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.

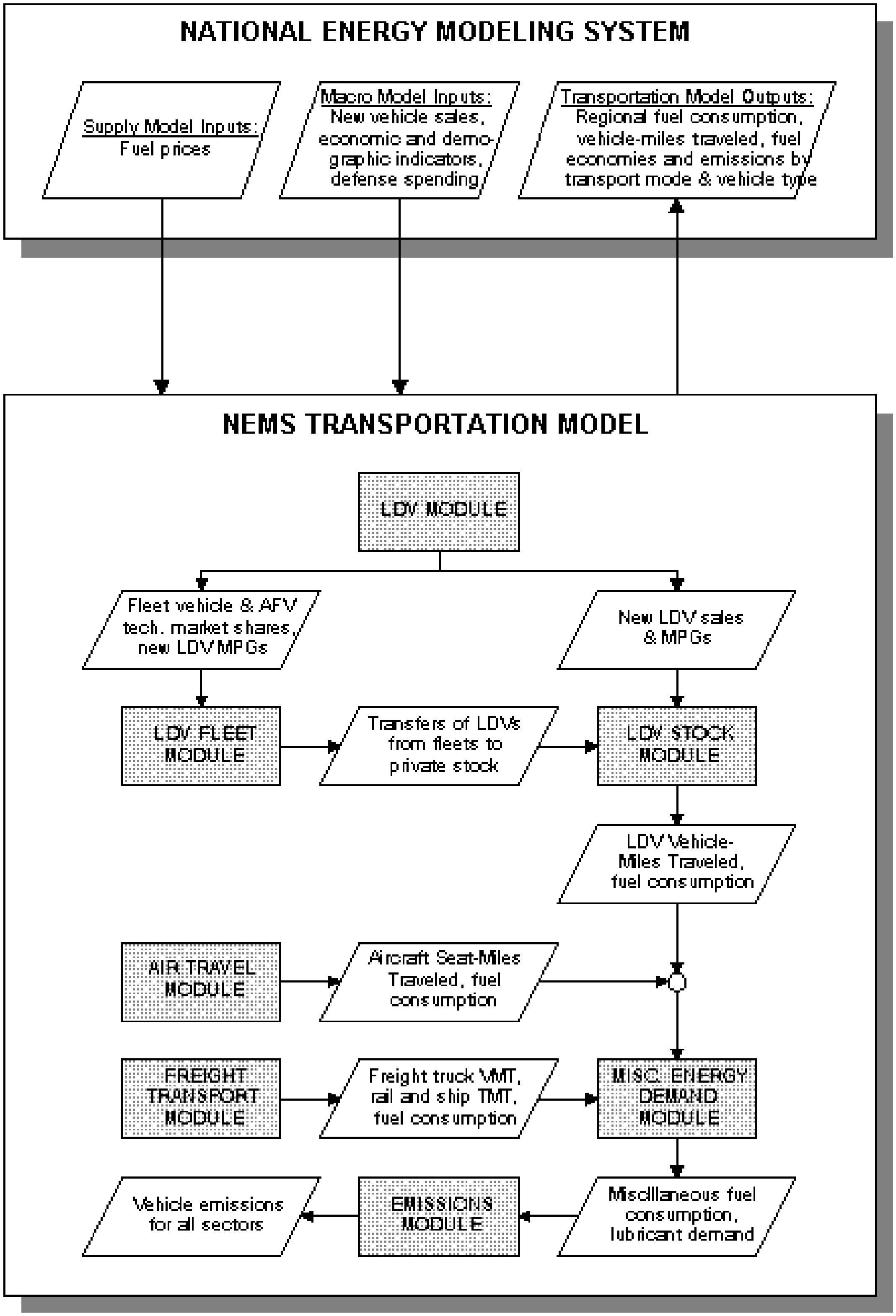
The LDV Stock Module uses vintage-dependent constants such as vehicle survival and relative driving rates, and fuel economy degradation factors to obtain estimates of stock efficiency.

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. Because of the disparate characteristics of the various classes of light duty vehicle, this model addresses the commercial viability of fifty-five separate technologies within each of fourteen vehicle market classes and four corporate average fuel economy (CAFE) groups. 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 dasses 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. 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. 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. The seven classes for cars and for light duty trucks are described in Appendix A, Table A-2. 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.

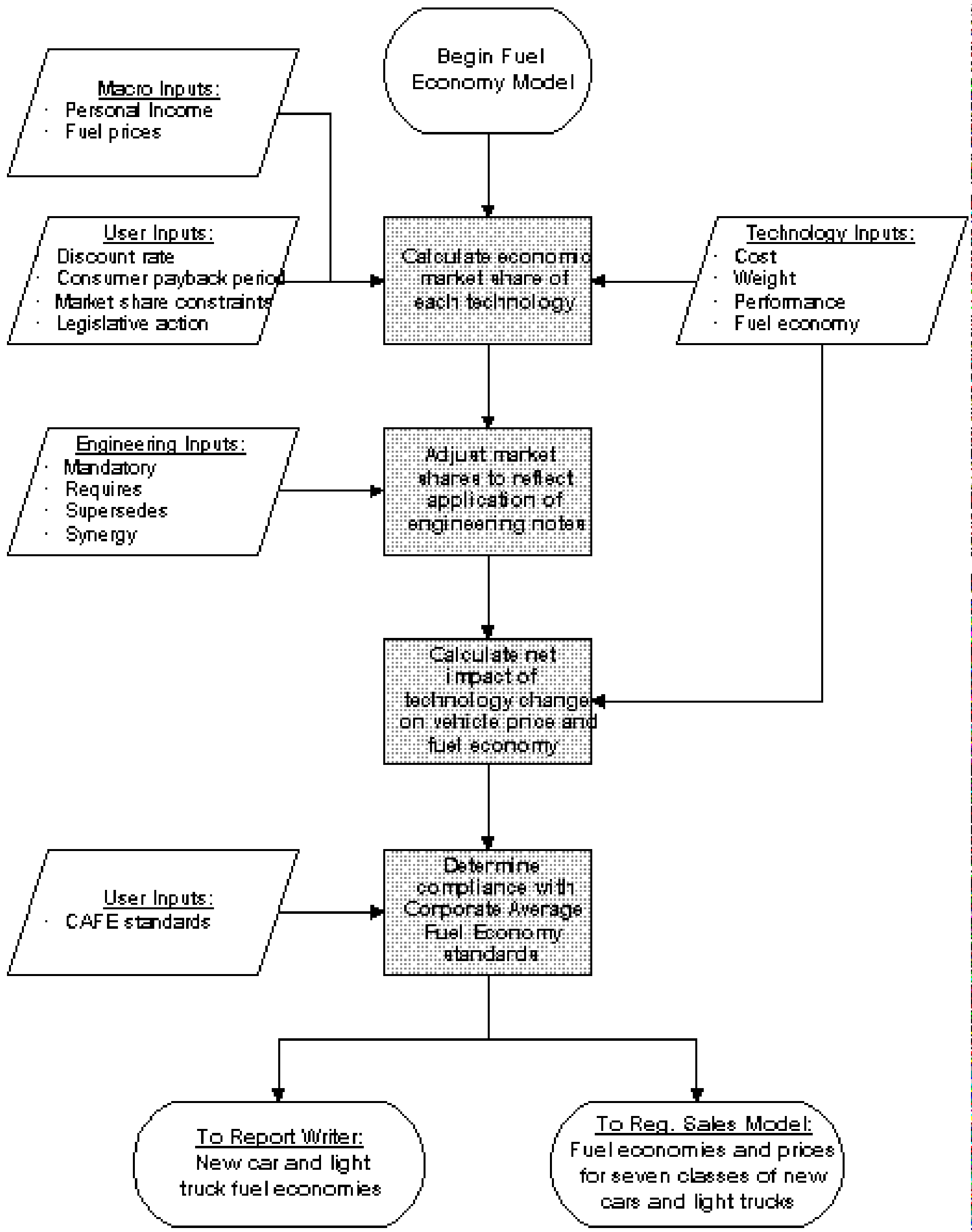
In certain cases there are adjustments which must be made to the calculated market shares. Some of these adjustments reflect engineering limitations to what may be adopted. Other adjustments reflect external forces that require certain types of technologies; safety and emissions technologies are both 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.

The Fuel Economy Model flowchart is presented in Figure 3A-1 below. In the interest of readability, more detailed flowcharts describing the order in which FEM calculations are made are presented at the end of Section 3A.

Figure 3A-1. Fuel Economy Model



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

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 and Class. In the interest of legibility, these

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[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.

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:

$$PSLOPE = \frac{MAX\ (0\ ,FUELCOST_{YEAR-3}\ -\ FUELCOST_{YEAR-5})}{2} \tag{1}$$

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

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

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

where:

VMT = Annual vehicle-miles traveled

itc = The index representing the technology under consideration

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{itc,YEAR-1}} - \frac{1}{(1 + DEL\$FE_{itc} * FE_{itc,YEAR-1})} \right) * PRICE\$EX_i * (1 + DISCOUNT)^{-i} \qquad (3)$$

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:

$$TECHCOST_{itc} = DEL\$COSTABS_{itc} - (DEL\$COSTWGT_{itc} * DEL\$WGTWGT_{itc} * WEIGHT_{BASEYR}) \qquad (4)$$

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:

$$VAL\$PERF_{itc} = VALUEPERF_{itc} * \frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} * \frac{FE_{YEAR-1} * (1 + DEL\$FE_{itc})}{FE_{YEAR-1}} * \frac{FUELCOST_{YEAR-1}}{PRICE\$EX_{1}} * DEL\$HP_{itc} \tag{5}$$

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:

$$COSTEFFECT_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + VAL\$PERF_{itc} + (REGCOST * FE_{YEAR-1} * DEL\$FE_{itc})}{ABS(TECHCOST_{itc})} \tag{6}$$

where:

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

and:

$$ACTUAL\$MKT_{itc} = MMAX_{itc} * PMAX_{itc} * \left(1 + e^{-2 \cdot COSTEFFECT_{itc}}\right)^{-1} \tag{7}$$

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:

$$ACTUAL\$MKT_{itc} = MAX(MKT\$PEN_{YEAR-1},\ ACTUAL\$MKT_{itc}) \tag{8}$$

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:

$$ACTUAL\$MKT_{itc} = MAX(ACTUAL\$MKT_{itc},\ MANDMKSH_{itc}) \tag{9}$$

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:

$$SUM\$MKT = ACTUAL\$MKT_A + ACTUAL\$MKT_B + ACTUAL\$MKT_C \qquad (10)$$

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

$$MMAX = MAX(MKT\$MAX_A\ ,\ MKT\$MAX_B\ ,\ MKT\$MAX_C) \qquad (11)$$

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*):

$$REQ\$MKT = \sum_{req}^{RQ} ACTUAL\$MKT_{req} \qquad (12)$$

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:

$$FE_{YEAR} = FE_{YEAR} + \left(MKT\$PEN_{itc1,YEAR} - MKT\$PEN_{itc1,YEAR-1} \right) * \left(MKT\$PEN_{itc2,YEAR} - MKT\$PEN_{itc2,YEAR-1} \right) * SYNR\$DEL_{itc1,itc2} \tag{13}$$

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:

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,YEAR} - MKT\$PEN_{itc,YEAR-1} \tag{14}$$

$DELTA\$MKT_{itc}$ 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:

$$FE_{YEAR} = FE_{YEAR} + \sum_{itc=1}^{NUMTECH} FE_{YEAR-1} * DELTA\$MKT_{itc} * DEL\$FE_{itc} \tag{15}$$

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.

$$WEIGHT_{YEAR} = WEIGHT_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \Big[DEL\$WGTABS_{itc} + \left(WEIGHT_{BASEYR} * DEL\$WGTWGT_{itc} \right) \Big] \tag{16}$$

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.

$$PRICE_{YEAR} = PRICE_{YEAR} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \left[DEL\$COSTABS_{itc} + (WEIGHT_{YEAR} - WEIGHT_{BASEYR}) * DEL\$COSTWGT_{itc} \right] \qquad (17)$$

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.

D: 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:

$$HP_{YEAR} = HP_{BASEYR} * \frac{WEIGHT_{YEAR}}{WEIGHT_{BASEYR}} \qquad (18)$$

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):

$$ADJHP = PERFFACT * \left[\left(\frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} \right)^{0.9} * \left(\frac{PRICE_{YEAR-1}}{PRICE_{YEAR}} \right)^{0.9} * \left(\frac{FE_{YEAR}}{FE_{YEAR-1}} \right)^{0.2} * \left(\frac{FUELCOST_{YEAR-1}}{FUELCOST_{YEAR}} \right)^{0.2} - 1 \right] \quad (19)$$

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:

$$HP_{YEAR} = HP_{YEAR} * \left(1 + \sum_{1990}^{YEAR} ADJHP \right) \quad (20)$$

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.

E: 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:

$$ADJFE = -0.22 * ADJHP - 0.560 * ADJHP^2 \tag{21}$$

Adjusted Fuel Economy

The final vehicle fuel economy is then determined as follows:

$$FE = FE * (1 + ADJFE) \tag{22}$$

Adjusted Vehicle Price

Vehicle price is finally estimated:

$$PRICE = PRICE + ADJHP * VALUEPERF \tag{23}$$

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 next step is to calculate the market shares of each vehicle class within each CAFE group.

CALCULATE CLASS MARKET SHARES

This routine calculates vehicle class market shares within each "corporate" average fuel economy group (i.e. Domestic Cars, Import Cars, Domestic Trucks and Import Trucks.) 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]

$$\ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR} - \$13{,}000}{INCOME_{1990} - \$13{,}000}\right) \quad (24)$$

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.

$$\ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR}}{INCOME_{1990}}\right) \quad (25)$$

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
4) Import Trucks

[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.

For each vehicle group the CAFE calculation proceeds as follows:

$$CAFE_{i,k,YEAR} = \frac{\sum_{i=1}^{7} CLASS\$SHARE_{i,k,YEAR}}{\sum_{i=1}^{7} \frac{CLASS\$SHARE_{i,k,YEAR}}{FE_{i,k,YEAR}}} \quad (26)$$

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.

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):

$$FE_{CLASS} = \left[\frac{.742}{FE_{CLASS,Domestic}} + \frac{.258}{FE_{CLASS,Import}} \right]^{-1} \quad (27)$$

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.

$$FE_{CLASS} = \left[\frac{.868}{FE_{CLASS,Domestic}} + \frac{.132}{FE_{CLASS,Import}} \right]^{-1} \quad (28)$$

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

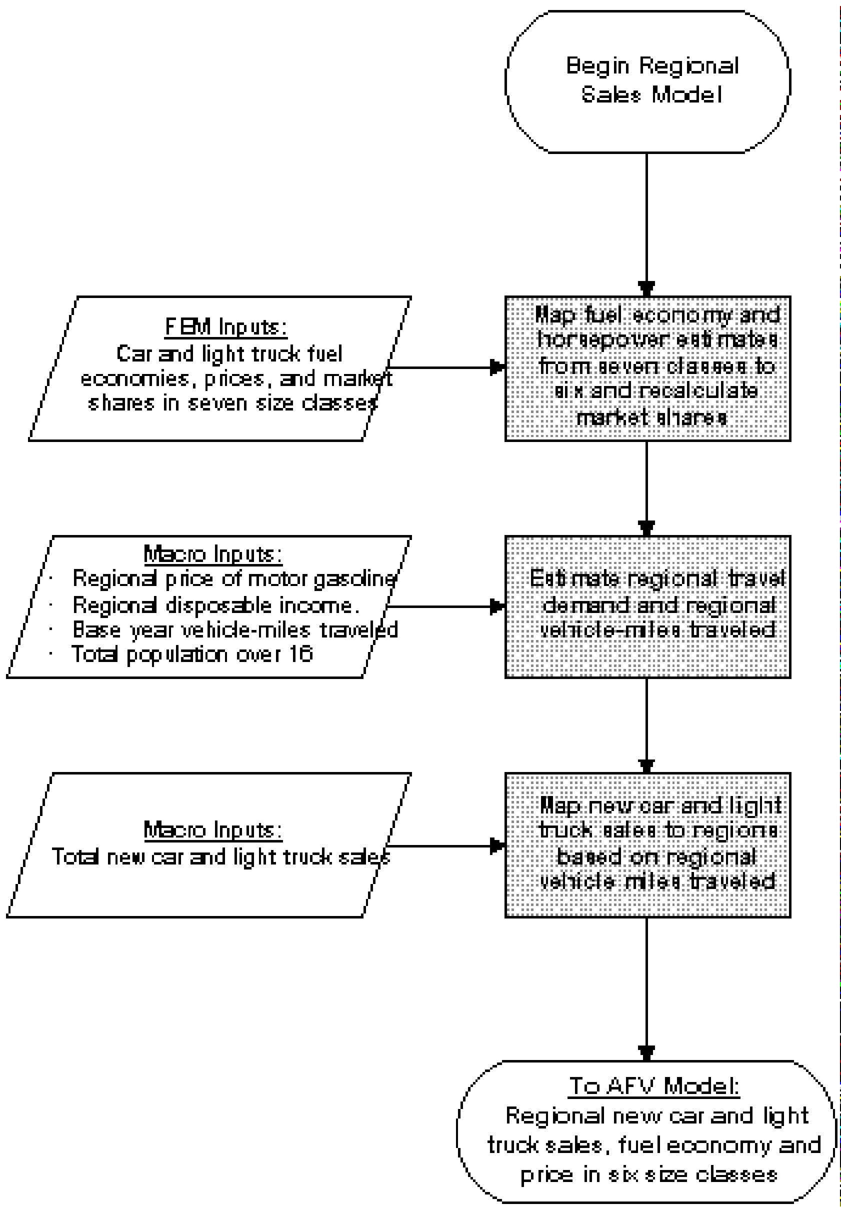
No alternative models were considered.

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.

For Cars:

$$NCS7SC_{CLASS,T} = MKTC_{CLASS,T} * TMC\_SQTRCARS_{T} * (1 - FLTCRAT_{1990}) \tag{29}$$

where:

NCS7SC = New car sales in the original seven FEM size classes
TMC_SQTRCARS = Total new car sales (supplied by the MACRO module)
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:

$$NTS7SC_{CLASS,T} = MKTT_{CLASS,T} * TMC\_SQDTRUCKSL_{T} * (1 - FLTTRAT_{1990}) \tag{30}$$

where:

NTS7SC = New light truck sales in the original seven FEM size classes
TMC_SQDTRUCKSL = Total light truck sales (supplied by the MACRO module)
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:

$$NCSTSC_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} (NCS7SC_{CLASS,GROUP}) * \beta 1_{CLASS,GROUP,SC} \tag{31}$$

and:

$$NLTSTSC_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} (NTS7SC_{CLASS,GROUP}) * \beta 2_{CLASS,GROUP,SC} \tag{32}$$

where:

NCSTSC = New car sales in the modified six size classes, *SC*
SC = Index for six size classes
NLTSTSC = New light truck sales
$\beta 1, \beta 2$ = 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:

$$PASSHRR_{SC} = \frac{NCSTSC_{SC}}{\sum_{SC=1}^{6} NCSTSC_{SC}} \tag{33}$$

and:

$$LTSHRR_{SC} = \frac{NLTSTSC_{SC}}{\sum_{SC=1}^{6} NLTSTSC_{SC}} \tag{34}$$

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:

$$HPCAR_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} (HPC_{CLASS,GROUP}) * CARSHR_{GROUP} * \beta 1_{CLASS,GROUP,SC} \tag{35}$$

and:

$$HPTRUCK_{SC} = \sum_{GROUP=1}^{2} \sum_{CLASS=1}^{7} (HPT_{CLASS,GROUP}) * TRKSHR_{GROUP} * \beta 1_{CLASS,GROUP,SC} \tag{36}$$

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:
and:

$$AHPCAR_{SC} = \sum_{SC=1}^{6} HPCAR_{SC} * PASSHRR_{SC} \qquad (37)$$

$$AHPTRUCK_{SC} = \sum_{SC=1}^{6} HPTRUCK_{SC} * LTSHRR_{SC} \qquad (38)$$

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:

$$SEDSHR_{FUEL,REG,T} = \frac{SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}}\right)}{\sum_{REG=1}^{9} SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}}\right)} \qquad (39)$$

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:

where:

$$COSTMIR_{REG,T} = 0.1251 * \left(\frac{TPMGTR_{REG,T}}{MPGFLT_{T-1}} \right) \quad (40)$$

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:

$$INCOMER_{REG,T} = \left(\frac{TMC\_YD_{REG,T}}{TMC\_POPAFO_{REG,T}} \right) \quad (41)$$

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]

$$\begin{aligned} VMT16R_{REG,T} = {} & \rho\, VMT16R_{REG,T-1} + \beta_0 (1 - \rho) + \beta_1 (COSTMIR_{REG,T} - \rho\, COSTMIR_{REG,T-1}) \\ & + \beta_2 (INCOMER_{REG,T} - \rho\, INCOMER_{REG,T-1}) + \beta_3 (PRFEM_T - \rho\, PRFEM_{T-1}) \end{aligned} \quad (42)$$

and:

$$VMTEER_{REG,T} = VMT16R_{REG,T} * TMC\_POP16_{REG,T} * DAF_T \quad (43)$$

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

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

Calculate regional VMT shares (RSHR):

$$RSHR_{REG,T} = \frac{VMTEER_{REG,T}}{\sum_{REG=1}^{9} VMTEER_{REG,T}} \tag{44}$$

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

$$NCS_{REG,SC,T} = NCSTSC_{SC,T} * RSHR_{REG,T} \tag{45}$$

and:

$$NLTS_{REG,SC,T} = NLTSTSC_{SC,T} * RSHR_{REG,T} \tag{46}$$

where:

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

3A-3. AFV Model

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

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 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

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[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.

