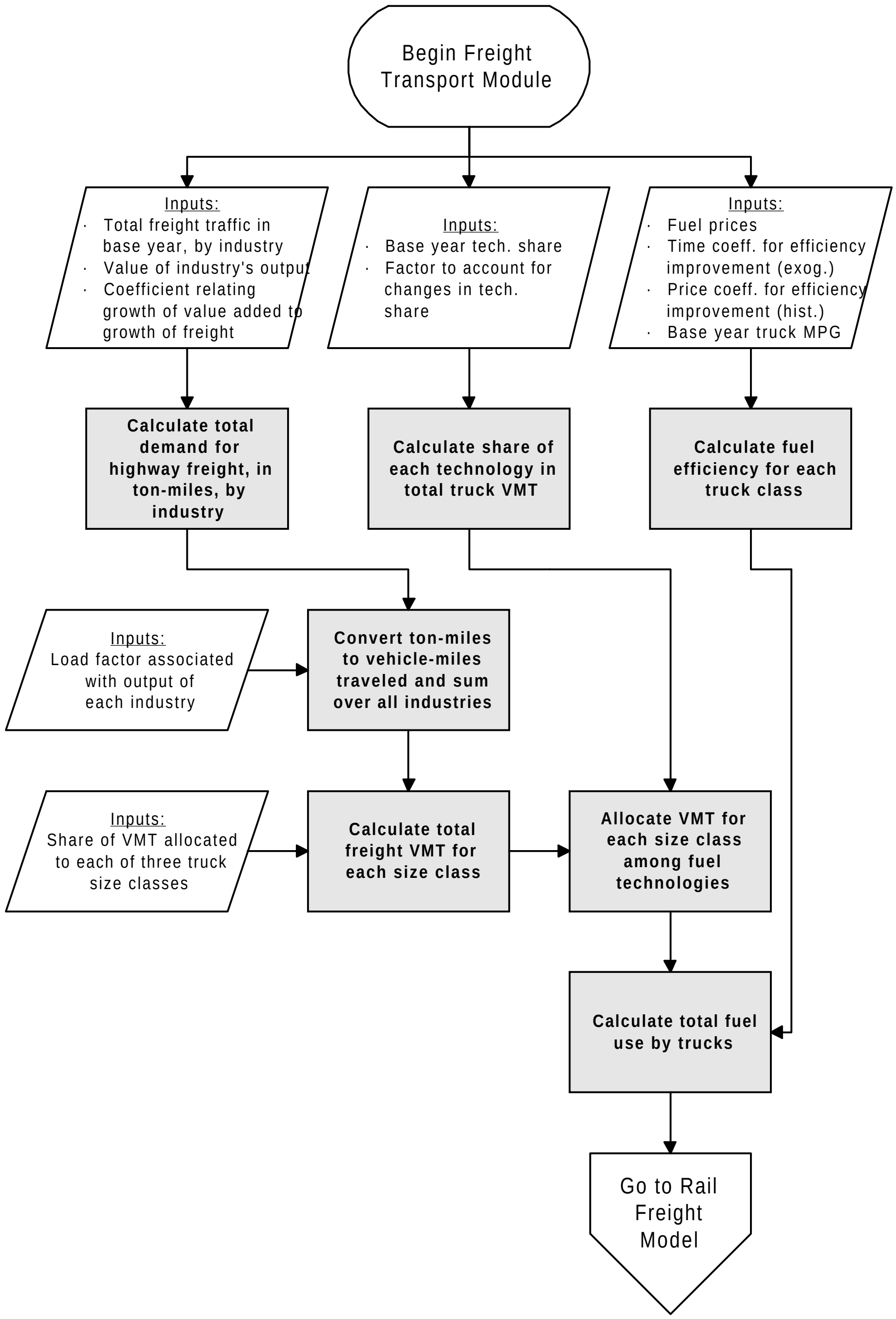


Figure 3E-3. Rail Freight Model

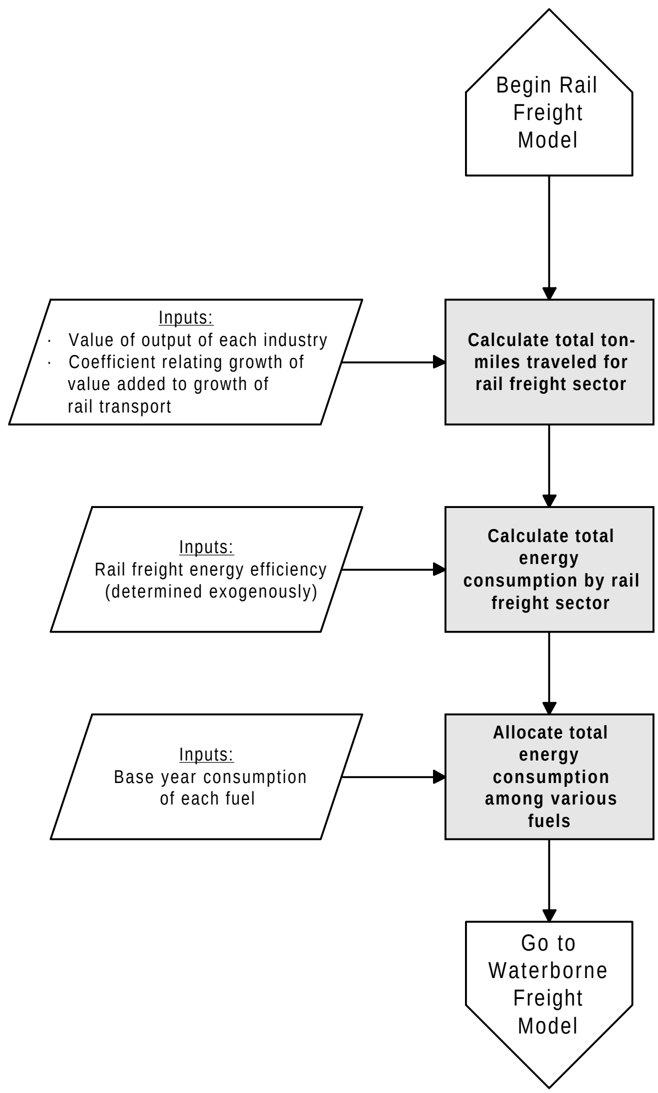
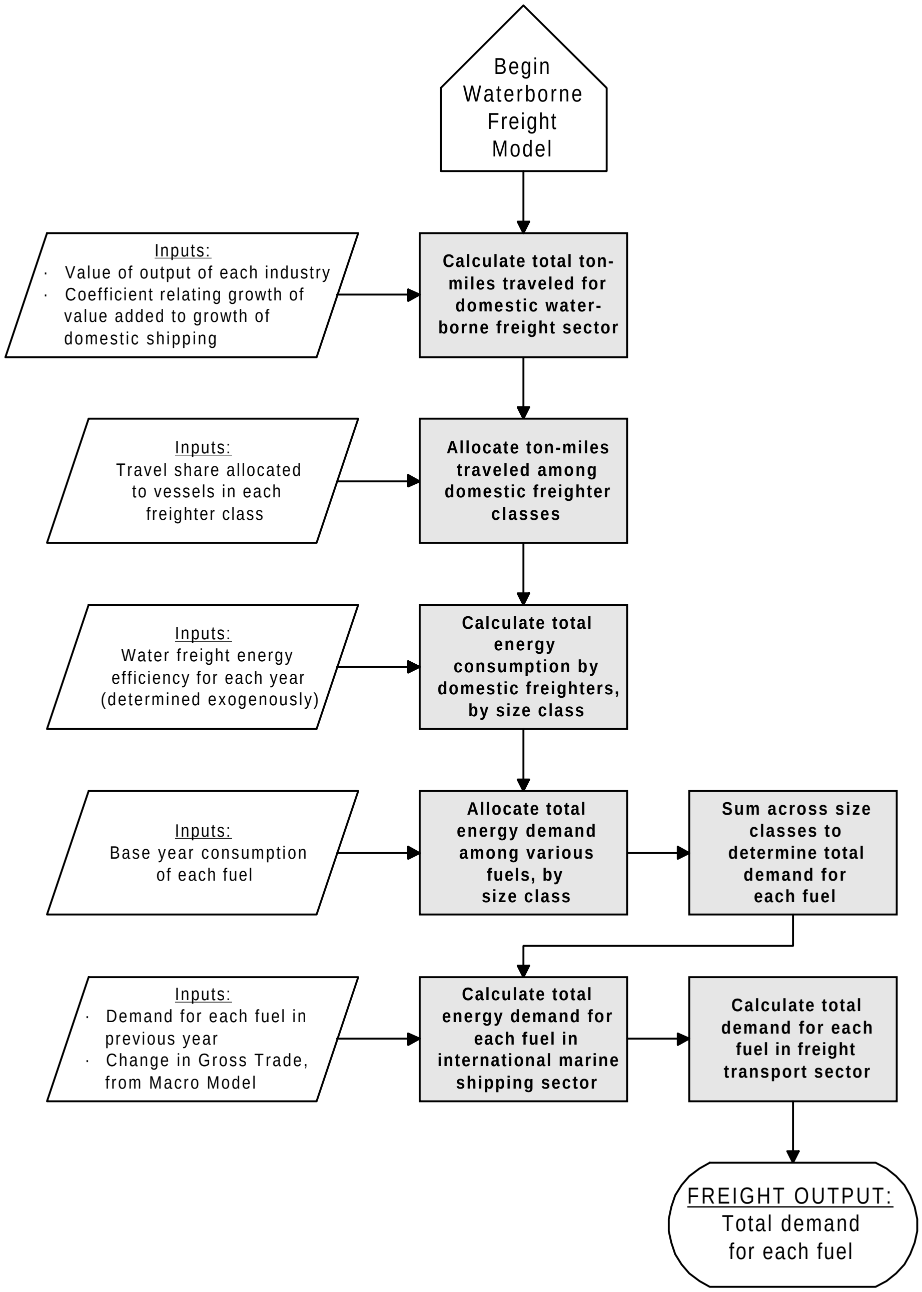


Figure 3E-4. Waterborne Freight Model



3F. Miscellaneous Energy Use Module

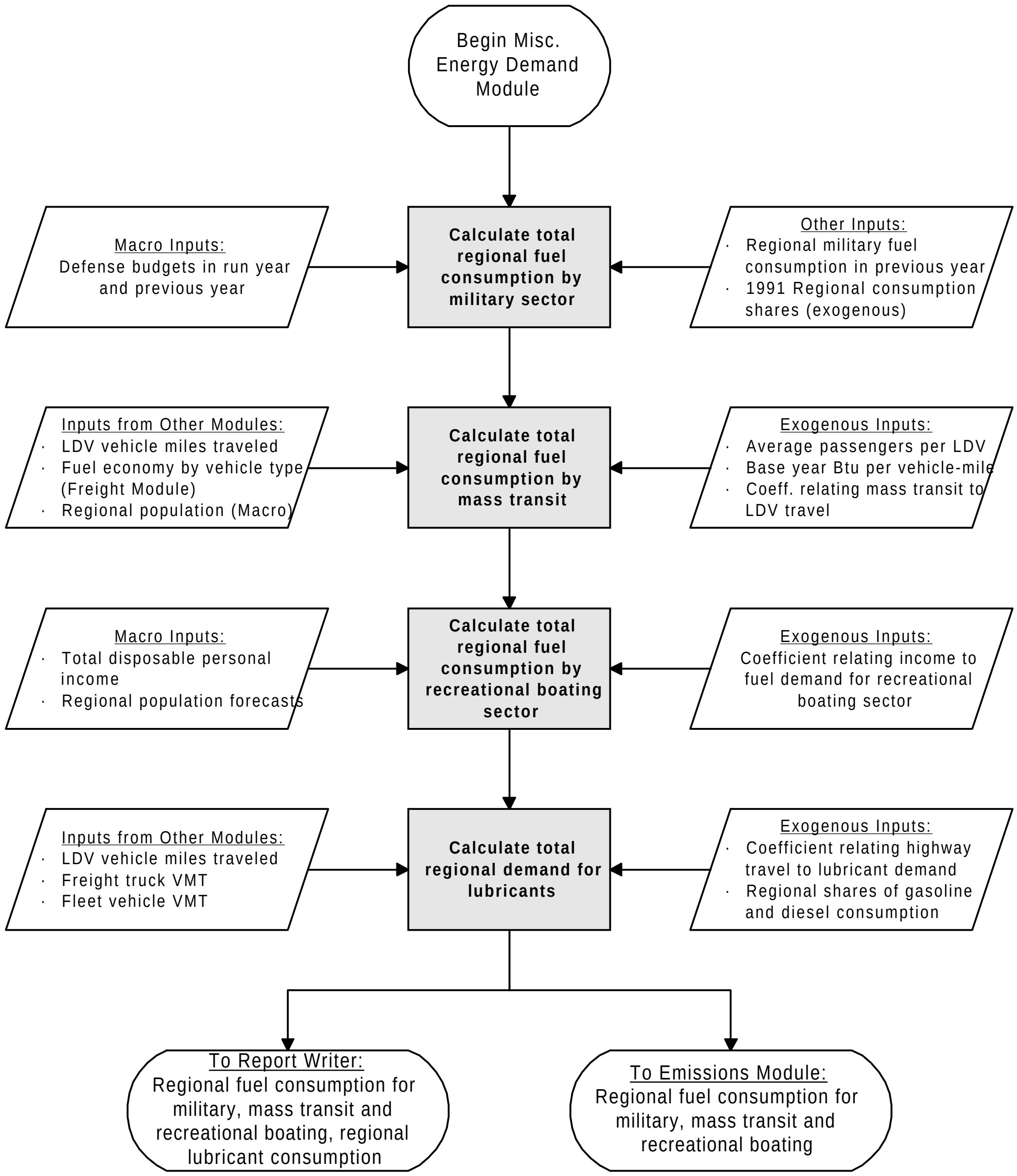
RATIONALE

This module addresses the projection of demand for several transportation fuels and end-use categories that have not been considered in earlier modules. These energy uses include military operations, mass transit (passenger rail and buses), recreational boating, and lubricants used in all modes of transportation. The NEMS approach represents an incremental improvement over the estimation methodology used in the predecessor AEO model.