[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.*

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:

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

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

The 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

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[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.

[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.

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.:

$$V = ß_1 X_1 + ß_2 X_2 + \ldots + ß_k X_k$$

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

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

The *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

[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.

(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.

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

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. 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.

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

[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.

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.

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

$$AFCOST_{EVTECH,REG} = \frac{\sum_{FUEL} (RFP_{FUEL,REG} \cdot FAVAIL_{FUEL,REG})}{\sum_{FUEL} FAVAIL_{FUEL,REG}} \qquad (47)$$

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*

2) Calculate EV operating costs, by region.

$$COPCOST_{EVTECH,REG} = \frac{AFCOST_{EVTECH,REG}}{BASEFF \cdot VEFFBTU_{EVTECH}} \qquad (48)$$

where:

COPCOST = Fuel operating costs for each technology, in 1990 cents per mile
BASEFF = Baseline efficiency of gasoline internal combustion engines (ICEs), in MPG

VEFFBTU = Efficiency of a given EV technology relative to the gasoline ICE

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

$$FAVAIL_{EVTECH,REG} = MAX\ (FAVAIL_{FUEL,REG}) \tag{49}$$

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

$$\begin{aligned} EVECT_{EVTECH,REG} = EXP\ [\ & BETACONST_{EVTECH} + \beta_1\ VPRICE_{EVTECH} + \beta_2\ COPCOST_{EVTECH,REG} \\ & + \beta_3\ VRANGE_{EVTECH} + \beta_4\ VRANGE^2_{EVTECH} + \beta_5\ VEMISS_{EVTECH} \\ & + \beta_6\ VEMISS^2_{EVTECH} + \beta_7\ FAVAIL_{EVTECH,REG} + \beta_8\ FAVAIL^2_{EVTECH,REG}\ ] \end{aligned} \tag{50}$$

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

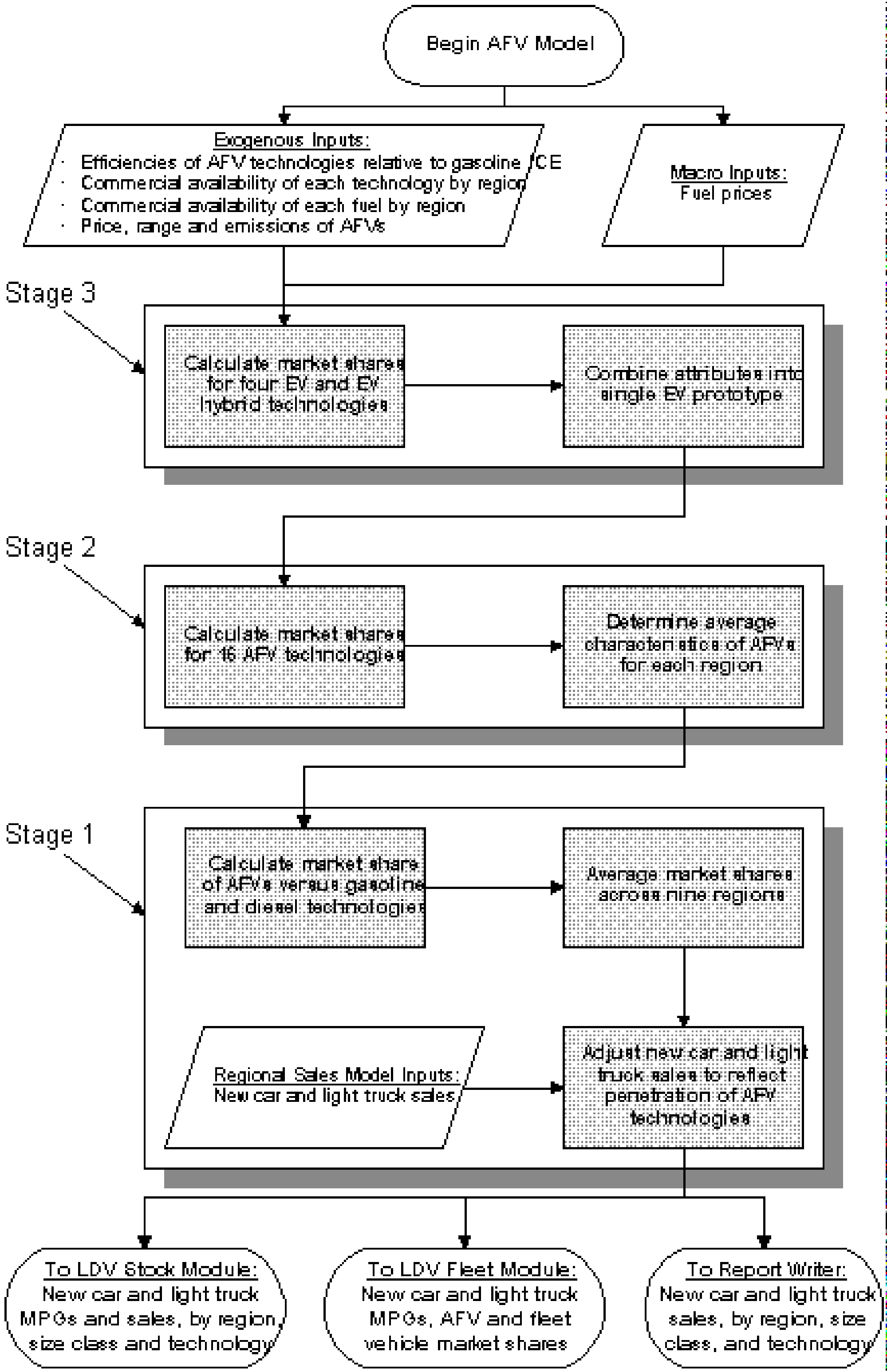
5) Calculate EV market shares, by region.

$$APSHR33_{EVTECH,REG} = \frac{EVECT_{EVTECH,REG} \cdot COMAVAIL_{EVTECH}}{\sum_{EVTECH=1}^{4} (EVECT_{EVTECH,REG} \cdot COMAVAIL_{EVTECH})} \tag{51}$$

where:

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

Figure 3A-3. Alternative Vehicle Model



6) Calculate average market

shares across Census regions:

$$APSHR33_{EVTECH} = \frac{1}{9}\sum_{REG=1}^{9} APSHR33_{EVTECH,REG} \tag{52}$$

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

$$\Psi_{EV} = \sum_{EVTECH=1}^{4} \Psi_{EVTECH} \cdot APSHR33_{EVTECH} \tag{53}$$

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.

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

$$AFCOST_{AFVTECH,REG} = \frac{\sum_{FUEL} (RFP_{FUEL,REG} \cdot FAVAIL_{FUEL,REG})}{\sum_{FUEL} FAVAIL_{FUEL,REG}} \tag{54}$$

where:

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

9) Calculate AFV operating costs, by region.

where:

COPCOST = Fuel operating costs for each technology, in 1990$ per mile
VEFFBTU = Efficiency of a given AFV technology relative to the gasoline internal combustion engine

$$COPCOST_{AFVTECH,REG} = \frac{AFCOST_{AFVTECH,REG}}{BASEFF \cdot VEFFBTU_{AFVTECH}} \tag{55}$$

10) 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.

$$FAVAIL_{AFVTECH,REG} = MAX\,(\,FAVAIL_{FUEL,REG}\,) \tag{56}$$

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

$$\begin{aligned} AFVECT_{AFVTECH,REG} = EXP\,[\,&BETACONST_{AFVTECH} + \beta_1\, VPRICE_{AFVTECH} + \beta_2\, COPCOST_{AFVTECH,REG} \\ &+ \beta_3\, VRANGE_{AFVTECH} + \beta_4\, VRANGE^2_{AFVTECH} + \beta_5\, VEMISS_{AFVTECH} \\ &+ \beta_6\, VEMISS^2_{AFVTECH} + \beta_7\, FAVAIL_{AFVTECH,REG} + \beta_8\, FAVAIL^2_{AFVTECH,REG}\,] \end{aligned} \tag{57}$$

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

12) Calculate AFV market shares, by region.

$$APSHR22_{AFVTECH,REG} = \frac{AFVECT_{AFVTECH,REG} \cdot COMAVAIL_{AFVTECH}}{\sum_{AFVTECH=1}^{11} (\,AFVECT_{AFVTECH,REG} \cdot COMAVAIL_{AFVTECH}\,)} \tag{58}$$

where:

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

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

$$\Psi_{AFV,REG} = \sum_{AFVTECH=1}^{11} \Psi_{AFVTECH,REG} \cdot AFVMSH_{AFVTECH,REG} \tag{59}$$

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.

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

$$\begin{aligned} VECT_{TECH,REG} = EXP\,[\,& BETACONST_{TECH} + \beta_1\, VPRICE_{TECH} + \beta_2\, COPCOST_{TECH,REG} \\ & + \beta_3\, VRANGE_{TECH} + \beta_4\, VRANGE^2_{TECH} + \beta_5\, VEMISS_{TECH} \\ & + \beta_6\, VEMISS^2_{TECH} + \beta_7\, FAVAIL_{TECH,REG} + \beta_8\, FAVAIL^2_{TECH,REG}\,] \end{aligned} \tag{60}$$

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

15) Calculate market shares, by region.

$$APSHR11_{TECH,REG} = \frac{VECT_{TECH,REG} \cdot COMAVAIL_{TECH}}{\sum_{TECH} (VECT_{TECH,REG} \cdot COMAVAIL_{TECH})} \tag{61}$$

where:

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

16) Average market shares across nine regions.

$$APSHR11_{TECH} = \frac{1}{9} \sum_{REG=1}^{9} APSHR11_{TECH,REG} \tag{62}$$

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):

$$APSHR44_{IT,REG} = APSHR33_{TECH,REG} \tag{63}$$

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

$$APSHR44_{IT,REG} = APSHR33_{AFV} * APSHR22_{AFVTECH} \tag{64}$$

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

$$APSHR44_{IT,REG} = APSHR33_{AFV} * APSHR22_{EV} * APSHR11_{EVTECH} \tag{65}$$

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

$$NCSTECH_{IT,REG,SC} = APSHR_{IT,REG,SC} * NCS_{REG,SC} \tag{66}$$

and:

$$NLTECH_{IT,REG,SC} = APSHR_{IT,REG,SC} * NLTS_{REG,SC} \tag{67}$$

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

These values are subsequently 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

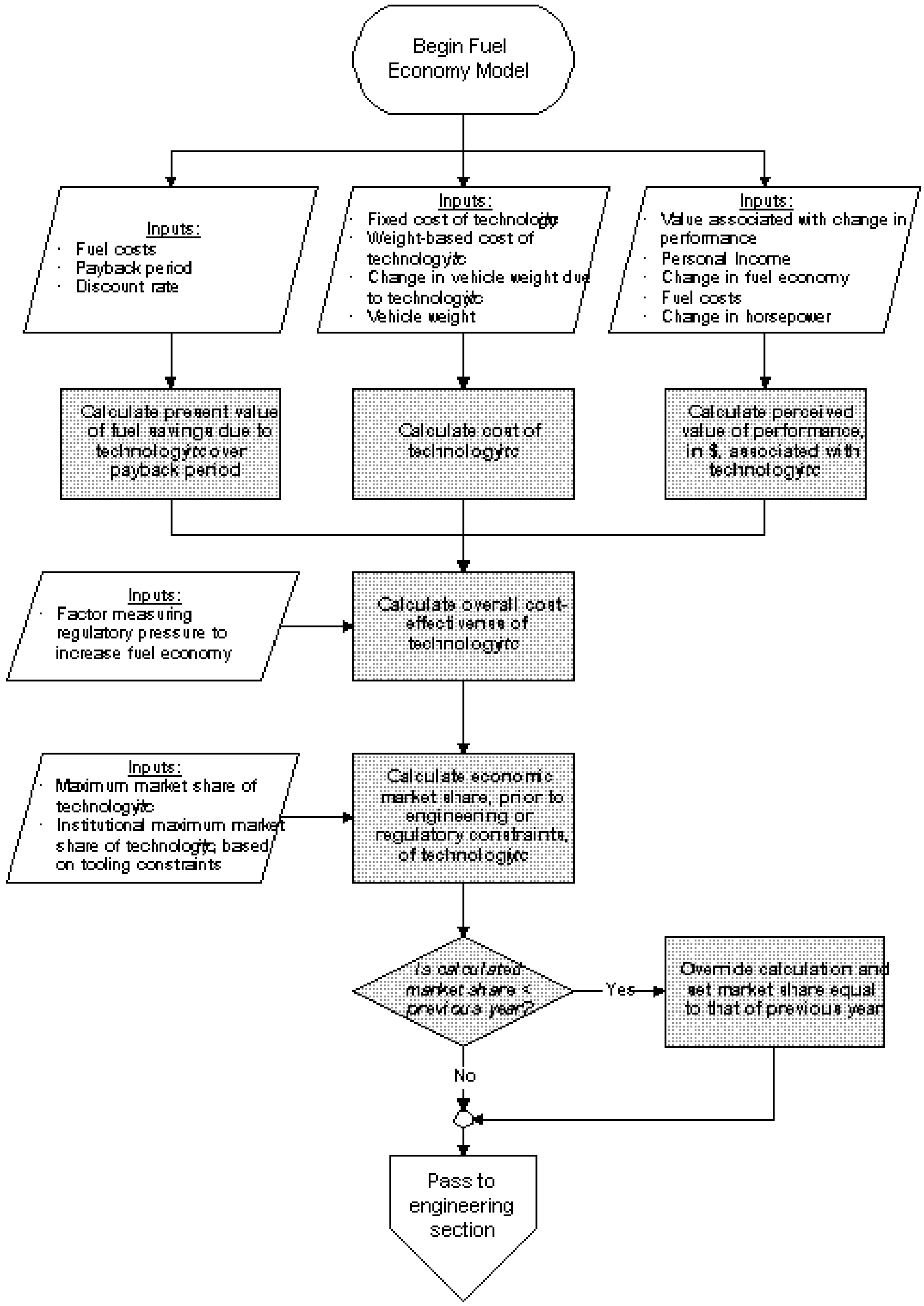
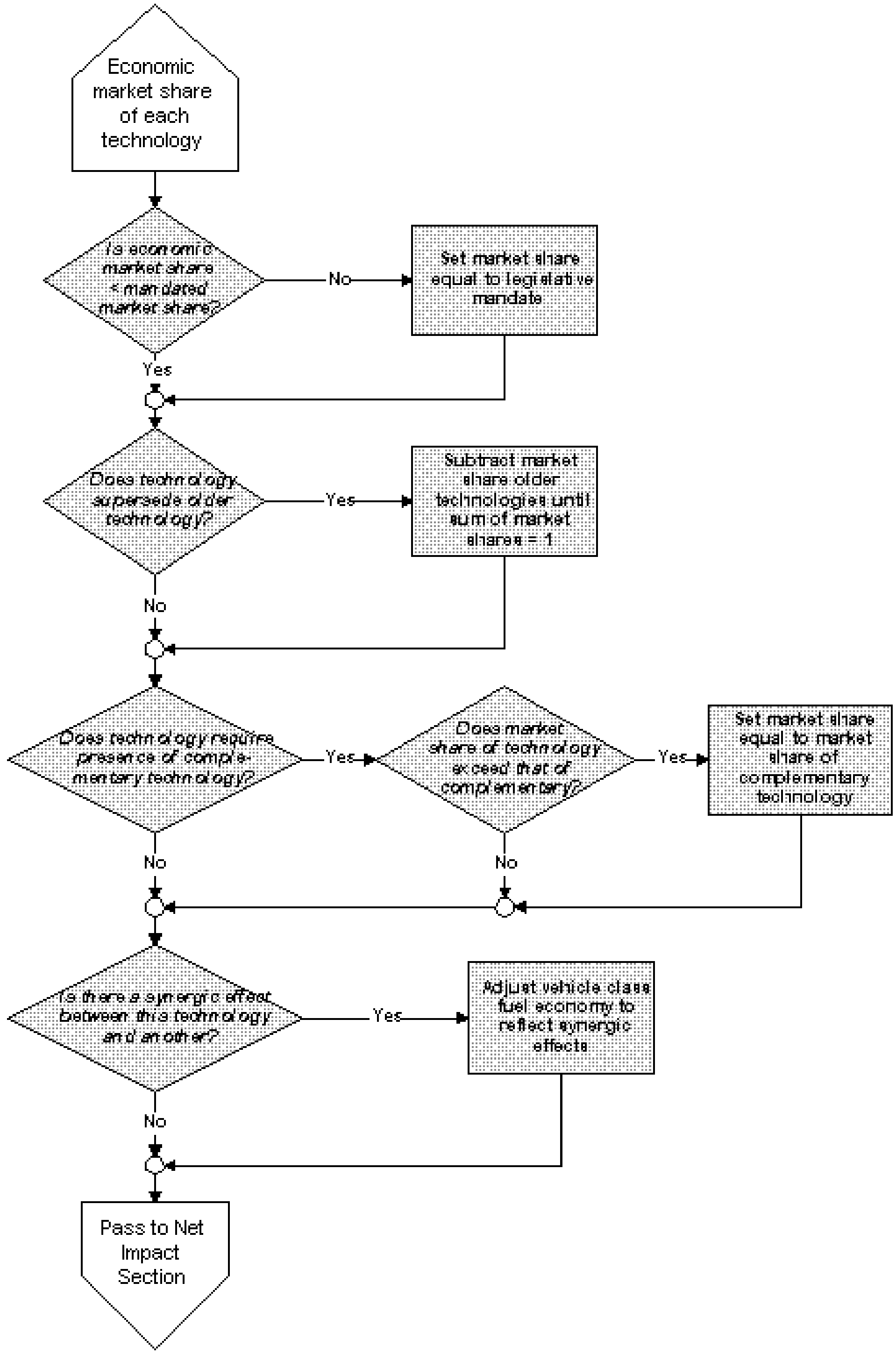


Figure 3A-5. Fuel Economy Model 2: Engineering Notes

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



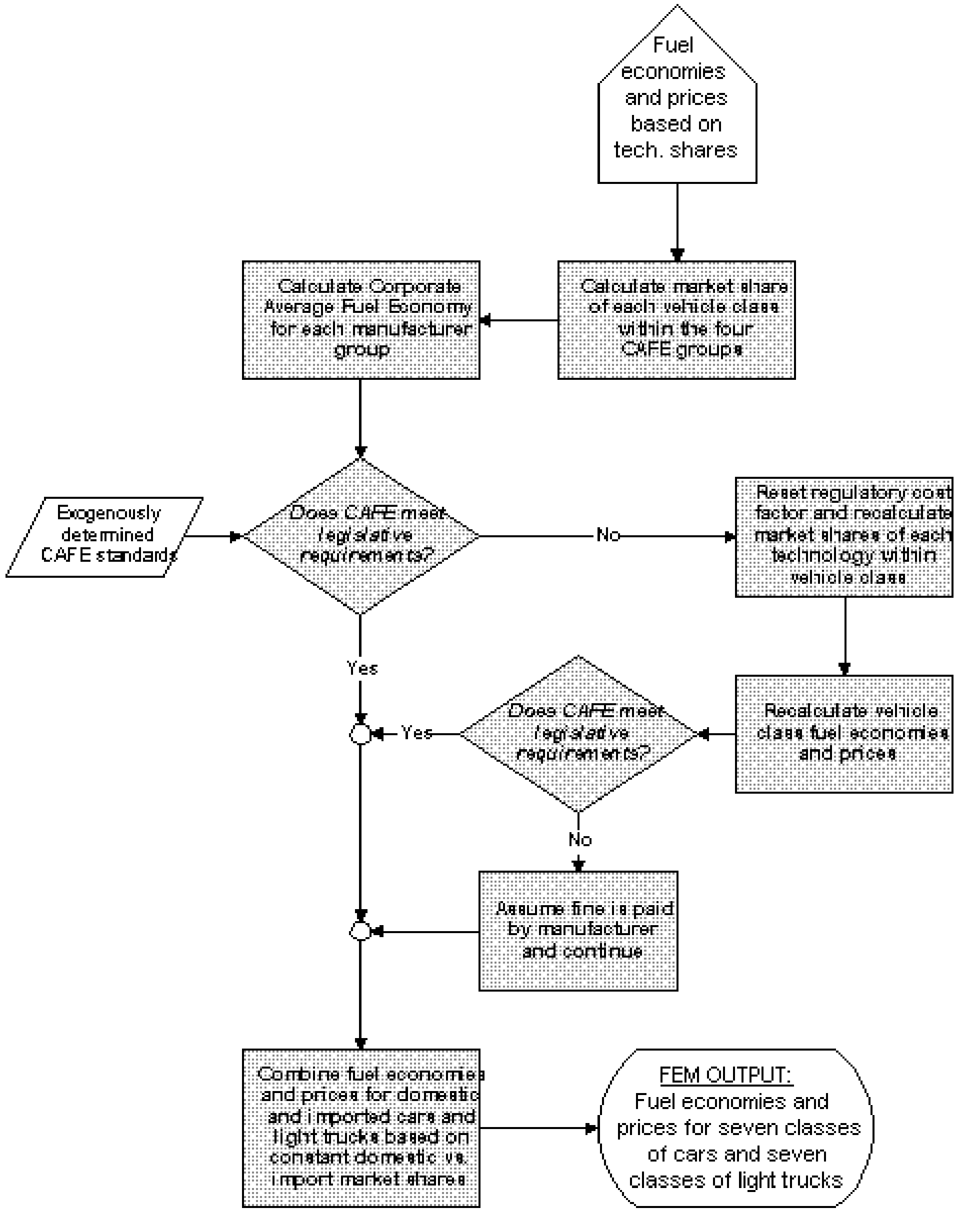


Figure 3A-8: Alternative Fuel Vehicle Model Stage 3

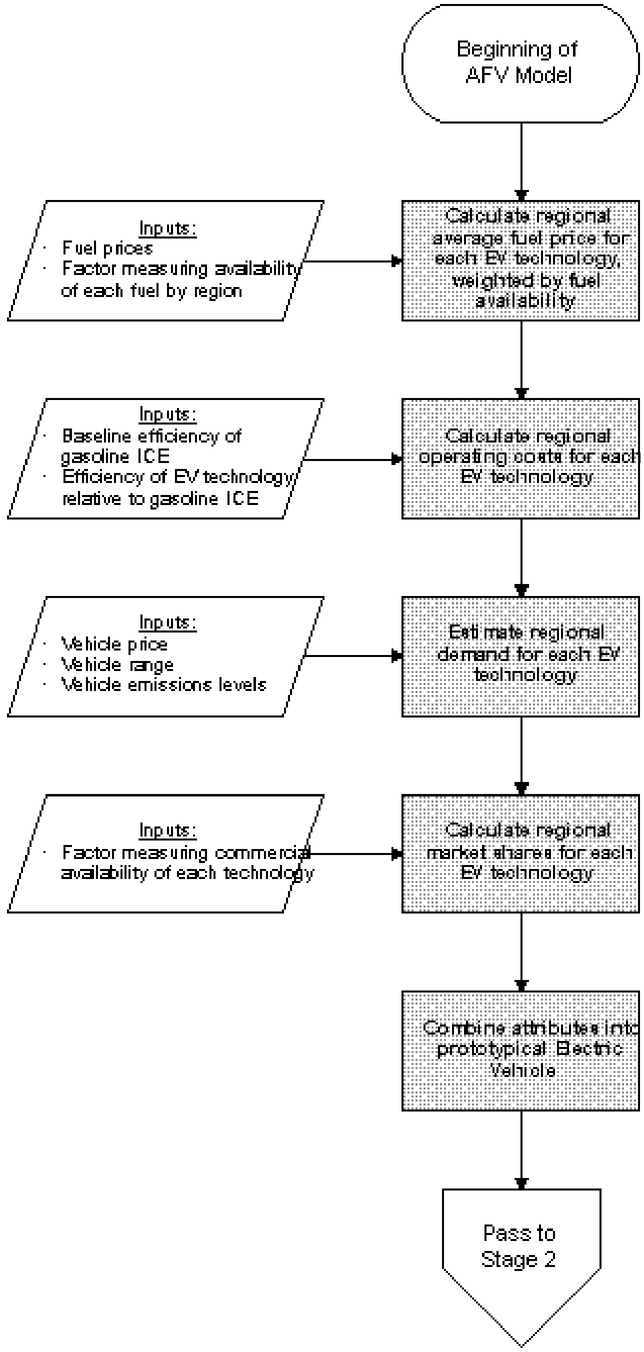


Figure 3A-9: Alternative Fuel Vehicle Model Stage 2

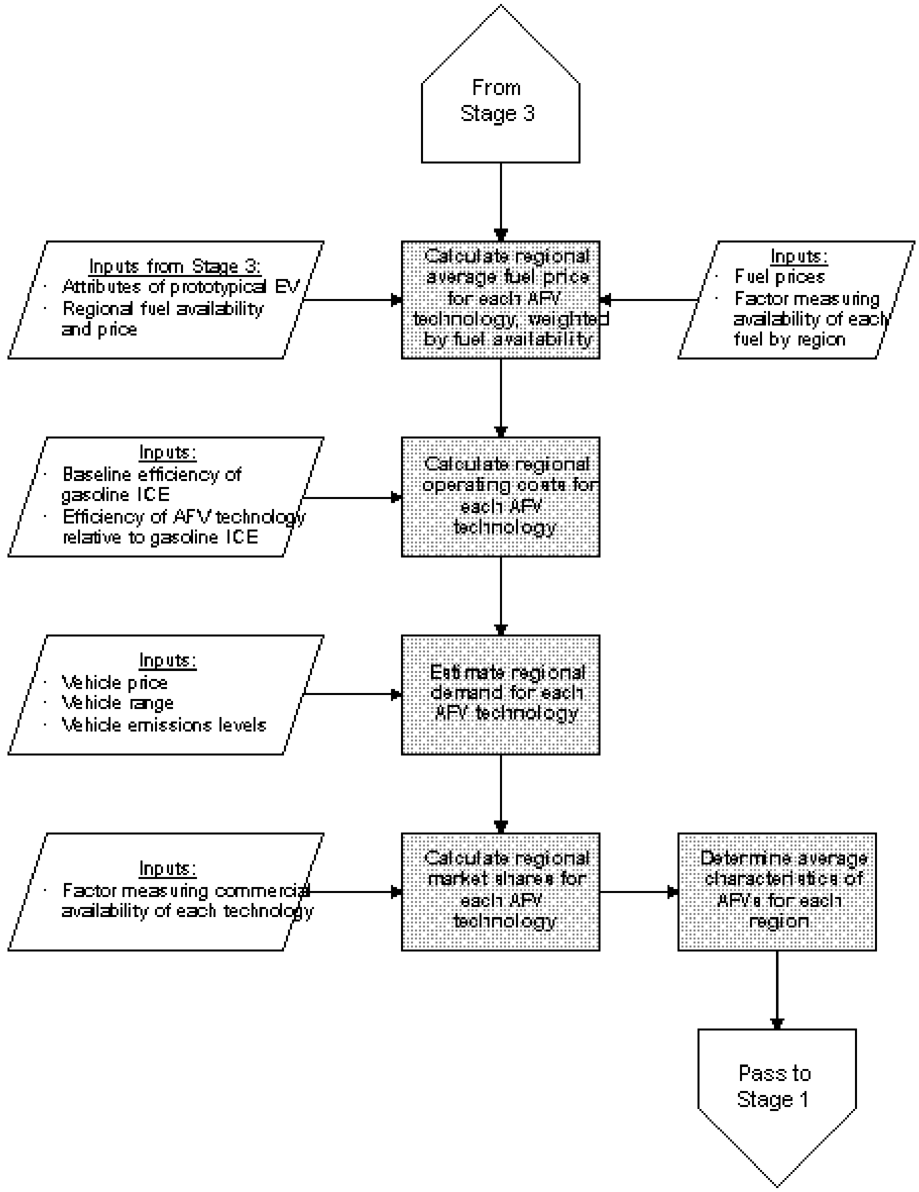
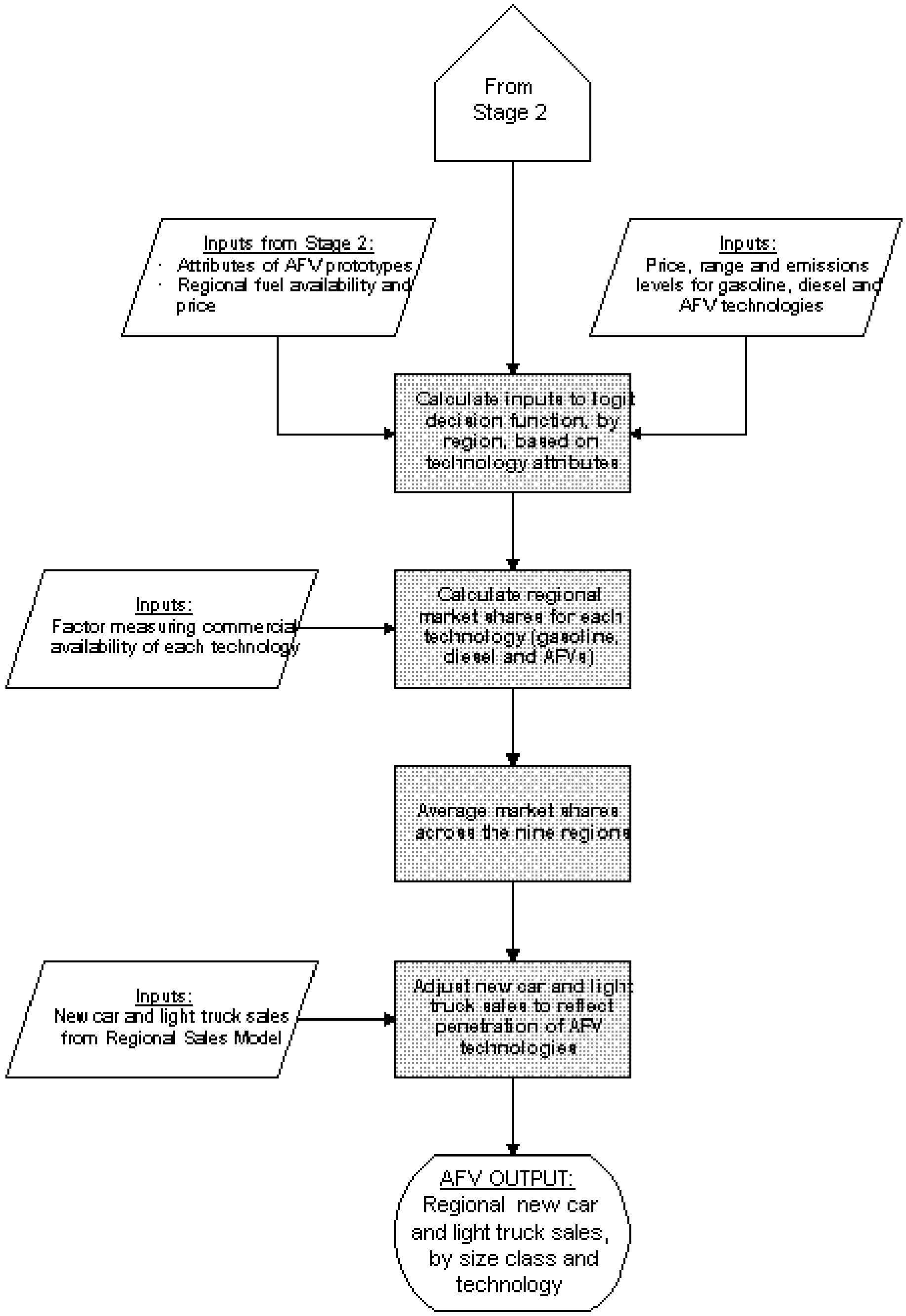


Figure 3A-10: Alternative Fuel Vehicle Model Stage 1


From
Stage 2
Inputs from Stage 2:
· Attributes of AFV prototypes
· Regional fuel availability and price
Inputs:
Price, range and emissions levels for gasoline, diesel and AFV technologies
Calculate inputs to logit decision function, by region, based on technology attributes
Inputs:
Factor measuring commercial availability of each technology
Calculate regional market shares for each technology (gasoline, diesel and AFVs)
Average market shares across the nine regions
Inputs:
New car and light truck sales from Regional Sales Model
Adjust new car and light truck sales to reflect penetration of AFV technologies
AFV OUTPUT:
Regional new car and light truck sales, by size class and technology

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.

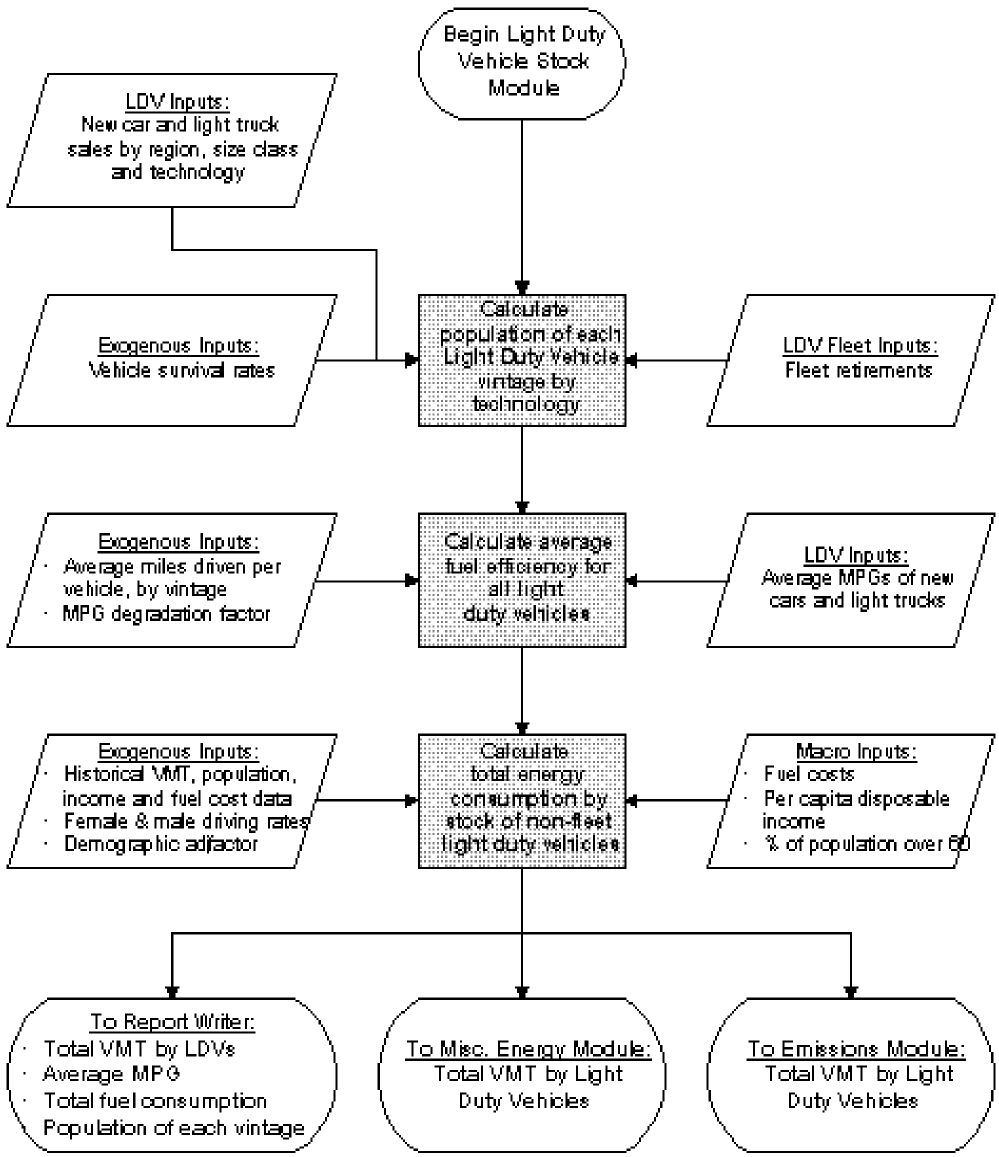
ALTERNATIVE SPECIFICATIONS

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: **(68)**

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

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: **(69)**

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

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: **(70)**

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

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: **(71)**

$$STKTR_{T} - \sum_{VINT-1}^{10} \sum_{IT-1}^{16} LTSTK_{IT,VINT,T}$$

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:

where:

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

$$VSPLDV_{IT,T} = \frac{\sum_{VINT=1}^{10} \left(PASSTK_{IT,VINT,T} + LTSTK_{IT,VINT,T} \right)}{STKCAR_T + STKTR_T} \tag{72}$$

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:

$$RATIO_{ASC,T} = \frac{AMPGT_{ASC,T}}{AMPGC_{ASC,T}} \tag{73}$$

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: **(74)**

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

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:

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

$$\text{and:} \qquad (75)$$

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

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:

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

$$\text{and:} \qquad (76)$$

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

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

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

necessary to weight the fuel efficiencies of each vintage according to the average number of miles driven. This is done by summing the total number of miles driven across all vintages and technologies:[12]

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

and: **(77)**

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

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: **(78)**

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

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

[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.

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: **(79)**

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

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

$$MPGFLT = \frac{TOTMICT_T + TOTMITT_T}{CMPGT_T + TMPGT_T} \qquad (80)$$

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.

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,

[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).

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:

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

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]
Although a stock-based model can provide a more robust extended forecast than one based solely

[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.

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

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.

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

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 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)

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[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.

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 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:
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,

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

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

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

In developing the current VMT model, it has been necessary to address data quality and functional specification issues. In order to make the new model consistent with the NEMS requirements, economic variables (driving cost per mile and disposable personal income per capita) have been transformed so that values are expressed in 1987 dollars rather than 1982 dollars. The demographic variable previously used (population between the ages of 20 and 29 divided by population over 65) has been removed from the specification and other demographic variables have been incorporated.

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:[21]

where:

VMTPC = the vehicle miles traveled per capita

---

[21] 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.

$$VMTPC_T = \rho\, VMTPC_{T-1} + 0.28\,(1-\rho) - 7.50\,(CPM87_T - \rho\, CPM87_{T-1}) + 3.6x10^{-4}\,(YPC87_T - \rho\, YPC87_{T-1}) + 8.36\,(PrFem_T - \rho\, PrFem_{T-1}) \quad (81)$$

CPM87 = the fuel cost of driving a mile, expressed in 1987 dollars.
YPC87 = the disposable personal income per capita, expressed in 1987 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 0.72.

In the second stage, the unadjusted forecast is modified by a demographic adjustment factor (DAF). This is an index which is based on projections of the proportion of the population of 60 years of age (P>60) and the expected ratio of per capita driving by those over 60 to those under 60 (PVMT60), and is set to 1.0 in 1990.

$$DAF = 1 - [P{>}60] \cdot (1 - PVMT60_T)]$$
$$ADJVMTPC_T = VMTPC_T \cdot DAF_T \quad (82)$$

where:

DAF = the demographic adjustment facto
ADJVMT= adjusted vehicle miles traveled per capita

The adjusted VMT per capita is 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.