In determining the impact of military operations, the predecessor model makes adjustments to energy consumption on a fuel-by-fuel bases to reflect recent military consumption levels. These levels are then assumed to remain constant over the forecast. In contrast, the NEMS model uses military budget estimates to forecast changes in fuel demand. In the public transit sector, the predecessor model does not explicitly consider passenger rail, which accounts for approximately fifteen percent of total rail energy consumption, or buses, which account for approximately one percent of total highway fuel consumption; energy use for each of these modes is considered as part of the benchmarking process, as is fuel use in recreational boats. NEMS models these sectors explicitly.

The flowchart for the Miscellaneous Energy Demand Module is presented below. Additional flowcharts portraying Miscellaneous Energy Demand Module calculations in more detail can be found at the end of this section.

Figure 3F-1. Miscellaneous Energy Demand Module



MODEL STRUCTURE

3F-1. Military Demand Model

Demand for fuel for military operations is considered to be proportional to the projected military budget. The fractional change in military budget is first calculated:

$$MILTARGR_T = \frac{TMC\_GFML87_T}{TMC\_GFML87_{T-1}} \tag{239}$$

where:

MILTARGR = The growth in the military budget from the previous year
TMC_GFML87 = Total defense budget in year T, from the macro economic segment of NEMS

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

$$MFD_{IF,T} = MFD_{IF,T-1} * MILTARGR_T \tag{240}$$

where:

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

Consumption is finally distributed among the nine census regions:

$$QMILTR_{IF,REG} = MFD_{IF,T} * MILTRSHR_{IF,REG} \tag{241}$$

where:

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

3F-2. Mass Transit Demand Model

The growth of passenger-miles in each mode of mass transit is assumed to be proportional to the growth of passenger-miles in light duty vehicles. This is determined from the output of the VMT module and the load factor for LDV's, held constant at 1989 levels:

$$TMOD_{1,T} = VMTEE_T * TMLOAD89_1$$

and:

$$TMOD_{IM,T} = TMOD_{IM,T-1} * \left[\frac{TMOD_{1,T}}{TMOD_{1,T-1}}\right]^{BETAMS} \tag{242}$$

where:

TMOD = Passenger-miles traveled, by mode
VMTEE = LDV vehicle-miles traveled, from the VMT module
TMLOAD89 = Average passengers per vehicle, by mode (1=LDV's)
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:

$$TMEFFL_{IM,T} = \frac{\left[TMEFF89_{IM} * \left(\frac{FMPG_{TYPE,T}}{FMPG89_{TYPE}}\right)\right]}{TMLOAD89_{IM}} \tag{243}$$

where:

TMEFFL = Btu per passenger-mile, by mass transit mode
TMEFF89 = Base-year Btu per vehicle-mile, by mode
FMPG = Fuel efficiency, by vehicle type, from the Freight Module
FMPG89 = Base-year fuel efficiency, by vehicle type, from the Freight Module
TYPE = Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail

Total fuel consumption may then be calculated and distributed among regions according to their populations:

$$QMODR_{IM,IR,T} = TMOD_{IM,T} * TMEFFL_{IM,T} * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}}\right] \tag{244}$$

where:

QMODR = Regional consumption of fuel, by mode
TMC_POPAFO = Regional population forecasts, from the Macro Module

3F-3. Recreational Boating Demand Model

The growth in fuel use by recreational boats is considered to be proportional to the growth in disposable personal income:

$$RECFD_T = RECFD_{T-1} * \left[\frac{TMC\_YD_T}{TMC\_YD_{T-1}} \right]^{BETAREC} \quad \textbf{(245)}$$

where:

RECFD = National recreational boat gasoline consumption in year T
TMC_YD = Total disposable personal income, from the Macro Module
BETAREC = Coefficient of proportionality relating income to fuel demand for boats

Regional consumption is calculated according to population, as with mass transit, above:

$$QRECR_{IR,T} = RECFD_T * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \quad \textbf{(246)}$$

where:

QRECR = Regional fuel consumption by recreational boats in year T

3F-4. Lubricant Demand Model

The growth in demand for lubricants is considered to be proportional to the growth in highway travel by all types of vehicles. Total highway travel is first determined:

$$HYWAY_T = VMTEE_T + FTVMT_T + FLTVMT_T \quad \textbf{(247)}$$

where:

HYWAY = Total highway VMT
FTVMT = Total freight truck VMT, from the Freight Module
FLTVMT = Total fleet vehicle VMT, from the Fleet Module

Lubricant demand is then estimated:

$$LUBFD_T = LUBFD_{T-1} * \left[\frac{HYWAY_T}{HYWAY_{T-1}}\right]^{BETALUB} \quad \textbf{(248)}$$

where:

LUBFD = Total demand for lubricants in year T
BETALUB = Constant of proportionality, relating highway travel to lubricant demand

Regional allocation of lubricant demand is finally determined by regional weighting of all types of highway travel:

$$QLUBR_{IR,T} = LUBFD_T * \left[\frac{\left(\left(VMTEE_T + FLTVMT_T\right) * SHRMG_{IR,T}\right) + \left(FTVMT_T * SHRDS_{IR,T}\right)}{HYWAY_T}\right] \quad \textbf{(249)}$$

where:

QLUBR = Regional demand for lubricants in year T, in Btu
SHRMG = Regional share of motor gasoline consumption, from SEDS
SHRDS = Regional share of diesel consumption, from SEDS