Figure 3B-2. LDV Stock Module 1: Process New Additions to LDV Stock

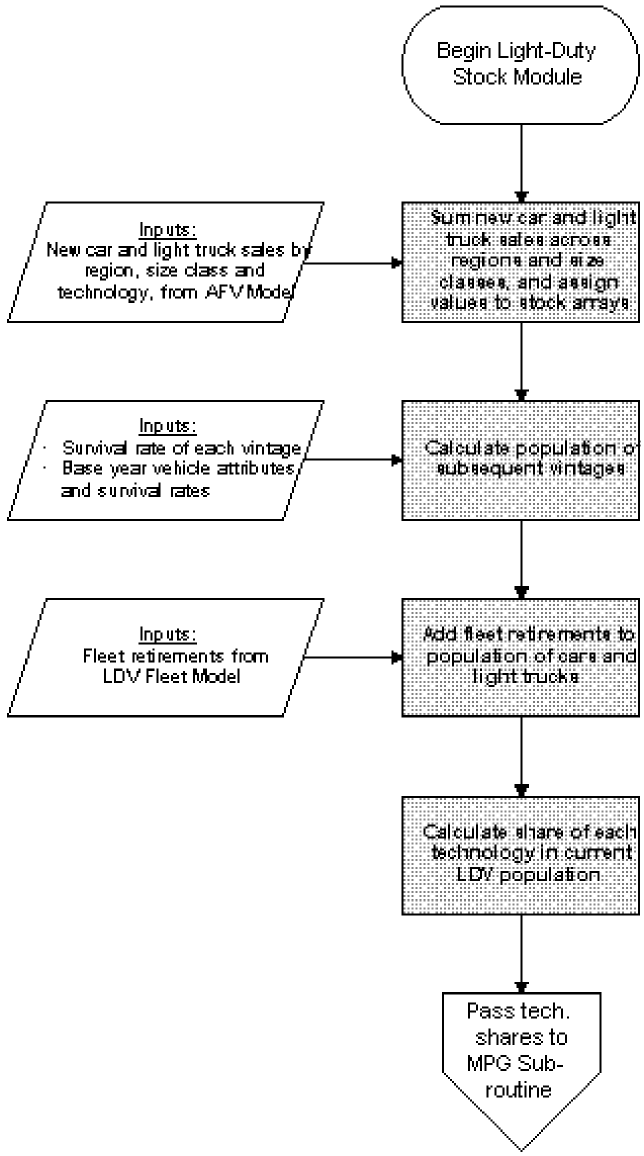

Figure 3B-3. LDV Stock Module 2: Determine Characteristics of Current LDV Stock

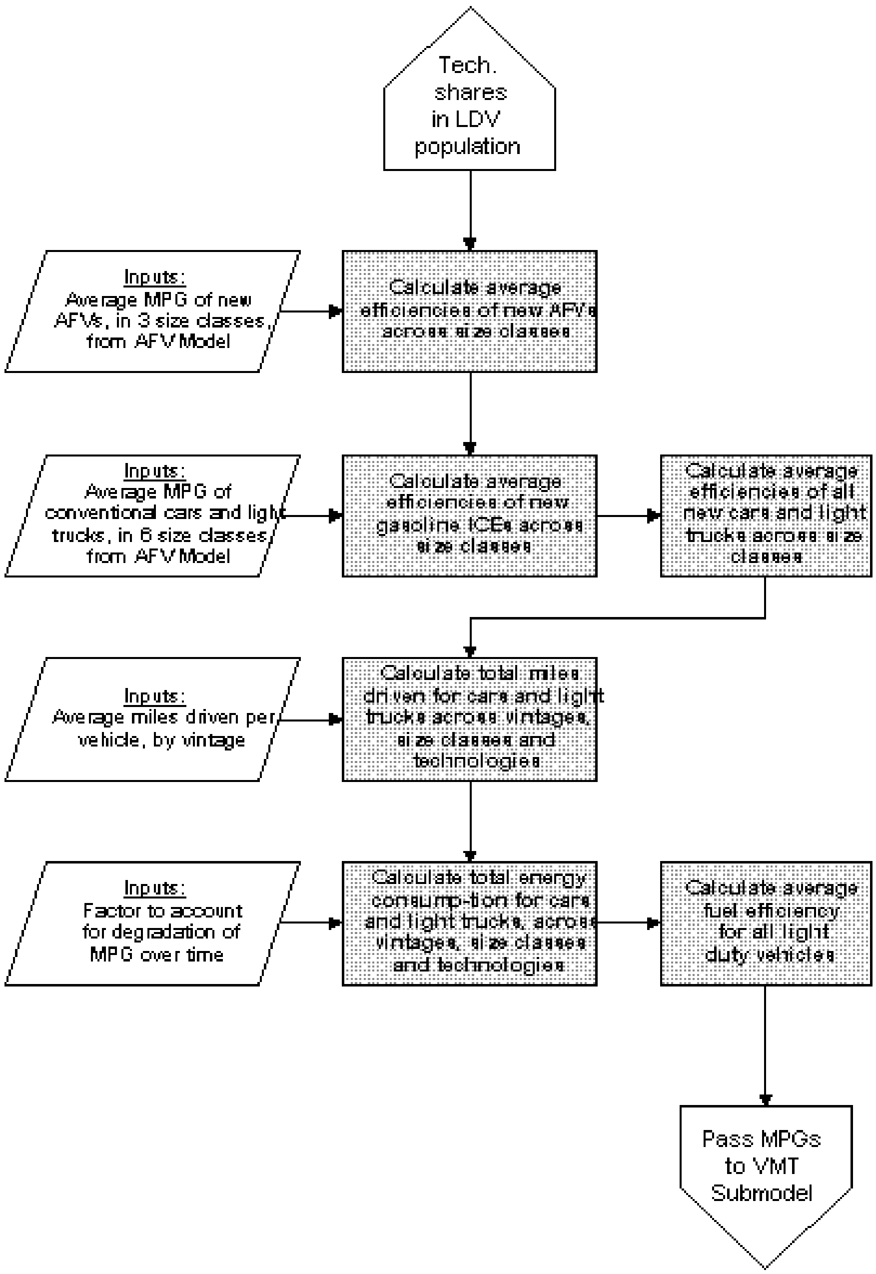

Figure 3B-4. LDV Stock Module 3: Vehicle Miles Traveled Model

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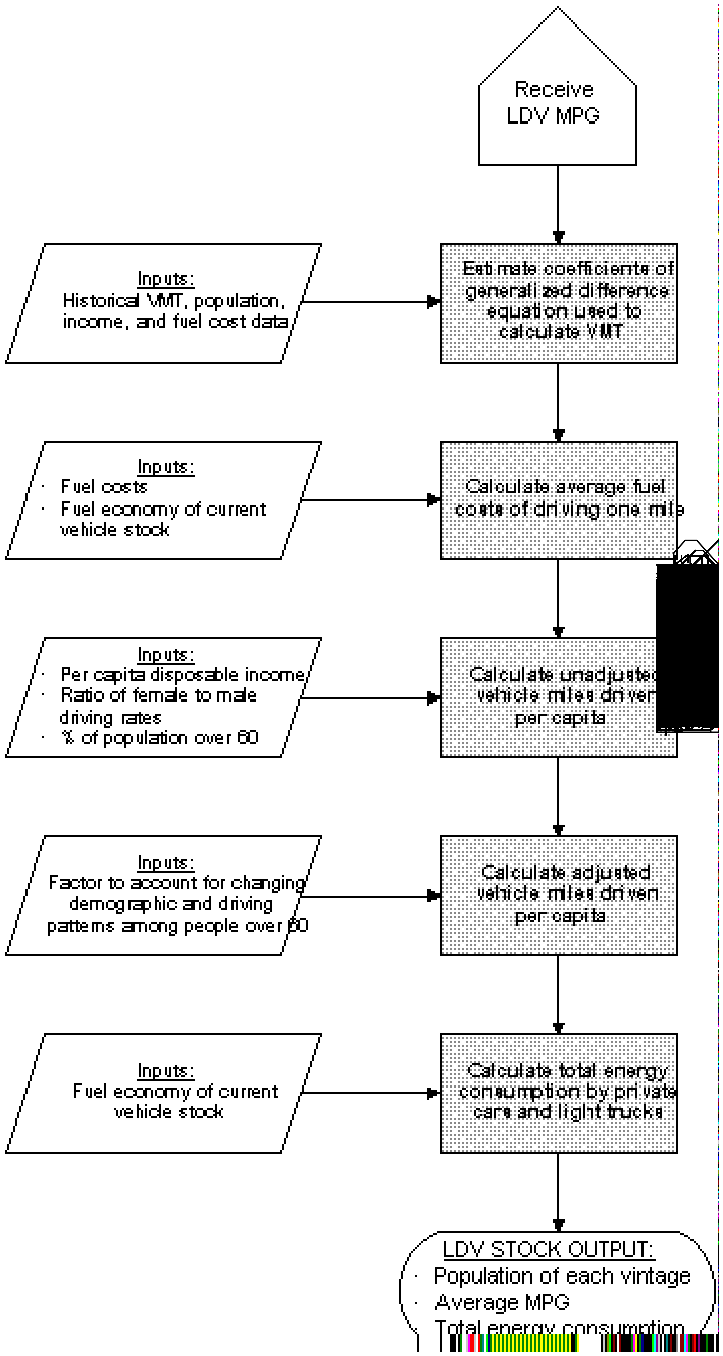


Receive
LDV MPG
Inputs:
Historical VMT, population, income, and fuel cost data
Estimate coefficients of generalized difference equation used to calculate VMT
Inputs:
· Fuel costs
· Fuel economy of current vehicle stock
Calculate average fuel costs of driving one mile
Inputs:
· Per capita disposable income
· Ratio of female to male driving rates
· % of population over 60
Calculate unadjusted vehicle miles driven per capita
Inputs:
Factor to account for changing demographic and driving patterns among people over 60
Calculate adjusted vehicle miles driven per capita
Inputs:
Fuel economy of current vehicle stock
Calculate total energy consumption by private cars and light trucks
LDV STOCK OUTPUT:
· Population of each vintage
· Average MPG
· Total energy consumption

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. 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.

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 flees, 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 was 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

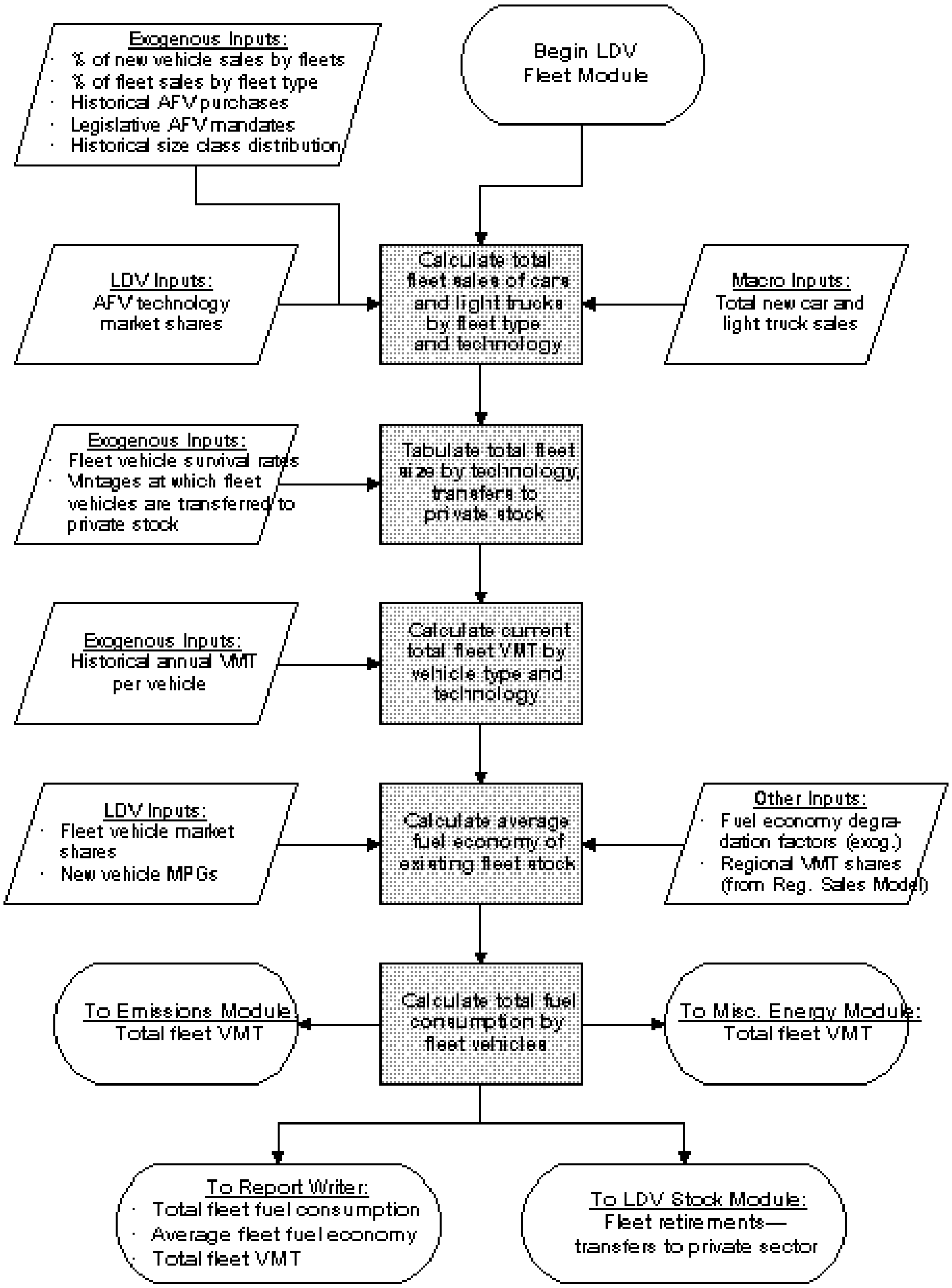
No alternative specifications were considered.

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 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:

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

and: **(81)**

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

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
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

Determine total alternative fuel fleet vehicle sales, using either the market-driven or legislatively mandated values :

$$FLTALT_{VT,ITY,T} = MAX\left[\left(FLTSAL_{VT,ITY,T} * FLTAPSHR1_{ITY}\right),\ EPACT_{VT,ITY,T}\right] \quad \textbf{(82)}$$

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:

$$FLTCONV_{VT,ITY,T} = FLTSAL_{VT,ITY,T} - FLTALT_{VT,ITY,T} \quad \textbf{(83)}$$

where:

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

Fleet purchases are subsequently divided by size class:

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

$$\text{and:} \tag{84}$$

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

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:

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

$$FLTECHSAL_{VT,ITY\neq 1,IS,ITECH} = FLTSLSCA_{VT,ITY\neq 1,IS} * FLTECHSHR_{ITECH,ITY} \tag{85}$$

$$\text{and:}$$

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

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:

$$FLTECH_{VT,ITY,ITECH} = \sum_{IS=1}^{3} FLTECHSAL_{VT,ITY,IS,ITECH} \tag{86}$$

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:

$$FLTSTKVN_{VT,ITY,ITECH,IVINT,T} = FLTSTKVN_{VT,ITY,ITECH,IVINT-1,T-1} * SURVFLTT_{VT,IVINT-1}$$

and: **(87)**

$$FLTSTKVN_{VT,ITY,ITECH,IVINT-1,T} = FLTECH_{VT,ITY,ITECH,T}$$

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:

$$OLDFSTK_{VT,ITY,ITECH,IVINT,T} = FLTSTKVN_{VT,ITY,ITECH,IVINT,T} \qquad (88)$$

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:

$$TFLTECHSTK_{VT,ITY,ITECH,T} = \sum_{IVIN=1}^{6} FLTSTKVN_{VT,ITY,ITECH,IVIN,T} \tag{89}$$

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:

$$VFSTKPF_{VT,ITY,ITECH,T} = \frac{TFLTECHSTK_{VT,ITY,ITECH,T}}{\sum_{VT=1}^{2}\sum_{ITY=1}^{3}\sum_{ITECH=1}^{6} TFLTECHSTK_{VT,ITY,ITECH,T}} \tag{90}$$

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:

$$FLTVMT_{T} = \sum_{VT=1}^{2}\sum_{ITY=1}^{3}\sum_{ITECH=1}^{6} \left(TFLTECHSTK_{VT,ITY,ITECH,T} * FLTVMTYR_{VT,ITY,T} \right) \tag{91}$$

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:

$$FLTVMTECH_{VT,ITY,ITECH,T} = FLTVMT_{T} * VFSTKPF_{VT,ITY,ITECH,T} \tag{92}$$

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:

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

and: **(93)**

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

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:

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

and: **(94)**

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

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:

where:

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

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

and: **(95)**

$$MPGFSTK_{VY,ITY,ITECH,IVIN-1,T} = FLTMPG_{VT,ITY,ITECH,T}$$

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

$$MPGFLTSTK_{VT,ITY,ITECH} = \left[\sum_{IVINT=1}^{MAXVINT} \frac{\left(\dfrac{FLTSKTVN_{VT,ITY,ITECH,IVINT}}{MPGFSTK_{VT,ITY,ITECH,IVINT} * VDF_{VT}} \right)}{\left(TFLTECHSTK_{VT,ITY,ITECH} \right)} \right]^{-1} \quad (96)$$

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:

$$FLTTOTMPG_{VT,T} = \left[\sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \frac{VFSTKPF_{VT,ITY,ITECH,T}}{MPGFLTSTK_{VT,ITY,ITECH,T}} \right]^{-1} \quad (97)$$

where:

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

Calculate Fuel Consumption by Fleet Vehicles

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

$$FLTLDVC_{VT,ITY,ITECH,T} = \frac{FLTVMTECH_{VT,ITY,ITECH,T}}{MPGFLTSTK_{VT,ITY,ITECH,T}} \quad (98)$$

where:

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

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

$$FLTFCBTU_{VT,ITECH,T} = \sum_{ITY=1}^{3} FLTLDVC_{VT,ITY,ITECH,T} * QBTU_{ITECH} \qquad (99)$$

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:

$$FLTFCBTUR_{IR,ITECH,T} = \sum_{VT=1}^{2} FLTFCBTU_{VT,ITECH,T} * RSHR_{IR,T} \qquad (100)$$

where:

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

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

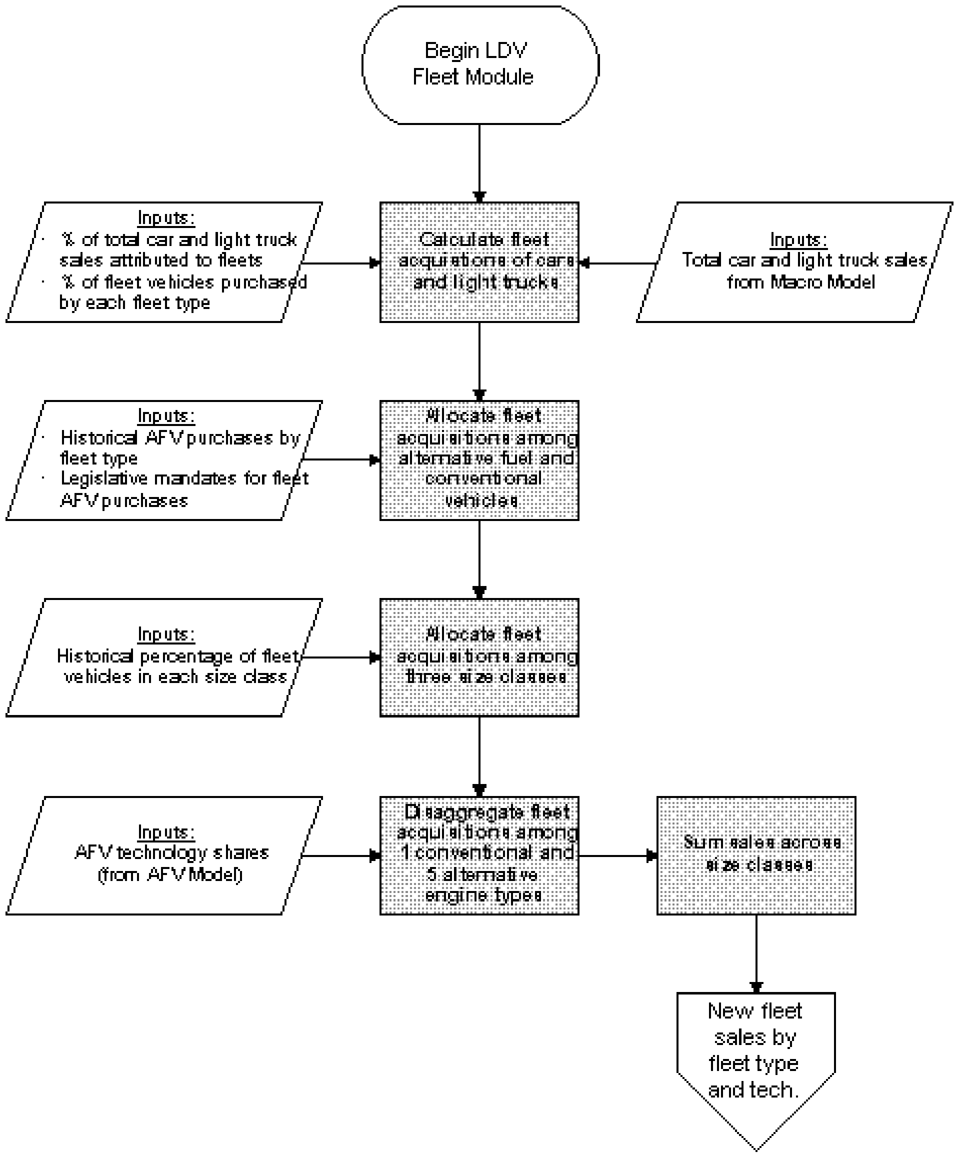


Figure 3C-3. LDV Fleet Module 2: Determine Characteristics of Existing Fleets

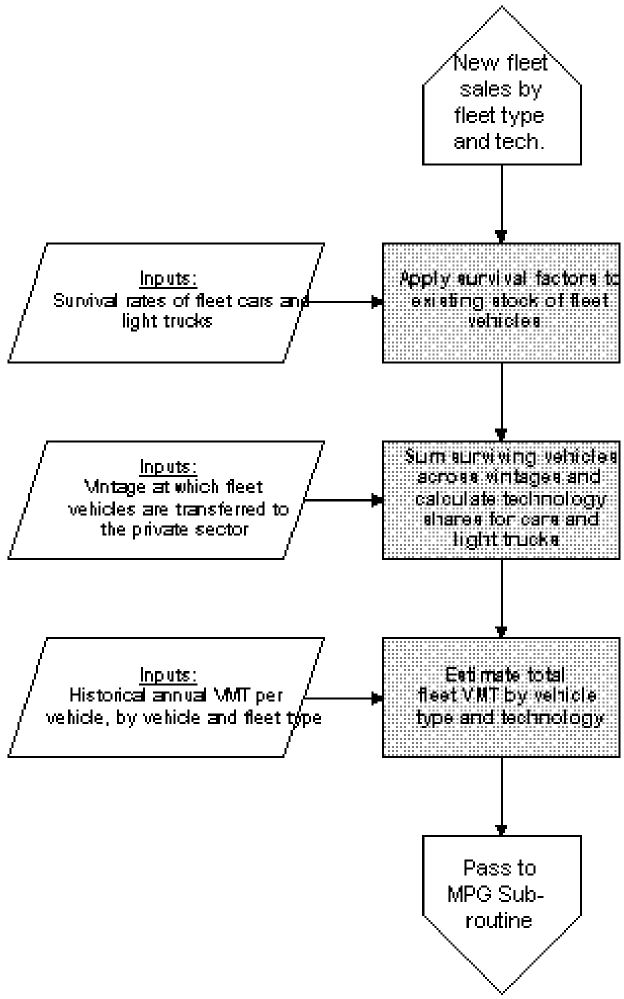
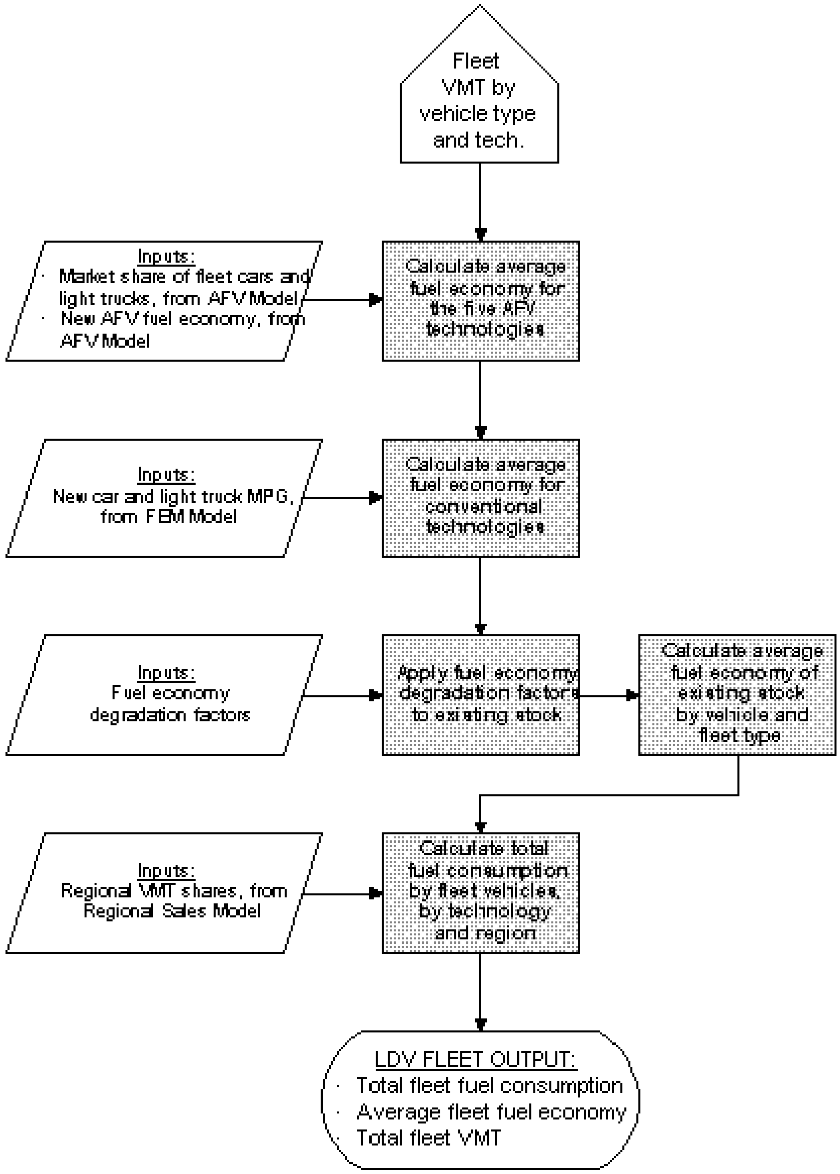


Figure 3C-4. LDV Fleet Module 3: Determine Fleet Fuel Economy and Consumption



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.[21] 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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[21] *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.[22] RPM and RTM are estimated by separate models, both of which are functions of GNP and the cost of flying, represented by the yield.[23] The yield is considered solely as a function of fuel price, whose contribution to total costs

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

[23] "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.

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.[24] 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 algorithm is the same for both passengers and cargo:[25]

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

Revenue passenger and cargo ton miles are subsequently calculated:

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

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

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

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.[26] 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 airport operations are then estimated using predictions about load factors,[27] 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

[26] 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.

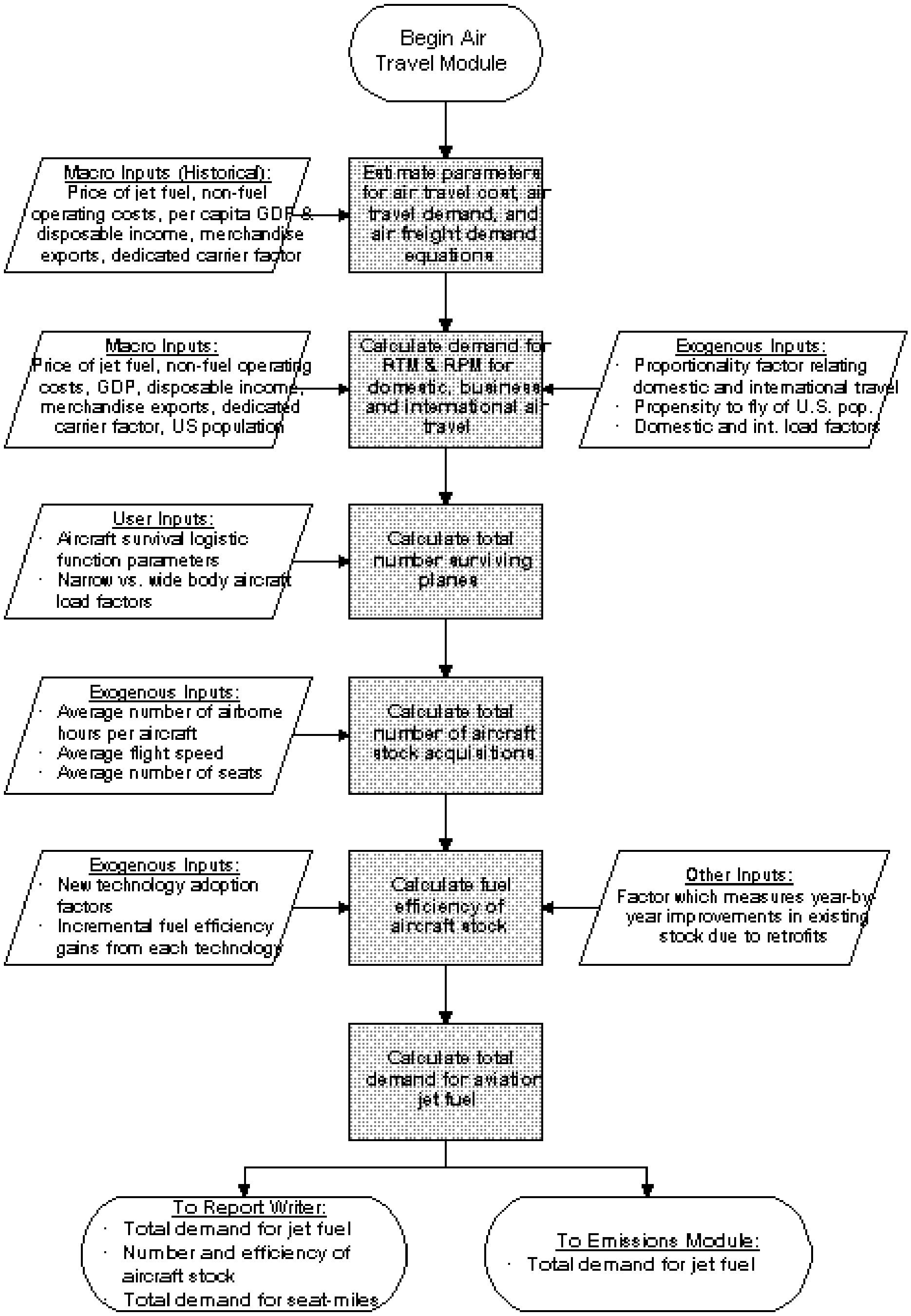
[27] The "load factor" is the ratio of revenue passenger-miles to available seat-miles; it provides an estimate of the average occupancy rate of passenger aircraft.

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.

Figure 3D-1. Air Travel Module



1) Calculate the cost of flying:

$$YIELD = 4.22 + .94\,PJF + 65.42\,OPCST \qquad \textbf{(103)}$$

where:

YIELD = Cost of air travel, expressed in cents per RPM
PJF = Price of jet fuel, in dollars per million Btu
OPCST = Non-fuel operating costs, in dollars per available seat-mile

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

Business:

$$RPMBPC = -587.8 + .118\,\frac{TMC\_GDP}{TMC\_POPAFO} - 20.56\,YIELD \qquad \textbf{(104)}$$

Personal:

$$RPMPPC = -126.8 + .050\,\frac{TMC\_YD}{TMC\_POPAFO} - 12.80\,YIELD \qquad \textbf{(105)}$$

International:

$$RPMIPC = PCTINT \cdot (RPMBPC + RPMPPC) \qquad \textbf{(106)}$$

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[28]

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

$$RTM = (-18{,}165.6 + 22.35\,TMC\_EXDN87 + 5.77\,TMC\_GDP) \cdot DFRT \qquad \textbf{(107)}$$

where:

TMC_EXDN87 = Value of merchandise exports, in 1987 dollars
DFRT = Fraction of freight ton-miles transported by dedicated carriers[29]

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

[29] 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:

$$RPMB = RPMBPC \cdot TMC\_POPAFO \qquad \textbf{(111)}$$

$$RPMP = RPMPPC \cdot TMC\_POPAFO \cdot DI \qquad \textbf{(108)}$$

$$RPMI = RPMIPC \cdot TMC\_POPAFO \qquad \textbf{(109)}$$

$$RPMD = RPMB + RPMP \qquad \textbf{(110)}$$

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[30]

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:

$$ASMDEMD = \left(\frac{RPMD}{LFDOM} \right) + \left(\frac{RPMI}{LFINTER} \right) + (RTM \cdot EQSM) \qquad \textbf{(112)}$$

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

[30] The Demographic Index is derived in Appendix F, Attachment 5.

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:[31]

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

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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[31] *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.[32] 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.[33] 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

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

[33] *Ibid.*, pp. 2-9 — 2-14.

increasingly efficient technologies in newly acquired aircraft.[34] 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.[35] 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.[36] 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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[34] Greene, D.L., *Energy Efficiency Improvement Potential of Commercial Aircraft to 2010,* Oak Ridge National Laboratory, ORNL-6622, June 1990.

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

[36] 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:

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

$$= \left[\left(\frac{SMDEMD_{NARROW,T-1}}{SMDEMD_{T-1}} \right) \cdot (1+\delta) \right] \quad ; \quad \delta < 0 \qquad \textbf{(114)}$$

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.[37]

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

$$SMDEMD_{TYPE,T} = SMFRAC_{TYPE,T} \cdot SMDEMD_{T} \qquad \textbf{(113)}$$

The number of surviving aircraft of each type are subsequently estimated. 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:

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

$$NSURV_{TYPE,T} = \sum_{VINT=0}^{n} NPCHSE_{TYPE,T-VINT} \cdot f(VINT) \qquad \textbf{(114)}$$

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

The logistic function, f(VINT), is defined as follows:

$$f(VINT) = \left[\frac{1}{1 + Exp^{-k(t_{.5} - VINT)}} \right] \qquad \textbf{(115)}$$

where $t_{.5}$ represents the vintage at which half of the original stock is assumed to retire, and the constant, *k*, is explicitly determined by another assumption: the vintage at which ninety percent of the stock is retired:

$$k = \left[\frac{Ln(9)}{(t_{.9} - t_{.5})} \right] \qquad \textbf{(116)}$$

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 **(117)**

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

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:

$$NPCHSE_{TYPE,T} = \left[\frac{SMDEMD_{TYPE,T} - SMSURV_{TYPE,T}}{ASMP_{TYPE,T}}\right] \tag{118}$$

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:

$$MPG_{TYPE,T} = \left[\left(\frac{STKFRAC_{OLD,TYPE,T}}{(1 + \rho_{TYPE}) \cdot (SMPG_{OLD,TYPE,T})}\right) + \left(\frac{STKFRAC_{NEW,TYPE,T}}{SMPG_{NEW,TYPE,T}}\right)\right. \tag{119}$$

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

$$STKFRAC_{NEW,TYPE,T} = (1 - STKFRAC_{OLD,TYPE,T}) \tag{120}$$

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:

$$Penetration_{TECH} = \frac{1}{1 + \exp^{-(PE+TE-6)}} \qquad \textbf{(121)}$$

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:

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

when

$$(0 < Trigger\ Price \leq Fuel\ Price) \tag{122}$$

and

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

where 10 is a scaling factor.

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:

$$SMPG_T = \left[\sum_{TYPE=1}^{2} \left(\frac{SMFRAC_{TYPE,T}}{SMPG_{TYPE,T}} \right) \right]^{-1} \tag{123}$$

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:

$$JFDEMD_T = \frac{SMDEMD_T}{SMPG_T}$$

where:

JFDEMD = The total demand for aviation jet fuel

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

Figure 3D-2. Air Travel Demand Model 1: Seat-Mile Demand Estimation

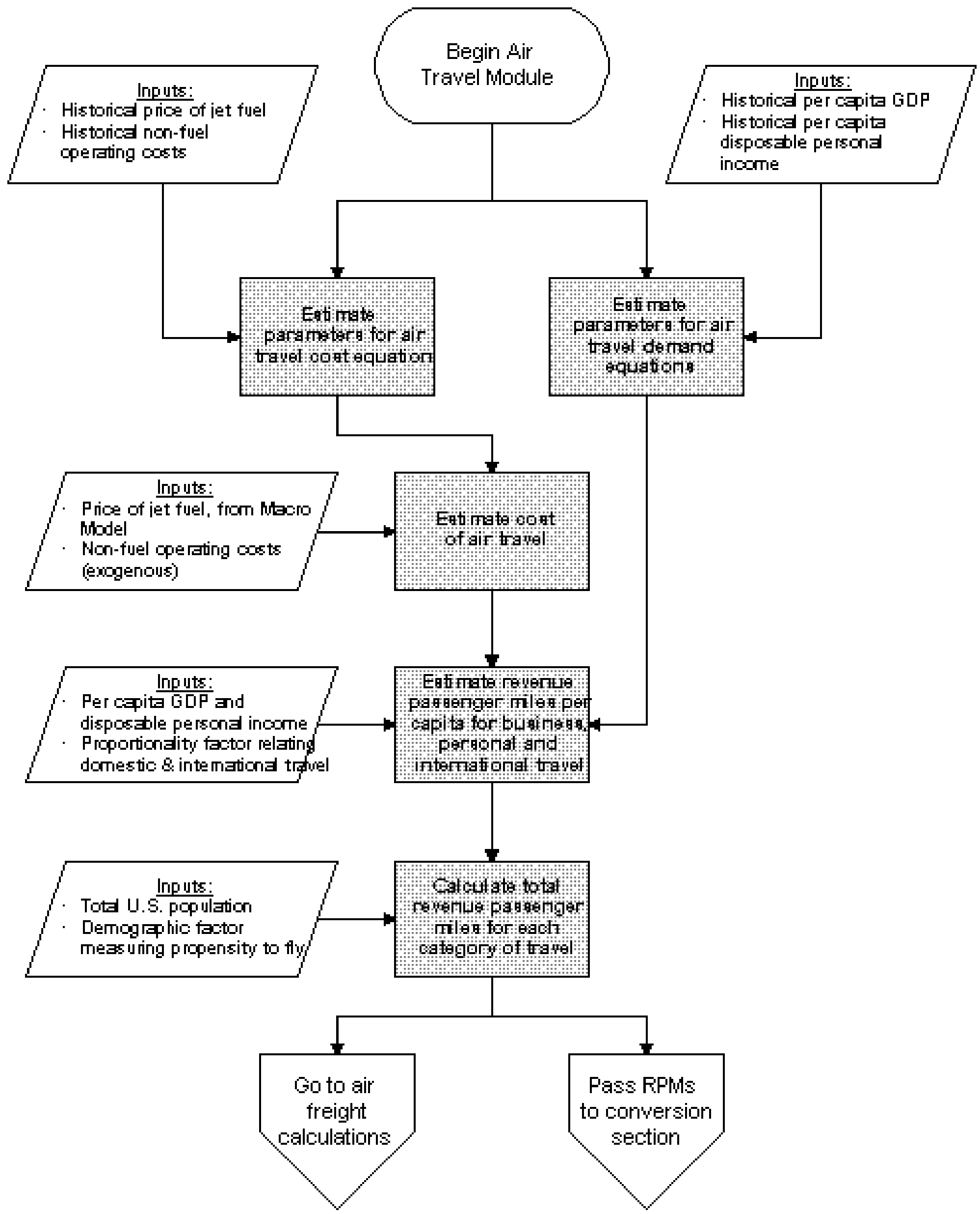


Figure 3D-3. Air Travel Demand Model 2: Air Freight Demand Estimation

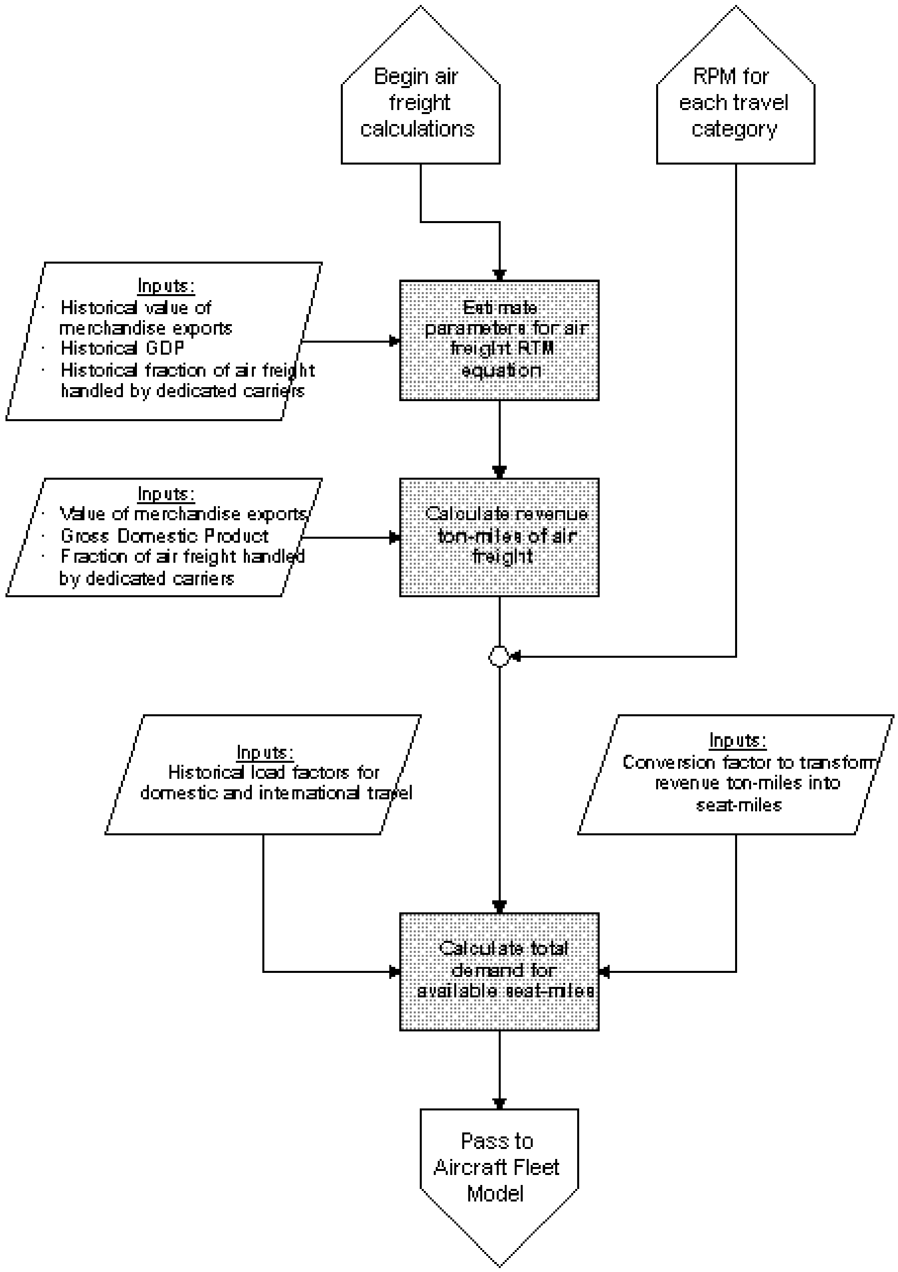


Figure 3D-4. Aircraft Fleet Efficiency Model 1: Process Changes to Existing Fleet