Figure 3F-2. Military Demand Model

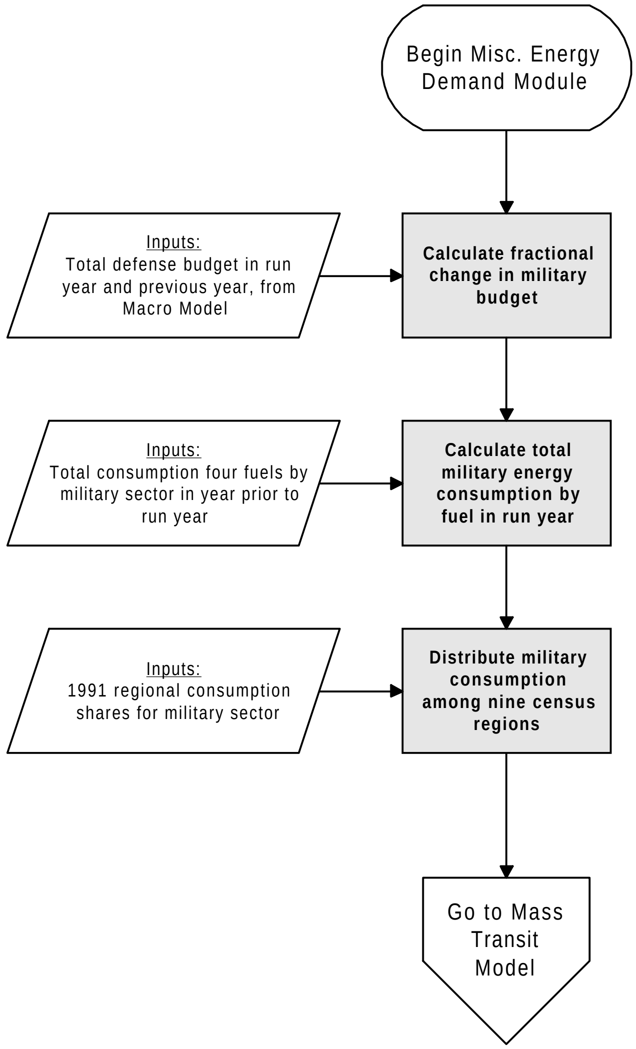


Figure 3F-3. Mass Transit Demand Model

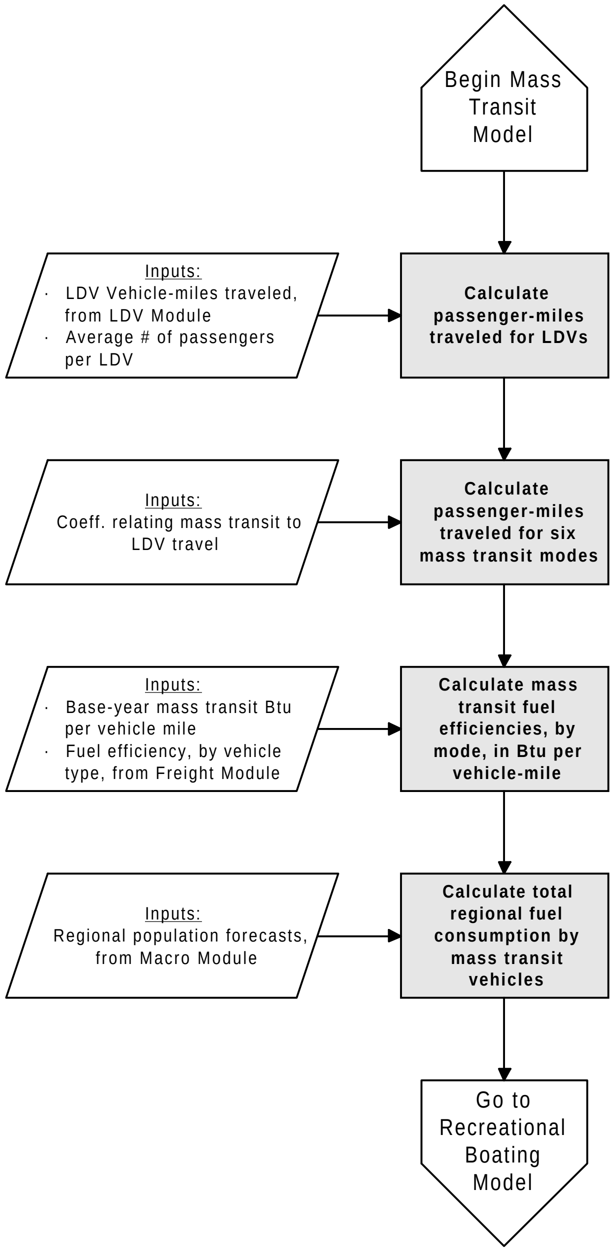


Figure 3F-4. Recreational Boating Demand Model

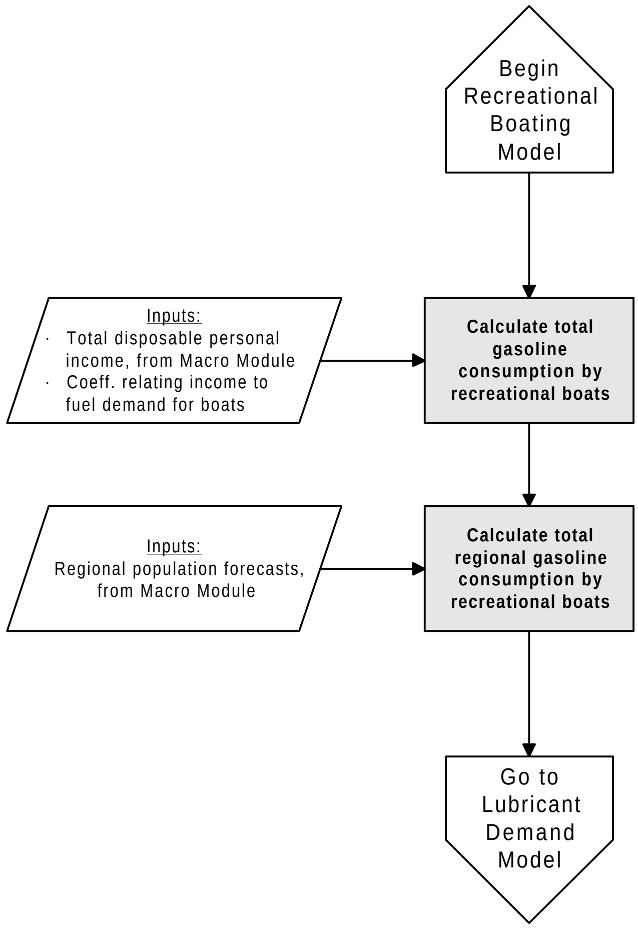
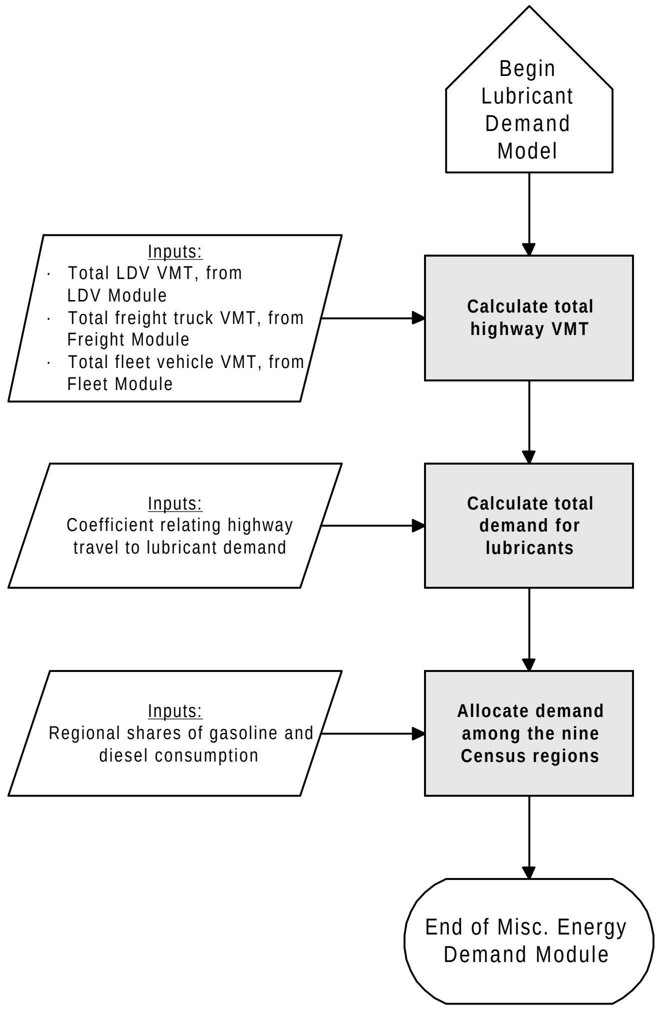