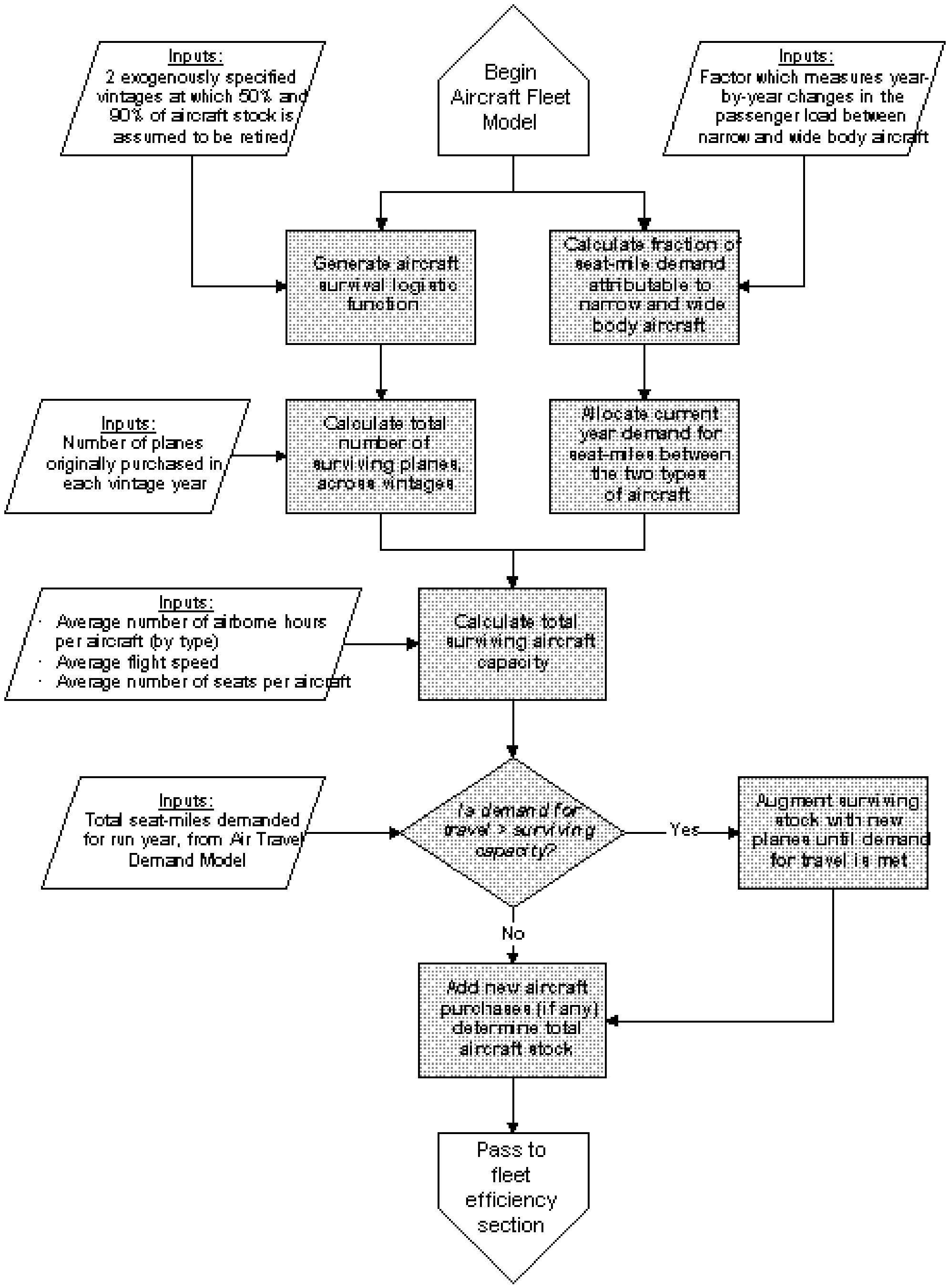
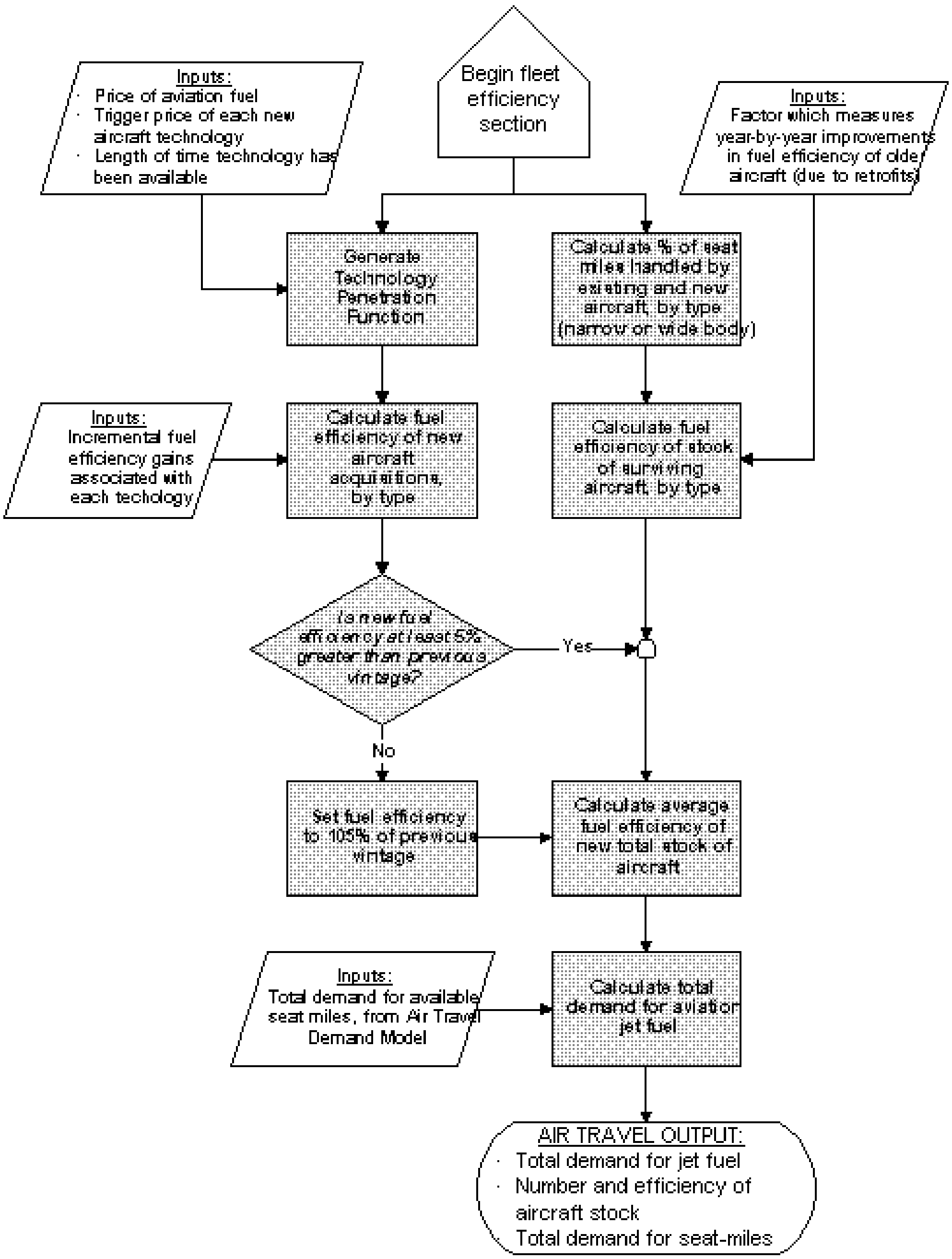


Figure 3D-5. Aircraft Fleet Efficiency Model 2: Process New Stock and Calculate Fuel Demand



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 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.[38]

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*[39] and the Association of American Railroads' *Railroad Facts*[40] were used to estimate rail ton-miles of travel; *Waterborne Commerce of the United States,*[41] 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,*[42] and growth indices of sectoral economic output from Data Resource Inc.'s macroeconomic model.[43] 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*.[44] The differences between energy intensities of various sectors have been held constant from 1977.

Figure 3E-1. Freight Transport Module

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[38] 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.

[39] *One Percent Waybill Sample*, Federal Railroad Administration, Washington, D.C., 1987.

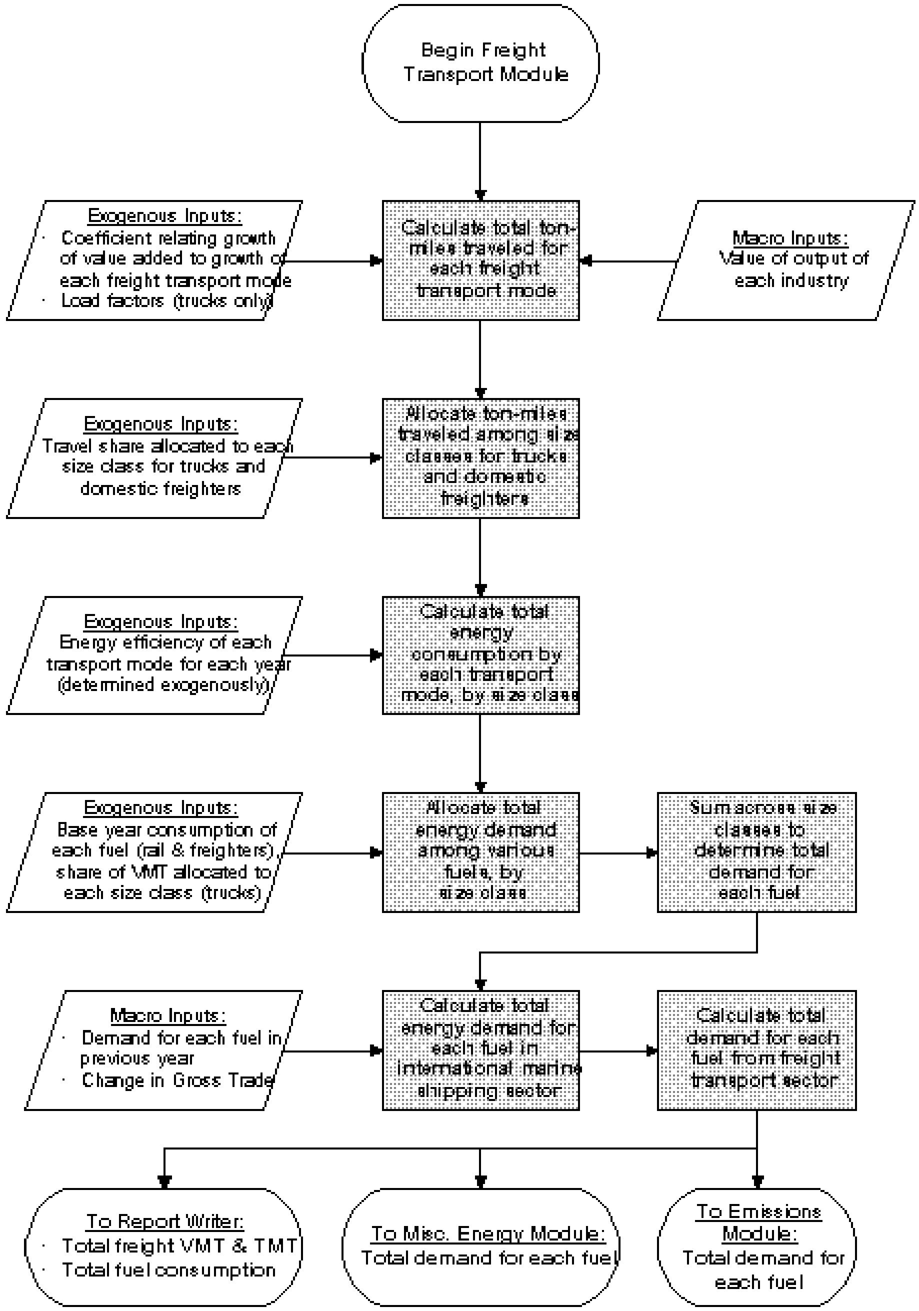
[40] *Railroad Facts*, Association of American Railroads, Washington, D.C., 1987.

[41] *Waterborne Commerce of the United States*, U.S. Army Corps of Engineers, Water Resources Support Center, New Orleans, LA, 1987.

[42] *The 1982 Truck Inventory and Use Survey: Public Use Tape*, Bureau of the Census, U.S. Department of Commerce, Washington, D.C., 1984.

[43] *The DRI Annual Model of the U.S. Economy: PC Version*, Data Resources, Inc., Lexington, MA, 1986.

[44] *Petroleum Marketing Monthly*, Energy Information Administration, U.S. Department of Energy, Washington, D.C., 1986.



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. Highway Freight Model

The growth in fuel demand by trucks is considered to be directly related to the growth in industrial output forecast for specific industries. The freight truck module will estimate the total ton-miles of highway freight, then allocate shares of that travel demand amongst the three classes of trucks considered in this component. For a given set of industries:

$$FTMT_{I,T} = FTMT_{I,T_0} \cdot FACTR_{I,Mode} \cdot \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_0}}\right] \quad \textbf{(125)}$$

where:

FTMT = Total highway freight traffic for industry I in year T
OUTPUT = Value of output of industry I, in base year dollars
FACTR = Freight adjustment coefficient for trucks
I = Index referring to NEMS industrial sector

The freight adjustment coefficients correct for the difference between the rate of growth of the value added and the freight requirements of the specified industry and mode of transport. This total freight travel demand is subsequently converted to VMT using the following relationship:

$$FVMT_{I,T} = \frac{FTMT_{I,T}}{FRLOAD_I} \quad \textbf{(126)}$$

where:

FVMT = Total freight vehicle-miles traveled for a given industry in year T
FRLOAD = Load factor associated with a given industry's output

The load factor ratios are expressed as the ratio of ton-miles traveled to vehicle-miles traveled, and are assumed to remain constant throughout the forecast. The total VMT attributed to freight trucks is the sum over all industries:

$$FVMT_T = \sum_I FVMT_{I,T} \quad \textbf{(127)}$$

The total freight VMT is next allocated among the three classes of trucks considered by the model:

$$FVMTSC_{C,T} = TS_{C,T} \cdot FVMT_T \qquad \textbf{(128)}$$

where:

FVMTSC = Total highway freight VMT, by size class
TS = Travel share allocated to trucks of class *C* in a given year
C = Index referring to truck size class

Until further research can provide an indication of how travel shares are changing over time, they will be considered constant, and allocated according to the most recent data:

$$TS_{C,T} = \frac{FVMT_{C,T_0}}{FVMT_{T_0}} \qquad \textbf{(129)}$$

Total VMT associated with each class of truck is then allocated among the various fuel technologies (such as diesel or gasoline) considered by the model:

$$FVMTECHSC_{C,TECH,T} = FVMTSC_{C,T} \cdot FLVMTSHR_{C,TECH,T} \qquad \textbf{(130)}$$

where:

FVMTECHSC = Total highway freight VMT, by size class and technology

where FLVMTSHR represents the share of each technology in total truck VMT, and is determined as follows:

$$FLVMTSHR_{C,TECH,T} = \left[\frac{FVMT_{C,TECH,T_0}}{FVMT_{C,T_0}} \right] \cdot GROWTH_{TECH} \qquad \textbf{(131)}$$

In the above equation, each technology's VMT share changes over time, according to an exogenously specified $GROWTH_{TECH}$ factor. These shares are subsequently renormalized to 1.

The next step is to calculate freight truck fuel efficiency. Efficiency improvements within the various classes of trucks also have a significant impact on fuel demand. Improvements are considered to fall into two categories: time-sensitive and price-sensitive. It is assumed that the average efficiency of each class will improve at a steady rate, as determined by historical patterns. This would be the result of simple retrofit measures used to increase aerodynamics, the retirement of older, less efficient stock, and the acquisition of newer, more efficient trucks. Increases in fuel prices are also expected to stimulate gains in efficiency, either by making technological improvements cost effective, or by encouraging the more efficient scheduling of freight shipments. These two forms of improvement are further assumed to be multiplicative:

$$PG_{C,TECH,T} = FMPG_{C,TECH,T-1} \cdot (1 + \beta1_C) \cdot \left(MAX\ \{1.0,\ \left[\frac{TPMGTR_T}{TPMGTR_{T-1}}\right]\} \right) \quad \textbf{(132)}$$

where:

$FMPG_{C,TECH,T}$ = Freight truck fuel efficiency, by size class and technology
$TPMGTR_{C,T}$ = Price of motor gasoline for trucks, from Macro Module

The time sensitivity coefficient, $\beta1_C$, is exogenously specified, and the fuel price sensitivity coefficient, $\beta2_C$, is estimated from historical trends. One final assumption holds that efficiency changes motivated by fuel price occur only in the positive sense—that is, a reduction in the price of fuel will not result in a lowering of truck efficiency.

Fuel use is subsequently estimated, using the average fuel efficiency for each class of truck:

$$FFD_{C,TECH,T} = \frac{FVMTECHSC_{C,TECH,T}}{FMPG_{C,TECH,T}} \cdot QBTU_{TECH} \quad \textbf{(133)}$$

where:

$FFD_{C,TECH,T}$ = Fuel demand for a given class of truck and fuel type
$FMPG_{C,TECH,T}$ = Fuel efficiency for each truck class
$QBTU_{TECH}$ = Heat content of fuel used by each technology, in MMBtu per gallon

This is then allocated to the nine census regions and summed over size classes:

$$TQFREIR_{TECH,R,T} = \sum_{C=1}^{3} FFD_{C,TECH,T} \cdot SEDSHRDS_{C,TECH,T} \quad \textbf{(134)}$$

where:

$TQFREIR_{TECH,T}$ = Total regional fuel consumption for each technology
$SEDSHRDS_{C,TECH,T}$ = Regional share of truck fuel consumption, from SEDS

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:

$$RTMT_T = \sum_{I=1}^{10} RTMT_{I,T_0} \cdot FACR_I \cdot \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_0}} \right] \quad (135)$$

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:

$$TQRAILT_T = FERAIL_T \cdot RTMT_T \quad (136)$$

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:

$$TQRAIL_{FUEL,T} = TQRAIL_{FUEL,T-1} \cdot \left(\frac{TQRAILT_T}{TQRAILT_{T-1}} \right) \quad (137)$$

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:

$$TQRAILR_{TECH,R,T} = TQRAIL_{C,TECH,T} \cdot SEDSHRDS_{C,TECH,T} \qquad \textbf{(138)}$$

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:

$$STMT_T = \sum_{I=1}^{10} STMT_{I,T_0} \cdot FACS_I \cdot \left[\frac{OUTPUT_{I,T}}{OUTPUT_{I,T_0}} \right] \qquad \textbf{(139)}$$

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:

$$STMT_{C,T} = TS_{C,T} \cdot STMT_T \qquad \textbf{(140)}$$

where:

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

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

$$TS_C = \frac{STMT_C}{STMT_{Total}} \quad (141)$$

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):

$$SFDT_T = FESHIP_T \cdot STMT_T \quad (142)$$

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):

$$SFD_{IF,T} = SFDT_T \cdot SFSHARE_{IF,T} \quad (143)$$

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:

$$TQSHIPR_{IF,REG,T} = SFD_{IF,T} \cdot SEDSHR_{IF,REG,T} \quad (144)$$

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:

$$ISFDT_{T} = ISFDT_{T-1} + \left[\frac{GROSST_{T}}{GROSST_{T-1}} - 1 \right] \cdot O.5 \cdot ISFDT_{T-1} \tag{145}$$

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:

$$ISFD_{IF,T} = ISFDT_{T} \cdot ISFSHARE_{IF,T} \tag{146}$$

where:

ISFD = International freighter energy demand, by fuel

ISFSHARE = International shipping fuel allocation factor

Regional fuel consumption is then calculated:

$$TQISHIPR_{IF,IR,T} = ISFD_{IF,T} \cdot SEDSHR_{IF,IR,T} \tag{147}$$

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

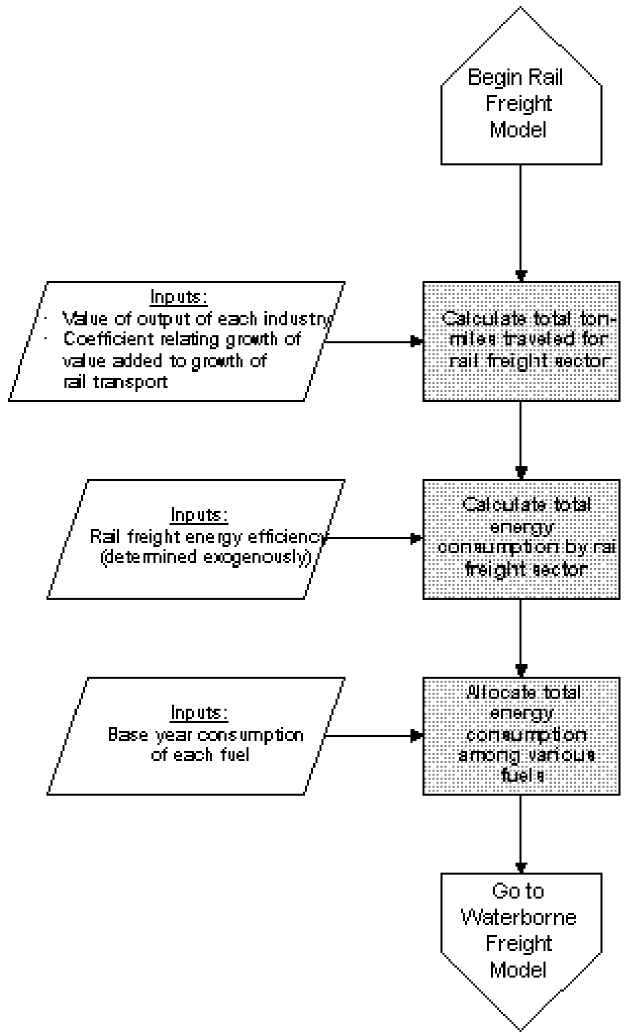
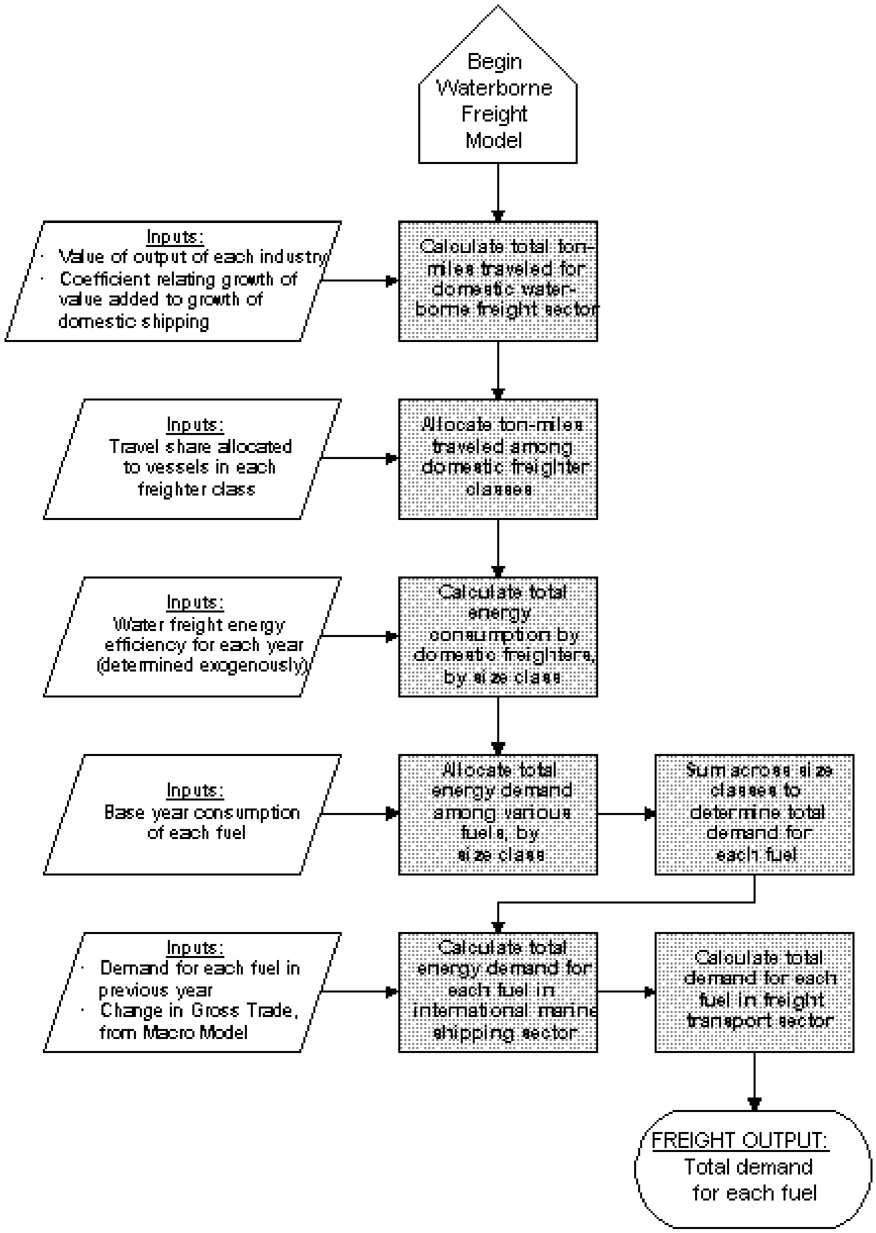


Figure 3E-4. Waterborne Freight Model



3F. Miscellaneous Energy Use Module

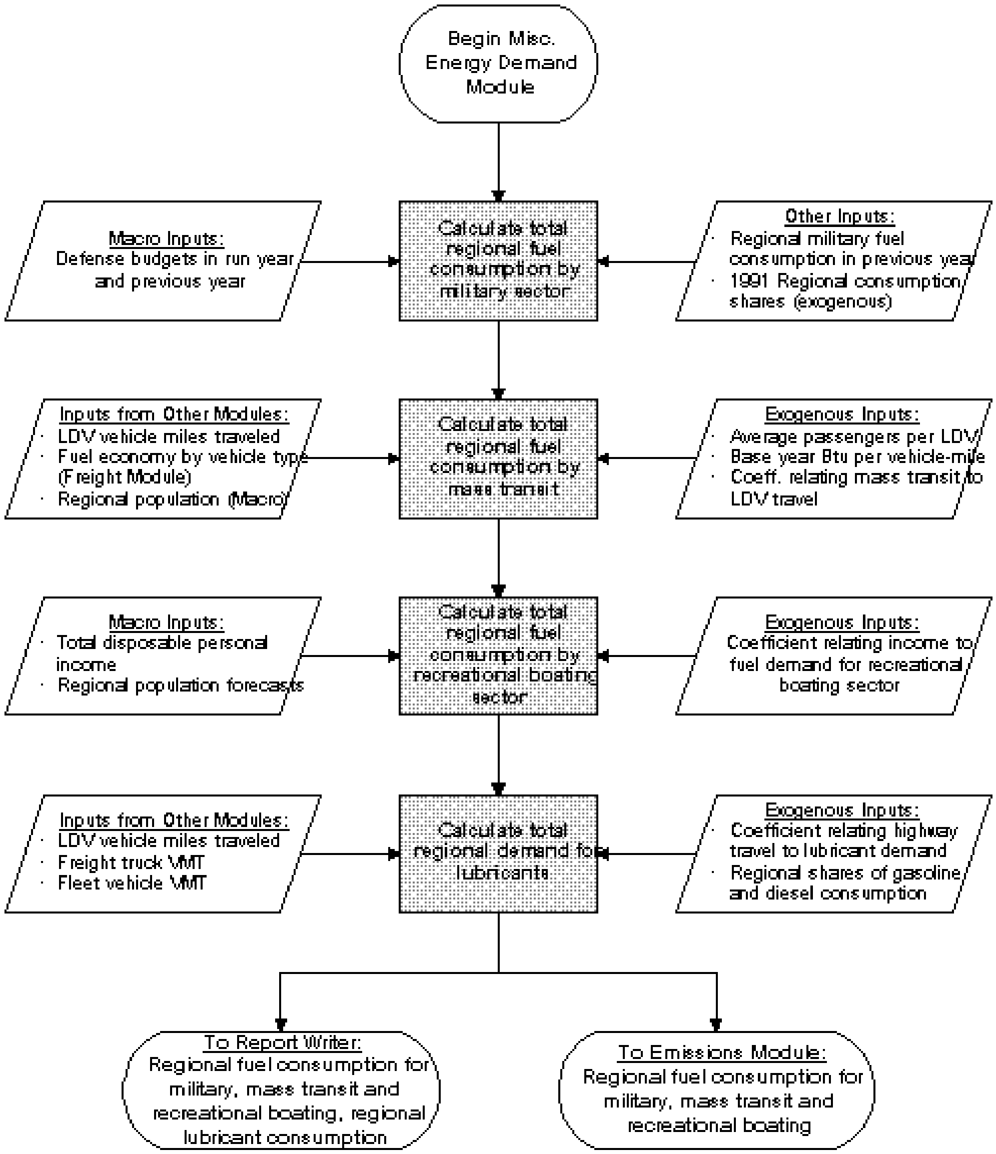
RATIONALE

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



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:

$$MILTARGR_T = \frac{TMC\_GFML87_T}{TMC\_GFML87_{T-1}} \tag{148}$$

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:

$$MFD_{IF,T} = MFD_{IF,T-1} * MILTARGR_T \tag{149}$$

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:

$$QMILTR_{IF,REG} = MFD_{IF,T} * MILTRSHR_{IF,REG} \tag{150}$$

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:

$$TMOD_{IM,T} = TMOD_{IM,T-1} * \left[\frac{TMOD_{1,T}}{TMOD_{1,T-1}} \right]^{BETAMS} \quad (151)$$

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:

$$TMEFFL_{IM,T} = \frac{\left[TMEFF89_{IM} * \left(\frac{FMPG_{TYPE,T}}{FMPG89_{TYPE}} \right) \right]}{TMLOAD89_{IM}} \quad (152)$$

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:

$$)R_{IM,IR,T} = TMOD_{IM,T} * TMEFFL_{IM,T} * \left[\frac{TMC\_POPAFO}{\sum_{IR=1}^{9} TMC\_POPAF} \right. \quad (153)$$

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:

$$RECFD_T = RECFD_{T-1} * \left[\frac{TMC\_YD_T}{TMC\_YD_{T-1}} \right]^{BETAREC} \quad \textbf{(154)}$$

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:

$$QRECR_{IR,T} = RECFD_T * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \quad \textbf{(155)}$$

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:

$$HYWAY_T = VMTEE_T + FTVMT_T + FLTVMT_T \quad \textbf{(156)}$$

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:

$$LUBFD_T = LUBFD_{T-1} * \left[\frac{HYWAY_T}{HYWAY_{T-1}} \right]^{BETALUB} \quad \textbf{(157)}$$

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:

$$FD_T * \left[\frac{\left(\left(VMTEE_T + FLTVMT_T\right) * SHRMG_{IR,T}\right) + \left(FTVM\right.}{HYWAY_T} \right. \quad \textbf{(158)}$$

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

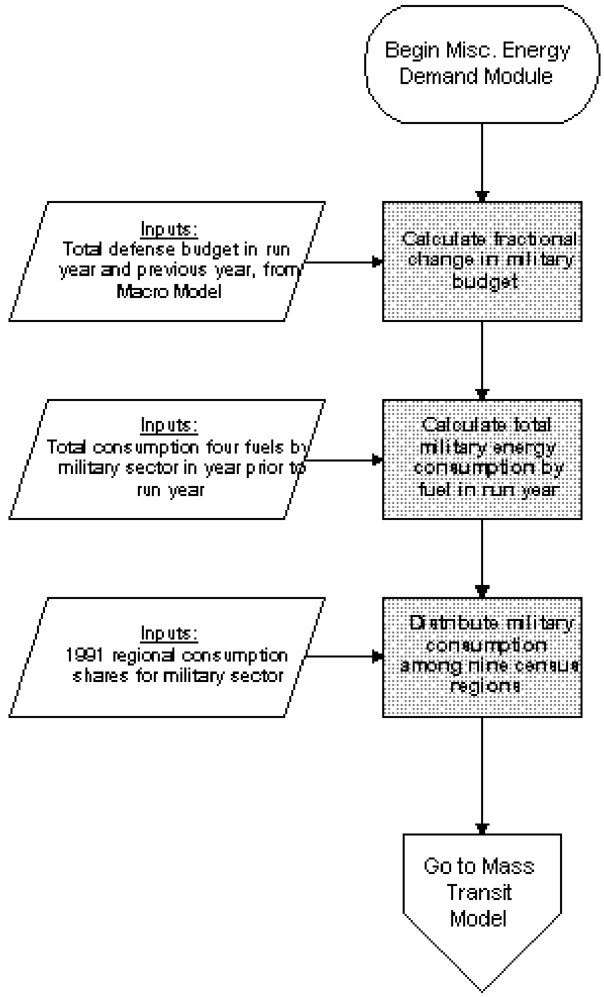


Figure 3F-3. Mass Transit Demand Model

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.

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T} \quad \textbf{(159)}$$

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

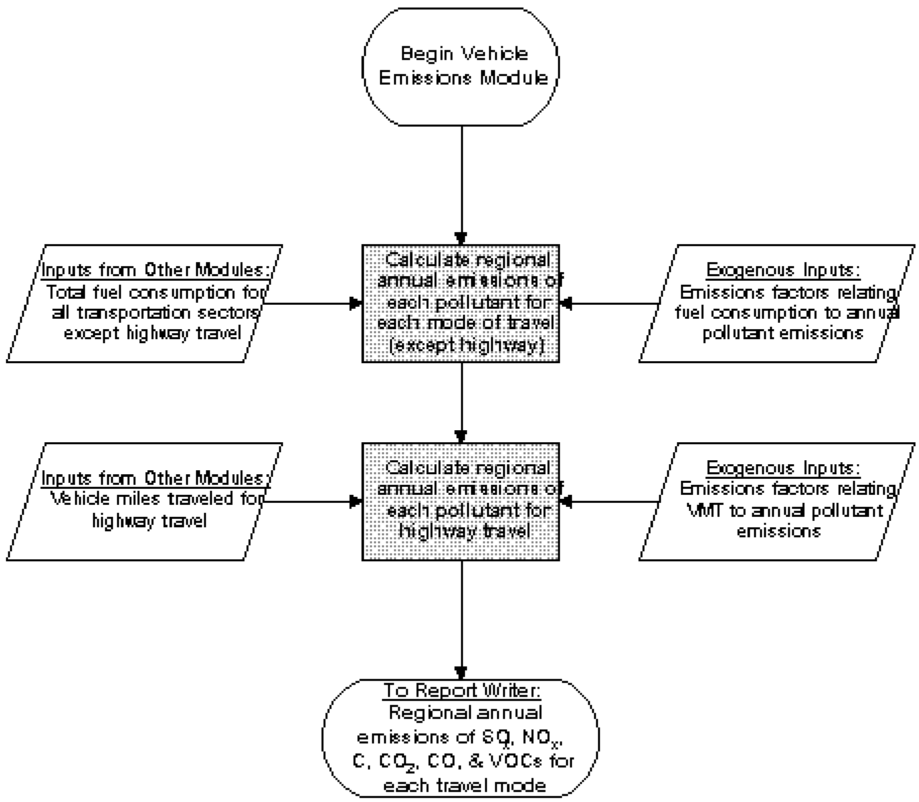
IM = Index of travel mode: references individual vehicle types used in the preceding modules

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 6.

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.[45,46] 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.[47]

Table 4-2. Car and Light Truck Fuel Economy Degradation Factors

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[45] 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.

[46] Decision Analysis Corporation of Virginia, "Fuel Efficiency Degradation Factor," Final Report, Subtask 1, prepared for: Energy Information Administration, August 3, 1992.

[47] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

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.[48]

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.[49] 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.

Table 4-3. Alternative-Fuel Vehicle Attributes For Three-Stage Logit Model

[48] Science Applications International Corporation, "Alternative-Fuel Vehicle Module Database," Draft Report, Subtask 4, Prepared for Energy Information Administration, September 15, 1992.

[49] 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.

		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.[50] 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 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

[50] California Air Resources Board, "Proposed Regulations for Low-Emission Vehicles and Clean Fuels, Staff Report," August 13, 1990.

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.[51]

Light Duty Vehicle Fleet Module

With the current focus of transportation legislation on commercial fleets and their composition, the 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

[51] U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 1990, FHWA-PL-91-003, 1990.

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.[52]

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.[53, 54] Size class sales of alternative-fuel and conventional vehicles are held constant at historical levels.[55]

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.

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

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[52] 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.

[53] 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.

[54] California Air Resources Board, "Proposed Regulations for Low-Emission Vehicles and Clean Fuels, Staff Report," August 13, 1990.

[55] 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.

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.[56] 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.

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					

[56] 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.

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.[57] A demographic index based on the propensity to fly was introduced into the air travel demand equation.[58] The propensity to fly was made a function of the age and sex group distribution over the forecast period.[59, 60] The air travel demand module assumes that these relationships between the groups and their propensity to fly remain constant over time. International revenue passenger miles is a fixed percentage of domestic revenue passenger miles based on historical data.[61] 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

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[57] U.S. Department of Transportation, Research and Special Programs Administration, Air Carrier Financial Statistics Quarterly and Monthly, December 1990/1989, and prior issues.

[58] Transportation Research Board, Forecasting Civil Aviation Activity: Methods and Approaches, Appendix A, Transportation Research Circular Number 372, June 1991.

[59] Decision Analysis Corporation of Virginia, Proposed Methodology For Projecting Air Transportation Demand, Final Report, Subtask 2, July 8, 1992.

[60] Air Transport Association of America, Air Travel Survey, Washington D.C., 1990.

[61] U.S. Department of Transportation, U.S. International Air Travel Statistics, Transportation Systems Center, Cambridge, MA, annual issues.

a constant historical annual one percent rate.[62] 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.[63, 64] Fuel efficiency of new aircraft acquisitions represent at a minimum, a five percent improvement over the stock efficiency of surviving airplanes.[65] 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

[62] U.S. Department of Transportation, Federal Aviation Administration, FAA Aviation Forecasts Fiscal Years 1993-2004, February 1993.

[63] Oak Ridge National Laboratory, Energy Efficiency Improvement of Potential Commercial Aircraft to 2010, ORNL-6622, June 1990.

[64] Oak Ridge National Laboratory, Air Transport Energy Use Model, April 1991, Draft.

[65] U.S. Department of Transportation, Federal Aviation Administration, FAA Aviation Forecasts Fiscal Years 1993-2004, February 1993.

State Energy Data Report estimate of regional jet fuel shares.[66]

Freight Transport Module

Highway Freight Model

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.[67, 68] Freight truck load factors (ton-miles per truck) by SIC code are constants formulated from historical load factors.[69] 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

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%

[66] Department of Energy, Energy Information Administration, State Energy Demand Survey, May 1993.

[67] 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.

[68] Reebie Associates, TRANSEARCH Freight Commodity Flow Database, Greenwich, Connecticutt.

[69] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

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.

relative to fuel prices are tied to historical growth rates by size class.[70] 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.[71]

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.[72, 73] Initial rail freight fuel efficiencies are based on the freight model from Argonne National Laboratory.[74] The distribution of rail fuel consumption by fuel type remains constant and is based on historical data.[75] Regional freight rail consumption estimates are distributed according to the State Energy Data Report 1991.[76]

Waterborne Freight Model

The waterborne freight model also converts industrial output by SIC code measured in dollars, to a volumetric equivalent by SIC code.[77] These freight adjustment coefficients are based on analysis of historical data[78], and remain constant throughout the forecast period. Domestic shipping

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[70] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[71] U.S. Department of Energy, Energy Information Administration, State Energy Demand Report 1991 , May 1993.

[72] 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.

[73] 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.

[74] Argonne National Laboratory, Transportation Energy Demand Through 2010, 1992.

[75] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[76] Department of Energy, Energy Information Administration, State Energy Demand Survey, May 1993.

[77] 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.

[78] Army Corp of Engineers, Waterborne Commerce of the United States, Waterborne Statistics Center, New Orleans, La., 1991.

efficiencies are based on the freight model by Argonne National Laboratory.[79] The distribution of domestic and international shipping fuel consumption by fuel type remains constant throughout the analysis, and is based on historical data.[80] Regional domestic and international shipping consumption estimates are distributed according to the State Energy Data Report 1991 residual oil regional shares.[81]

Emissions Module

The NEMS Transportation model uses the same emissions coefficients by fuel type that are contained in the Industrial Sector Module Assumptions section.

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.

[79] Argonne National Laboratory, Transportation Energy Demand Through 2010, 1992.

[80] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 13, March 1993.

[81] Department of Energy, Energy Information Administration, State Energy Demand Survey, May 1993.

Appendix A. Input Data and Parameters

LIST OF TABLES

The following table itemizes the variables, data inputs, parameters, and indices employed in each of the Transportation Model's constituent components. These variables are grouped by module, and are identified by the equation number in Appendix B in which they are first encountered. The sources of parameters and data inputs are provided immediately following this table.