Figure 3F-5. Lubricant Demand Model



3G. Vehicle Emissions Module

RATIONALE

Vehicular emissions at the national level account for roughly two-fifths of total Carbon and NO_x emissions. This importance is reflected in the prominent role vehicles have in the Clean Air Act Amendment of 1990 (CAA90). This module reports vehicular emissions based on both the mix of vehicle technologies utilized over time, and the age distribution of these vehicles. This is a significant improvement over the predecessor model, which does not keep track of the level of emissions associated with vehicles. In NEMS, emissions from new, conventionally powered, light-duty vehicles decline over time in accordance with the provisions of the CAA90. Emissions may decline even further as alternative sources of energy and new technologies are utilized by light-duty vehicles. Direct emissions from battery-powered vehicles, for example, are zero. Specific pollutants addressed in this module include SO_x, NO_x, total Carbon, CO_2, CO, and Volatile Organic Compounds (VOC).

MODEL STRUCTURE

The solution algorithm consists of multiplying levels of travel by appropriate average emission factors for each mode of travel. Emission factors depend on the mix of technologies and fuels utilized within a mode. For example, the emission factor used for light-duty vehicles depends on the miles traveled utilizing each light-duty vehicle technology and fuel combination (see chapter 2). Even if no change occurs in the mix of technologies utilized in light-duty vehicles, emissions per vehicle-mile traveled will decline in the forecast as more stringent standards are phased in and older more polluting vehicles leave the fleet. It should be noted that the emissions factors implicitly reflect the effect of fuel efficiency improvements on carbon (including CO and CO_2) emissions and assume the compliance with increasingly stringent standards concerning other criteria pollutants. In the equation below, light-duty vehicle and freight truck emissions are estimated in units of grams of pollutant per mile of travel to be consistent with the definitions of vehicle emission standards.

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T} \tag{250}$$

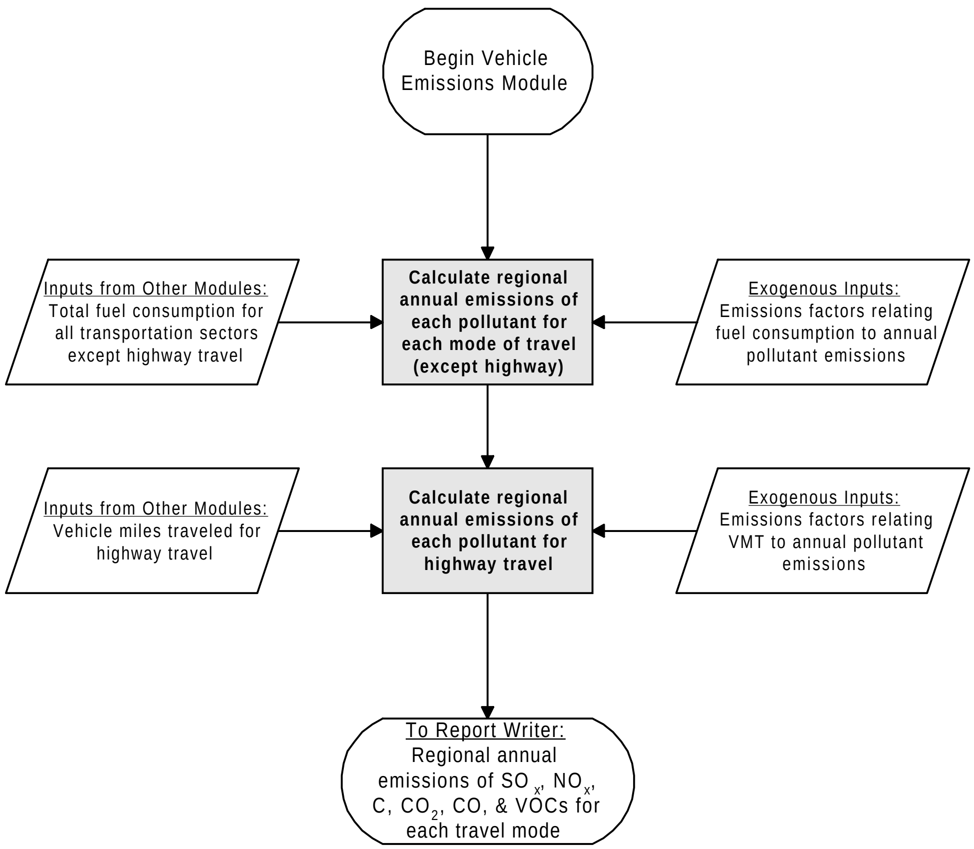
where:

EMISS = Regional emissions of a given pollutant, by mode of travel
EFACT = Emissions factor relating measures of travel to pollutant emissions
U = Measure of travel demand, by mode: units in VMT for highway travel, gallons of fuel consumption for other modes
IM = Index of travel mode: references individual vehicle types used in the preceding modules

IE = Index of pollutants: 1 = SO_x, 2 = NO_x, 3 = C, 4 = CO_2, 5 = CO, 6 = VOC
IR = Index identifying census region

The development of the emissions factors is documented in Appendix F, Attachment 7.

Figure 3G-1. Vehicle Emissions Module



4. MAJOR ASSUMPTIONS

Overview

This section reveals the key underlying assumptions that are critical to the generation of the base case and four side cases. These sets of assumptions discuss the following issues: technology penetration, environmental legislation, efficiency standards, and other important drivers for the transportation demand model. The NEMS transportation model estimates energy consumption across the nine census regions and over ten fuel types. Each fuel type is modeled according to fuel-specific technology attributes applicable by transportation mode. Total energy consumption is modeled by seven aggregate modes of transport: light-duty vehicles (cars, light trucks, and vans), freight trucks, freight and passenger airplanes, freight rail, freight shipping, mass transit, and miscellaneous transport. Light-duty vehicle fuel consumption is further sub-divided into personal usage, and commercial fleet consumption.

Inputs From NEMS Macro Model

Macroeconomic sector inputs used in the NEMS Transportation Model consist of the following: Gross Domestic Product, industrial output by SIC code, personal disposable income, new car and light truck sales, total population, driving age population, total value of imports and exports, and the military budget.

Table 4-1. Macroeconomic Inputs to the Transportation Model

Macroeconomic Input	1990	1995	2000	2005	2010
New Car Sales (mil)	9.51	9.27	9.76	10.12	10.41
New Light Truck Sales (mil)	4.39	5.27	5.65	6.29	6.51
Driving Age Population (mil)	192.7	202.1	212.8	223.8	235.4
Total Population (mil)	250.3	263.6	275.6	287.1	298.9

Source: Energy Information Administration, AEO94 Forecasting System runs AEO94B.D1221934.

Light-Duty Vehicle Module

Fuel Economy Model

The fuel economy model utilizes 52 new technologies for each size class based on the cost-effectiveness of each technology, and an initial availability year. The discounted stream of fuel savings are compared to the marginal cost of each technology. The fuel economy module assumes the following:

- 4 year payback period on all fuel saving technologies.
- 10% real discount rate.
- Corporate Average Fuel Economy (CAFE) standards remain constant at 1993 levels.
- Expected future fuel prices are calculated based on an extrapolation of the growth rate between fuel prices three years and five years prior to the present year. This assumption is founded upon an assumed lead time of three to five years to significantly modify the vehicles offered by a manufacturer.
- Degradation factors used to convert EPA rated fuel economy to actual "on the road" fuel economy, are based on application of a logistic curve to the projections of three factors: increase in city/highway driving, higher congestion levels, and rising highway speeds.[51, 52] Automobile and light truck degradation factors are assumed to be the same over time.

Regional Sales Model

The vehicle sales share section holds vehicle sales shares by import and domestic manufacturers constant within a vehicle size class benchmarked to 1990 Oak Ridge National Laboratory data.[53]

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[51] Maples, John D., "The Light-Duty Vehicle MPG Gap: It's Size Today and Potential Impacts in the Future," University of Tennessee Transportation Center, Knoxville, TN, May 28, 1993, Draft.

[52] Decision Analysis Corporation of Virginia, "Fuel Efficiency Degradation Factor," Final Report, Subtask 1, prepared for: Energy Information Administration, August 3, 1992.

[53] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

Table 4-2. Car and Light Truck Fuel Economy Degradation Factors

1990	2000	2005	2010
.854	.832	.823	.817

Source: Decision Analysis Corporation of Virginia, "Fuel Degradation Factor," Final Report, Subtask 1, prepared for: Energy Information Administration, August 3, 1992.

Alternative-Fuel Vehicle Model

The alternative-fuel technology choice model utilizes a discrete choice specification, which uses vehicle attributes as inputs, and forecasts vehicle sales shares among the following sixteen light-duty technologies: gasoline internal combustion engine (ICE), diesel ICE, ethanol flex, ethanol neat, methanol flex, methanol neat, electric dedicated (only uses electricity), electric hybrid with large ICE, electric hybrid with small ICE, electric hybrid with gas turbine, compressed natural gas (CNG), liquid petroleum gas (LPG), gas turbine gasoline, gas turbine CNG, fuel cell methanol, and fuel cell liquid hydrogen. Listed below are a few examples of the inputs variables that correspond to the vehicle attributes used in the analysis. With the exception of vehicle fuel economy, all other attributes are exogenously set based on offline analysis.[54]

Vehicle attributes vary by three size classes, and fuel availability varies by census division. However, all vehicle attributes correspond to prototype vehicles. It is assumed that once the logit model estimates future sales shares, these shares are applicable to both cars and light trucks. Vehicle prices are assumed to represent mass production prices. All alternative-fuel vehicle fuel efficiencies are calculated relative to conventional gasoline MPG. It is assumed that fuel efficiency improvements to conventional vehicles will be transferred to alternative-fuel vehicles.[55] Specific individual alternative-fuel technological improvements are handled separately by varying the fuel efficiency index over time. Commercial availability estimates are assumed values according to a logistic curve based on the initial technology introduction date, and were constructed in cooperation with the DOE Office of Efficiency and Renewable Energy. Model coefficients summarizing consumer valuation of vehicle attributes were derived from a stated preference survey conducted in California, and are assumed to be representative of the U.S.

[54] Science Applications International Corporation, "Alternative-Fuel Vehicle Module Database," Draft Report, Subtask 4, Prepared for Energy Information Administration, September 15, 1992.

[55] Energy and Environmental Analysis, K.G. Duleep, intial coefficients for alternative-fuel vehicles relative to conventional were used from the Department of Energy, Office of Policy Analysis IDEAS Model.

Table 4-3. Alternative-Fuel Vehicle Attributes For Three-Stage Logit Model

		Small Vehicle Size Class					
		Gasoline	**Ethanol Flex**	**Methanol Flex**	**CNG**	**Electric Vehicle Hybrid**	**Dedicated Electric Vehicle**
Vehicle Price (1990 $)	1990	$8,200	$12,700	$12,900	$10,950	$58,200*	$53,200 *
	2010	$12,180	$12,850	$13,050	$13,230	$22,800*	$22,340*
Vehicle MPG Relative to Gasoline	1990	1.000	1.055	1.095	0.960	1.419	1.541
	2010	1.000	1.060	1.130	0.950	1.380	1.520
Vehicle Range (miles)	1990	350	260	220	225	225	108
	2010	427	317	268	275	305	146
Fuel Availa-bility Relative to Gasoline	1990	1.00	0.01	0.01	0.01	0.05	0.05
	2010	1.00	0.06	0.06	0.06	1.00	1.00
Emission Level Relative to Gasoline	1990	1.00	0.73	0.60	0.51	0.16	0.00
	2010	1.00	1.19	1.27	0.87	1.71	0.01
Commercial Availability Relative to Gasoline	1990	1.00	0.00	0.01	0.00	0.01	0.00
	2010	1.00	0.25	0.50	0.06	0.81	0.09

* Electric vehicle battery replacement cost included.

Source: Science Applications International Corporation, "Alternative-Fuel Vehicle Module Database," Draft Report, Subtask 4, Prepared for the Energy Information Administration, September 15, 1992.

The Low Emission Vehicle Program (LEVP) which began in California, has now been instituted in New York and Massachusetts. The following Zero Emission Vehicle (ZEV) and Ultra Low Emission Vehicle (ULEV) sales numbers come from the California Air Resource Board.[56] In the low world oil price case and the base case scenarios, only the ZEV sales shares are used. With the high world oil price scenario, the ZEV and one half of the ULEV sales shares are included. Only half of the ULEV sales were included, because there is uncertainty with respect to meeting the ULEV air

[56] California Air Resources Board, "Proposed Regulations for Low-Emission Vehicles and Clean Fuels, Staff Report," August 13, 1990.

standards with reformulated gasoline and a heated catalytic converter. The AFV model compares these legislative mandated sales to the results from the alternative-fuel vehicle logit market driven sales shares. The legislative mandated sales serve as a minimum constraint to alternative-fuel vehicle sales.

Table 4-4. California Low Emission Vehicle Program Sales Mandates (Percentage of all LDV Sales)

	Ultra Low Emission Vehicles (ULEV)	Zero Emission Vehicles (ZEV)
1997	2%	-
1998	2%	2%
1999	2%	2%
2000	2%	2%
2001	5%	5%
2002	10%	5%
2003	15%	10%

Source: California Air Resources Board, "Proposed Regulations for Low-Emission Vehicles and Clean Fuels, Staff Report," August 13, 1990.

Light Duty Vehicle Stock Module

Vehicle-Miles Traveled Model

The vehicle-miles traveled (VMT) model forecasts VMT as a function of the cost of driving per mile, income per capita, ratio of female to male VMT, and age distribution of the driving population. The ratio of female to male VMT is assumed to asymptotically approach 72 percent by 2010. Total VMT is calibrated to Federal Highway Administration (FHWA) VMT data.[57]

Light Duty Vehicle Fleet Module

With the current focus of transportation legislation on commercial fleets and their composition, the

[57] U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 1990, FHWA-PL-91-003, 1990.

NEMS Transportation Model has been designed to divide commerical fleets into three types of fleets: business, government, and utility. Based on this classification, commercial fleet vehicles vary in survival rates and duration in the fleet, before being folded back into the personal vehicle stock.

Sales shares of fleet vehicles by fleet type remain constant over the forecast period. Automobile fleets are divided into the following shares: business (85.59%), government (7.09%), and utilities (7.27%). Both car (23.17%) and light truck (13.95%) fleet sales are assumed to be a constant fraction of total vehicle sales.[58]

Alternative-fuel shares of fleet sales by fleet type are initially set according to historical shares, then compared to a minimum constraint level of sales based on legislative initiatives such as the Energy Policy Act, and the Low Emission Vehicle Program.[59, 60] Size class sales of alternative-fuel and conventional vehicles are held constant at historical levels.[61]

Individual sales shares of alternative-fuel fleet vehicles by technology type are assumed to remain at historical levels for utility and government fleets, but vary for business fleets in accordance with the technology shares applied in the personal vehicle stocks. Annual VMT per vehicle by fleet type stays constant over the forecast period based on ORNL fleet data. Fleet fuel economy for both conventional and alternative-fuel vehicles are assumed to be the same as the personal vehicle new vehicle fuel economy, and is subdivided into three size classes.

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[58] Oak Ridge National Laboratory, Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices , Prepared for Department of Energy, Office of Transportation Technologies, and Office of Policy, Planning, and Analysis, March 1992.

[59] U.S. Department of Energy, Office of Domestic and International Energy Policy, "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Ten: Analysis of Alternative-Fuel Fleet Requirements," May 1992.

[60] California Air Resources Board, "Proposed Regulations for Low-Emission Vehicles and Clean Fuels, Staff Report," August 13, 1990.

[61] Oak Ridge National Laboratory, Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices , Prepared for Department of Energy, Office of Transportation Technologies, and Office of Policy, Planning, and Analysis, March 1992.

Table 4-5. Commercial Fleet Size Class Shares By Fleet and Vehicle Type

Fleet Type by Size Class	Automobiles	Light Trucks
Business Fleet		
Small	4.55	37.34
Medium	71.59	37.90
Large	23.86	24.76
Government Fleet		
Small	4.35	21.34
Medium	56.52	44.39
Large	39.13	34.27
Utility Fleet		
Small	16.67	30.03
Medium	70.00	38.51
Large	13.33	31.46

Source: Oak Ridge National Laboratory, Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices, Prepared for the Department of Energy, Office of Transportation Technologies, and Office of Policy, Planning, and Analysis, March 1992.

Fleet alternative-fuel vehicle sales necessary to meet the Energy Policy Act of 1992 (EPACT) regulations, come from the DOE Office of Domestic and International Energy Policy.[62] Total projected alternative-fuel vehicle sales are divided into fleets by government, utility, business, and fuel providers. The business fleets represent one half of the DOE Office of Policy Analysis estimate, because it is assumed that only half of the business fleets are capable of being centrally fueled (re-fueled at the same location) as required by EPACT. Although inclusion of the business fleet is dependent upon a ruling making by the Secretary of Energy, the assumption is that fuel displacement goals set in EPACT can only be reached by inclusion of the business fleet.

[62] U.S. Department of Energy, Office of Domestic and International Energy Policy, "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Ten: Analysis of Alternative-Fuel Fleet Requirements," May 1992.

Table 4-6. EPACT Alternative-Fuel Vehicle Fleet Sale Estimates

	1990	1995	2000	2005	2010
Automobiles					
State & Local Gov't	0	0	0	85,538	92,149
Federal Gov't	0	5,000	10,692	13,365	13,365
Business	0	64,637	69,633	405,826	437,189
Fuel Provider	0	129,274	139,265	150,028	161,623
Light Trucks					
State & Local Gov't	0	0	0	19,612	21,128
Federal Gov't	0	5,000	10,692	13,365	13,365
Business	0	32,319	34,816	94,612	101,924
Fuel Provider	0	64,637	69,632	75,014	80,811

Source: U.S. Department of Energy, Office of Domestic and International Energy Policy, "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Ten: Analysis of Alternative-Fuel Fleet Requirements, May 1992.

Air Travel Module

Air Travel Demand Model

The air travel demand model calculates the ticket price for travel as a function of fuel cost and other operating costs. Non-fuel operating costs are assumed to remain constant across the forecast horizon.[63] A demographic index based on the propensity to fly was introduced into the air travel demand equation.[64] The propensity to fly was made a function of the age and sex group distribution over the forecast period.[65, 66] The air travel demand module assumes that these relationships between the groups and their propensity to fly remain constant over time. International revenue passenger

[63] U.S. Department of Transportation, Research and Special Programs Administration, Air Carrier Financial Statistics Quarterly and Monthly, December 1990/1989, and prior issues.

[64] Transportation Research Board, Forecasting Civil Aviation Activity: Methods and Approaches, Appendix A, Transportation Research Circular Number 372, June 1991.

[65] Decision Analysis Corporation of Virginia, Proposed Methodology For Projecting Air Transportation Demand, Final Report, Subtask 2, July 8, 1992.

[66] Air Transport Association of America, Air Travel Survey, Washington D.C., 1990.

miles is a fixed percentage of domestic revenue passenger miles based on historical data.[67] Load factors, represented as the average number of passengers per airplane, are assumed to remain constant over the forecast period.

Aircraft Fleet Efficiency Model

The aircraft fleet efficiency model consists of a stock model of both wide and narrow body planes by vintage. The shifting of passenger load between narrow and wide body aircraft takes place at a constant historical annual one percent rate.[68] The available seat-miles per plane, which measures the carrying capacity of the airplanes by aircraft type, remains constant and is based on holding the following constant within an aircraft type: airborne hours per aircraft per year, average flight speed, and the number of seats per aircraft.

The difference between the seat-miles demanded and the available seat-miles represent newly purchased aircraft. Aircraft purchases in a given year cannot change above historical annual growth rates, which sets an upper limit on the application of new aircraft to meet the gap between seat-miles demanded and available seat-miles. With a constraint on new aircraft purchases, it is assumed that when the gap exceeds histiorical aircraft sales levels planes that have been temporarily stored or retired will be brought back into service. Technological availability,

Table 4-7. Constant Available Seat-Miles Assumptions By Aircraft Type

Seat-Mile Variable	Narrow Body Aircraft	Wide-Body Aircraft
Airborne Hrs./Aircraft per yr.	2,383	3,336
Average Flight Speed (mph)	400	485
Number of Seats/Aircraft	126	296

Source: Federal Aviation Administration, FAA Aviation Forecasts, fiscal years 1991-2002, FAA-APO 90-1, and previous editions.

economic viability, and efficiency characteristics of new aircraft are based on the technologies listed in the Oak Ridge National Laboratory Air Tranportation Energy Model.[69, 70] Fuel efficiency of new

[67] U.S. Department of Transportation, U.S. International Air Travel Statistics, Transportation Systems Center, Cambridge, MA, annual issues.

[68] U.S. Department of Transportation, Federal Aviation Administration, FAA Aviation Forecasts Fiscal Years 1993-2004, February 1993.

[69] Oak Ridge National Laboratory, Energy Efficiency Improvement of Potential Commercial Aircraft to 2010, ORNL-6622, June 1990.

[70] Oak Ridge National Laboratory, Air Transport Energy Use Model, April 1991, Draft.

aircraft acquisitions represent at a minimum, a five percent improvement over the stock efficiency of surviving airplanes.[71] Maximum growth rates of fuel efficiency for new aircraft are based on a future technology improvement list based on an estimate of the introduction year, jet fuel price, and an estimate of the projected marginal fuel efficiency improvement.

Regional shares of all types of aircraft fuel are assumed to be constant, and are consistent with the State Energy Data Report estimate of regional jet fuel shares.[72]

Table 4-8. Future New Aircraft Technology Improvement List

Proposed Technology	Year of Intro-duction	Jet Fuel Price Necessary For Cost-Effectiveness (87$/Gal)	Seat-Miles per Gallon (SMPG) Gain Over 1990's	
			Narrow Body	Wide Body
ENGINES				
Ultra-high Bypass	1995	$0.69	10%	10%
Propfan	2000	$1.36	23%	0%
AERODYNAMICS				
Hybrid Laminar Flow	2020	$1.53	15%	15%
Advanced Aerodynamics	2000	$1.70	18%	18%
OTHER				
Weight Reducing Materials	2000	-	15%	15%
Thermodynamics	2010	$1.22	20%	20%

Source: Greene, D.L., Energy Efficiency Improvement Potential of Commercial Aircraft to 2010, ORNL-6622, 6/1990., and from data tables in the Air Transportation Energy Use Model (ATEM), Oak Ridge National Laboratory.

Freight Transport Module

Highway Freight Model

[71] U.S. Department of Transportation, Federal Aviation Administration, FAA Aviation Forecasts Fiscal Years 1993-2004, February 1993.

[72] Department of Energy, Energy Information Administration, State Energy Demand Survey, May 1993.

The freight truck model converts industrial output in dollar terms to an equivalent measure of volume by using a freight adjustment coefficient. These freight truck adjustment coefficients vary by industrial SIC code, but remain constant over time, and are estimated from historical freight data.[73, 74] Freight truck load factors (ton-miles per truck) by SIC code are constants formulated from historical load factors.[75] Growth of VMT in the retail sector is assumed to be proportional to growth in total industrial output. Growth of VMT in the construction sector is assumed to be proportional to the growth in total disposable income. All freight trucks are subdivided into light, medium, medium-heavy, and heavy-duty trucks. Freight truck fuel efficiency growth rates relative to fuel prices are tied to historical growth rates by size class.[76] VMT freight estimates by size class and technology are based on historical growth rates. Fuel consumption by freight trucks is regionalized according to the State Energy Data System 1991 distillate regional shares.[77]

Rail Freight Model

The rail freight model receives industrial output by SIC code measured in real 1987 dollars and converts these dollars into an adjusted volume equivalent. Rail freight adjustment coefficients, which are used to convert dollars into volume equivalents, remain constant and are based on historical data.[78, 79] Initial rail freight fuel efficiencies are based on the freight model from Argonne National Laboratory.[80] The distribution of rail fuel consumption by fuel type remains constant and is based on historical data.[81] Regional freight rail consumption estimates are distributed according to the State Energy Data Report 1991.[82]

Waterborne Freight Model

The waterborne freight model also converts industrial output by SIC code measured in dollars, to

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[73] Decision Analysis Corporation of Va., Freight Transportation Requirements Analysis For The NEMS Transportation Sector Model, Subtask 5, Prepared for Energy Information Administration, August 3, 1992.

[74] Reebie Associates, TRANSEARCH Freight Commodity Flow Database, Greenwich, Connecticutt.

[75] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[76] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[77] U.S. Department of Energy, Energy Information Administration, State Energy Demand Report 1991 , May 1993.

[78] Decision Analysis Corporation of Va., Freight Transportation Requirements Analysis For The NEMS Transportation Sector Model, Subtask 5, Prepared for Energy Information Administration, August 3, 1992.

[79] U.S. Department of Transportation, Federal Railroad Administration, 1989 Carload Waybill Statistics; Territorial Distribution, Traffic and Revenue by Commodity Classes, September 1991 and prior issues.

[80] Argonne National Laboratory, Transportation Energy Demand Through 2010, 1992.

[81] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[82] Department of Energy, Energy Information Administration, State Energy Demand Survey, May 1993.

a volumetric equivalent by SIC code.[83] These freight adjustment coefficients are based on analysis of historical data[84], and remain constant throughout the forecast period. Domestic shipping efficiencies are based on the freight model by Argonne National Laboratory.[85] The distribution of domestic and international shipping fuel consumption by fuel type remains constant throughout the analysis, and is based on historical data.[86] Regional domestic and international shipping consumption estimates are distributed according to the State Energy Data Report 1991 residual oil regional shares.[87]

Emissions Module

The NEMS Transportation model uses the same emissions coefficients by fuel type that are contained in the Industrial Sector Module Assumptions section.

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[83] Decision Analysis Corporation of Va., Freight Transportation Requirements Analysis For The NEMS Transportation Sector Model, Subtask 5, Prepared for Energy Information Administration, August 3, 1992.

[84] Army Corp of Engineers, Waterborne Commerce of the United States, Waterborne Statistics Center, New Orleans, La., 1991.

[85] Argonne National Laboratory, Transportation Energy Demand Through 2010, 1992.

[86] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[87] Department of Energy, Energy Information Administration, State Energy Demand Survey, May 1993.

Table 4-9. Distribution of Rail Fuel Consumption By Fuel Type

	Diesel Fuel	Electricity
FREIGHT	100%	0%
PASSENGER:		
Transit	0%	100%
Commuter	34%	66%
Intercity	73%	27%

Source: Oak Ridge National Laboratory, Transportation Energy Databook: Edition 13, March 1993.