Table A-1. List of Transportation Sector Model Variables

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model

ITEM	CLASS. (Source)	DESCRIPTION	UNITS	SUBROUTINE	EQ #
ACTUAL$MKT	Variable	The economic share of technology *itc*, prior to consideration of engineering or regulatory constraints.	Percent	FEMCALC	7
ADJFE	Variable	The fuel economy adjustment factor	Percent	FEMCALC	21
ADJHP	Variable	The fractional change in horspower from the previous year within a given vehicle class	Percent	FEMCALC	19
BENCHMPG	Input Data (B)	MPG benchmark factors to ensure congruence with most recent data from ORNL	—	FEMSIZE	39
CAFE	Variable	Actual CAFE values by group	Miles per Gallon	CAFECALC	34
CLASS$SHARE	Variable	Relative market share for each class. Basis for CAFE calculations	Percent	CAFECALC	31
CMKS	Variable	Class market share, subsequently reassigned to the appropriate vehicle class and group, $CLASS\$SHARE_{icl,igp}$	Percent	CMKSCALC	32
COSTEFFECT	Variable	A unitless measure of cost effectiveness	—	FEMCALC	6
DEL$COSTABS	Variable	Change in cost associated with technology *itc*	Percent	FEMCALC	4
DEL$COSTWGT	Variable	The weight-based change in cost of technology *itc*	$ per lb	FEMCALC	4
DEL$FE	Variable	The fractional change in fuel economy associated with technology *itc*	Percent	FEMCALC	3
DEL$HP	Variable	The fractional change in horsepower of technology *itc*	Percent	FEMCALC	5
DEL$MKT	Variable	The amount of the superseded technology's market share to be removed	Percent	NOTE$SUPER	26
DEL$WGTABS	Variable	The change in weight associated with technology *itc*	lbs	FEMCALC	16
DEL$WGTWGT	Variable	The fractional change in weight associated with technology *itc*	Percent	FEMCALC	4
DELTA$MKT	Variable	The change in market share for technology *itc*	Percent	FEMCALC	14
DIFF$LN	Variable	The increment from the base year (1990) of the log of the market share ratio	—	CMKSCALC	29
DISCOUNT	Parameter (A)	Discount rate used in payback calculation	Percent	FEMCALC	3

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FE	Variable	Fuel economy of technology *itc*, within seven size classes	Miles per Gallon	FEMCALC	3
FEMPG	Variable	Average fuel economy by six ORNL size classes	MPG	FEMSIZE	38
FESIXC	Variable	Fuel economy for cars within six size classes	MPG	FEMSIZE	40
FESIXT	Variable	Fuel economy for light trucks within six size classes	MPG	FEMSIZE	40
FUELCOST	Variable	Projected fuel cost	$ per MMBtu	FEMCALC	1
FUELSAVE	Variable	The expected present value of fuel savings over the payback period	$	FEMCALC	3
HP	Variable	Horsepower	HP	FEMCALC	18
icl	Index	FEM vehicle size class index (7)	—	FEMSIZE	—
igp	Index	CAFE group index: 1 = domestic car, 2 = import car, 3 = domestic light truck, 4 = import light truck	—	FEMSIZE	—
INCOME	Variable	Household income	$ per year	FEMCALC	198
ino	Index	The index identifying the technologies in the superseding group	—	NOTE$SUPER	—
isno	Index	An index indicating the superseded technology	—	NOTE$SUPER	—
itc	Index	The index representing the technology under consideration	—	FEMCALC	3
MANDMKSH	Input Data (A)	Mandatory market share	Percent	FEMCALC	9
MAP	Input Data (A)	Array of mapping constants, which converts FEM to ORNL size classes	—	FEMSIZE	35
MAPSALE	Variable	Disaggregate vehicle sales	Units	FEMSIZE	35
MAPSHR	Variable	Sales shares within the disaggregate array	Percent	FEMSIZE	37
MAX$SHARE	Input Data (A)	The maximum market share of the group, *ino*	Percent	NOTE$SUPER	25
MKT$MAX	Input Data (A)	Maximum market share of technology in given class	Percent	NOTE$SUPER	25
MKT$PEN	Variable	Market share of technology in given class and year	Percent	FEMCALC	8
MMAX	Variable	The maximum market share for technology *itc*, obtained from MKT$MAX	Percent	FEMCALC	7
N	Index	Time period index (1990 = 1)	—	FEMSIZE	—
num$sup	Index	The number of technologies in the superseding group	—	NOTE$SUPER	—
NVS7SC	Variable	New vehicle sales within the seven FEM size classes	Units	TSIZE	41
ORNLMPG	Input Data (B)	Most recent (1992) fuel economy data from ORNL	MPG	FEMSIZE	39
osc	Index	ORNL size class index (6)	—	FEMSIZE	—
PAYBACK	Input Data (A)	The user-specified payback period	Years	FEMCALC	3

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
PERFFACT	Input Data (A)	Performance factor (multiplier for horsepower adjustment)	—	FEMCALC	19
PMAX	Parameter (A)	The institutional maximum market share, which models tooling constraints on the part of the manufacturers	Percent	FEMCALC	7
PRICE	Variable	Vehicle price	$	FEMCALC	17
PRICE$EX	Variable	The expected price of fuel	$	FEMCALC	2
PSLOPE	Variable	The fuel cost slope	—	FEMCALC	1
RATIO$LN	Variable	Log of the market share ratio of the considered vehicle class	—	CMKSCALC	31
REGCOST	Variable	A factor representing regulatory pressure to increase fuel economy	$ per MPG	FEMCALC	6
REQ$MKT	Input Data (A)	The total market share of those technologies which are required for the implementation of technology *itc*, indicating that technology's maximum share	Percent	FEMCALC	10
SYNR$DEL	Input Data (A)	The synergistic effect of two technologies on fuel economy	—	FEMCALC	13
TECHCOST	Input Data (A)	The cost of technology *itc*	$	FEMCALC	4
TOT$MKT	Variable	The total market share of the considered group of technologies	Percent	NOTE$SUPER	27
TOTNVS7	Variable	Total new vehicle sales within the six ORNL size classes	Units	FEMSIZE	36
VAL$PERF	Input Data (A)	The dollar value of performance of technology *itc*	$	FEMCALC	5
VALUEPERF	Variable	The value associated with an incremental change in performance	$	FEMCALC	5
WEIGHT	Variable	The base year vehicle weight, absent the considered technology	lbs	FEMCALC	4
YEAR	Index	Year index (*YEAR* = *N*+1)	—	FEMSIZE	—

LIGHT DUTY VEHICLE MODULE: Regional Sales Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AHPCAR	Variable	Average automobile horsepower	HP	TSIZE	49
AHPTRUCK	Variable	Average light truck horsepower	HP	TSIZE	50
COMTSHR	Data Input (B)	Fraction of new light trucks dedicated to commercial freight	Percent	TSIZE	42
COSTMIR	Variable	The cost of driving in region *REG*	$ per Mile	TREG	52
DAF	Parameter (C)	A demographic adjustment factor, to reflect different age groups' driving patterns	—	TEXOG	55
FLTCRAT	Parameter (B)	Fraction of new cars purchased by fleets	Percent	TSIZE	41
FLTTRAT	Parameter (B)	Fraction of new light trucks purchased by fleets	Percent	TSIZE	42
GROUP	Index	Index indicating domestic or imported vehicles	—	TSIZE	—
HP	Variable	Vehicle horsepower by FEM size class, group	HP	TSIZE	47
HPCAR	Variable	Average horsepower of new automobiles, by size class *SC*	HP	TSIZE	47
HPTRUCK	Variable	Average horsepower of new light trucks, by size class *SC*	HP	TSIZE	48
INCOMER	Variable	Regional per capita disposable income	$	TREG	53
LTSHRR	Variable	Non-fleet market shares of light trucks, by size class *SC*	Percent	TSIZE	46
NCS	Variable	New car sales, by size class and region	Units	TREG	57
NCSTSCC	Variable	New car sales in the modified six size classes, *SC*	Units	TSIZE	43
NLTS	Variable	New light truck sales, by size class and region	Units	TREG	58
NLTSTSCC	Variable	New light truck sales in six size classes *SC*	Units	TSIZE	44
NVS7SC	Variable	New vehicle sales in the original seven FEM size classes	Units	TSIZE	43
PASSHRR	Variable	Non-fleet market shares of automobiles, by size class *SC*	Percent	TSIZE	45

LIGHT DUTY VEHICLE MODULE: Regional Sales Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
PRFEM	Data Input (D)	Ratio of female to male driving rates	—	TVMT	54
RHO	Parameter (C)	Lag factor for the VMT difference equation	—	TVMT	54
RSHR	Variable	Regional VMT shares	Percent	TREG	57
SALESHR	Data Input (B)	Fraction of vehicle sales which are domestic/imported	Percent	TSIZE	41
SEDSHR	Variable	Regional share of the consumption of a given fuel in period *T*	Percent	TREG	51
TMC_POP16	Variable	Total regional population over the age of 16	—	TMAC	55
TMC_POPAFO	Variable	Total population in region *REG*	—	TMAC	53
TMC_SQDTRUCKSL	Variable	Total light truck sales (supplied by the MACRO module)	Units	TMAC	42
TMC_SQTRCARS	Variable	Total new car sales (supplied by the MACRO module)	Units	TSIZE	41
TMC_YD	Variable	Estimated disposable personal income by region, *REG*	$	TMAC	51
VMT16R	Variable	Vehicle-miles traveled per population over 16 years of age	—	TREG	54
VMTEER	Variable	Total VMT in region *REG*	—	TREG	55

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AFCOST	Variable	Alternative vehicle fuel price	$ per MMBtu	TALT3	60
APSHR11	Variable	Relative market shares of each aggregate technology	Percent	TALT1	76
APSHR22	Variable	Relative market shares of each AFV technology	Percent	TALT2	72
APSHR33	Variable	Relative market shares of each EV technology	Percent	TALT3	68
APSHR44	Variable	Absolute market shares of each technology	Percent	TALT1	79
BETACONST	Parameter (F)	Constant associated with each considered technology *IT*	—	TALT3	66
BETACONST1	Parameter (F)	Constant associated with each considered technology	—	TALT1	74

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
BETACONST2	Parameter (F)	Constant associated with each considered AFV technology	_	TALT2	70
BETAEM	Parameter (F)	Coefficient associated with vehicle emissions	—	TALT3	66
BETAEM2	Parameter (F)	Coefficient associated with the square of vehicle emissions	—	TALT3	66
BETAFA	Parameter (F)	Coefficient associated with fuel availability	—	TALT3	66
BETAFA2	Parameter (F)	Coefficient associated with the square of fuel availability	—	TALT3	66
BETAFC	Parameter (F)	Coefficient associated with fuel cost	$(\$)^{1}$	TALT3	66
BETAVP	Parameter (F)	Coefficient associated with vehicle price	$(\$)^{1}$	TALT3	66
BETAVR	Parameter (F)	Coefficient associated with vehicle range	$(\text{Miles})^{1}$	TALT3	66
BETAVR2	Parameter (F)	Coefficient associated with the square of vehicle range	$(\text{Miles})^{2}$	TALT3	66
COMAV	Input Data (E)	Commercial availability of each AFV technology	—	TALT3	59
COPCOST	Variable	Fuel operating costs for each AFV technology	Cents per Mile	TALT3	65
COPCOST1	Variable	Fuel operating costs for conventional and alternative vehicles	Cents per mile	TALT1	74
COPCOST2	Variable	Fuel operating costs for alternative vehicles	Cents per mile	TALT2	70
EMISS1	Input Data (E)	Emissions levels relative to gasoline ICE's	—	TALT1	74
EMISS2	Input Data (E)	AFV emissions levels relative to gasoline ICE's	—	TALT2	70
EMISS3	Input Data (E)	EV emissions levels relative to gasoline ICE's	Percent	TALT3	66
EVC1	Variable	Exponentiated value of vehicle utility vector	—	TALT1	75
EVC2	Variable	Exponentiated value of alternative vehicle utility vector	—	TALT2	71
EVC3	Variable	Exponentiated value of electric vehicle utility vector	—	TALT3	67
FAVAIL	Input Data (E)	Availability of each alternative fuel relative to gasoline	Percent	TALT3	60
FAVAIL11	Input Data (E)	Fuel availability for conventional and alternative technologies	Percent	TALT1	74
FAVAIL22	Input Data (E)	Alternative technology fuel availability	Percent	TALT2	70
FAVAIL33	Input Data (E)	Fuel availability for EV technologies	Percent	TALT3	66
FEC3SC	Variable	Automobile fuel economy within the three reduced size classes	MPG	TALT3	61

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FET3SC	Variable	Light truck fuel economy within the three reduced size classes	MPG	TALT3	62
IT	Index	Index of the sixteen engine technologies considered by the model	—	TALT3	—
RFP	Variable	Regional fuel price	Dollars per MMBtu	TALT3	50
TT50	Input Data (X)	The exogenously specified year in which 50% of the demand for technology *IT* can be met	Year	TALT3	59
VC1	Variable	Utility vector for conventional and alternative vehicles	—	TALT1	74
VC1	Variable	Utility vector for conventional and alternative vehicles	—	TALT1	74
VC2	Variable	Utility vector for alternative vehicles	—	TALT2	70
VC3	Variable	Utility vector for electric vehicles	—	TALT3	66
VEFF	Input Data (E)	Fuel economy of technology *IT*, relative to gasoline baseline	—	TALT3	64
VEFFACT	Variable	Baseline efficiency of gasoline ICE's, in MPG	Miles per MMBtu	TALT3	63
VPRICE1	Input Data (E)	Price of each considered technology in 1990$	1990 $	TALT1	74
VPRICE2	Input Data (E)	Price of each considered AFV technology in 1990$	1990 $	TALT2	70
VPRICE3	Input Data (E)	Price of each considered EV technology in 1990$	1990 $	TALT3	66
VRANGE1	Input Data (E)	Vehicle range of the considered technology	Miles	TALT1	74
VRANGE2	Input Data (E)	Vehicle range of the considered AFV technology	Miles	TALT2	70
VRANGE3	Input Data (E)	Vehicle range of the considered EV technology	Miles	TALT3	66

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ADJVMTPC	Variable	Demographically-adjusted per capita VMT	Vehicle-miles	TVMT	142
AMPGC	Variable	The average MPG of cars within the reduced AFV size class	Miles per gallon	TMPGSTK	129
AMPGT	Variable	The average MPG of trucks within the reduced AFV size class	Miles per gallon	TMPGSTK	129
ANCMPG	Variable	Average new car MPG	Miles per gallon	TMPGSTK	133
ANTMPG	Variable	Average new light truck MPG	Miles per gallon	TMPGSTK	133
APSHRNC	Variable	Absolute market share of new cars, by technology, from the AFV model	Percent	TMPGSTK	133
APSHRNT	Variable	Absolute market share of new light trucks, by technology, from the AFV model	Percent	TMPGSTK	133
ASC	Index	The three AFV size classes, onto which the six primary size classes are mapped	—		—
CCMPGLDV	Variable	New car MPG, by technology *IT*	MPG	TMPGAG	156
CMPGSTK	Variable	Automobile stock MPG, by vintage and technology	Miles per gallon	TMPGSTK	135
CMPGT	Variable	Automobile stock MPG	Miles per gallon	TMPGSTK	135
COSTMI	Variable	Cost of driving per mile	$ per mile	TVMT	139
DAF	Input Data (C)	Demographic adjustment factor	—	TVMT	142
FLTECHSAL	Variable	Fleet sales by size, technology, and fleet type	Units	TMPGAG	153
FLTECHSALT	Variable	Vehicle purchases by fleet type and technolgy	Units	TMPGAG	153
FLTECHSTK	Variable	Total fleet vehicle stock, by technology and fleet type	Units	TMPGAG	155
FLTMPG	Variable	Fleet vehicle MPG by vehicle type, size class, and technology	MPG	TMPGAG	154
FLTMPGNEW	Variable	New fleet vehicle MPG, by vehicle type and technology *ITECH*	MPG	TMPGAG	156
FLTSTOCK	Variable	New fleet stock, by vehicle type and technology *ITECH*	Units	TMPGAG	155
FLTVMT	Variable	Fleet VMT	Vehicle-miles	TVMT	144
FLVMTSHR	Variable	VMT-weighted shares by size class and technology	Percent	TFREISMOD	148
FVMTSC	Variable	Freight VMT by size class	Vehicle-miles	TVMT	144
INCOME	Variable	Per capita disposable personal income	$	TVMT	140
IS	Index	Index of size class (1-3)	—	TMPGAG	—
IT	Index	Index of vehicle technology (1-16)	—	TMPGAG	—
IT2	Index	Reassigned indices of vehicle technology *IT2* = 1-16; *IT* = 16,15,1-14	—	TMPGAG	—

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ITECH	Index	Index of fleet vehicle technologies which correspond to the *IT* index	—	TMPGAG	—
ITY	Index	Index of fleet type: Business, Government, Utility	—	TMPGAG	—
LTSTK	Variable	Surviving light truck stock, by technology and vintage	Units	TSMOD	120
LVMT	Variable	Average light truck VMT, by vintage, from RTECS	Vehicle miles traveled	TEXOG	134
MPGC	Variable	New car fuel efficiency, by engine technology	Miles per gallon	TMPGSTK	131
MPGC	Variable	New car MPG, by technology *IT*	MPG	TMPGAG	156
MPGFLT	Variable	Stock MPG for all light duty vehicles	Miles per gallon	TMPGSTK	137
MPGT	Variable	New light truck fuel efficiency, by engine technology	Miles per gallon	TMPGSTK	131
MPGTECH	Variable	Average stock MPG by technology	MPG	TMPGSTK	138
NCMPG	Variable	New car MPG, from the FEM model	Miles per gallon	TMPGSTK	132
NCS3A	Variable	New car sales by reduced size class and engine technology: *IS* = 1, *OSC* = 1,6; *IS* = 2, *OSC* = 2,3; *IS* = 3, *OSC* = 4,5	Units	TMPGSTK	125
NCS3SC	Variable	Total new car sales by reduced size class	Units	TMPGSTK	127
NCSR	Variable	Regional new car sales by reduced size class	Units	TMPGSTK	126
NCSTECH	Variable	New car sales, by region, size class, and technology, from the AFV Module	Units	TSMOD	119
NLT3A	Variable	New light truck sales by reduced size class and technolgy: *IS* = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6	Units	TMPGSTK	125
NLTECH	Variable	New light truck sales, by region, size class, and technology	Units	TSMOD	119
NLTMPG	Variable	New light truck MPG, from the FEM model	Miles per gallon	TMPGSTK	132
NLTS3SC	Variable	Total new light truck sales by reduced size class	Units	TMPGSTK	127
NLTSR	Variable	Regional new light truck sales by reduced size class	Units	TMPGSTK	126
NNCSCA	Variable	New conventional car sales by six size classes	Units	TMPGSTK	128
NNLTCA	Variable	New conventional light truck sales by six size classes	Units	TMPGSTK	128
OLDFSTK	Variable	Number of fleet vehicles rolled over into corresponding private categories	Units	TSMOD	122
PASSTK	Variable	Surviving automobile stock, by technology and vintage	Units	TSMOD	120
PrFem	Data Input (C)	The ratio of per capita female driving to per capita male driving.	—	TVMT	141

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
PVMT	Variable	Average automobile VMT, by vintage, from RTECS	Vehicle miles traveled	TEXOG	134
RATIO	Variable	Light truck MPG adjustment factor	—	TMPGSTK	130
RHO	Parameter (C)	Difference equation lag factor, estimated, using the Cochrane-Orcutt iterative procedure, to be 0.72	—	TVMT	141
SCMPG	Variable	Stock MPG for automibles	Miles per gallon	TMPGSTK	136
SSURVLT	Input Data (B)	Fraction of a given vintage's light trucks which survive	Percent	TSMOD	120
SSURVP	Input Data (B)	Fraction of a given vintage's automobiles which survive	Percent	TSMOD	120
STKCAR	Variable	Total stock of non-fleet automobiles in year *T*	Units	TSMOD	123
STKCT	Variable	Stock of non-fleet vehicles, by technology	Units	TMPGAG	158
STKTR	Variable	Total stock of non-fleet light trucks in year *T*	Units	TSMOD	123
STMPG	Variable	Stock MPG for light trucks	Miles per gallon	TMPGSTK	136
STOCKLDV	Variable	Total stock of fleet and non-fleet vehicles, by technology	Units	TMPGAG	158
TECHNCS	Variable	Non-fleet new car sales, by technology *IT*	Units	TMPGAG	156
TECHNCS	Variable	Total new car sales, by technology	Units	TSMOD	119
TECHNLT	Variable	Total new light truck sales, by technology	Units	TSMOD	119
TECHNLT	Variable	Non-fleet new light truck sales, by technology *IT*	Units	TMPGAG	157
TLDVMPG	Variable	Average fuel economy of light-duty vehicles	MPG	TMPGAG	161
TMC_POPAFO	Variable	Total population, from MACRO module	Units	TVMT	140
TMC_SQDTRUCKSL	Variable	Total light truck sales, from MACRO module	Units	TFREISMOD	147
TMC_YD	Variable	Total disposable personal income, from MACRO module	$	TVMT	140
TMPGLDVSTK	Variable	Average MPG by vehicle type *VT*	MPG	TMPGAG	160
TMPGT	Variable	Light truck stock MPG	Miles per gallon	TMPGSTK	135
TOTMICT	Variable	Total miles driven by cars	Miles	TMPGSTK	134
TOTMITT	Variable	Total miles driven by light trucks	Miles	TMPGSTK	134
TPMGTR	Variable	Price of motor gasoline	$ per gallon	TVMT	139
TRFLTMPG	Variable	Average light truck MPG	MPG	TFREISMOD	152
TRSAL	Variable	Light truck sales for freight	Units	TFREISMOD	147
TRSALTECH	Variable	Light truck sales by technology	Units	TFREISMOD	148
TRSTK	Variable	Total light truck stock	Units	TFREISMOD	151
TRSTKTECH	Variable	Light truck stock by technology	Units	TFREISMOD	149
TRSTKTOT	Variable	Total light truck stock by technology	Units	TFREISMOD	150

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
TSTOCKLDV	Variable	Total stock by vehicle type *VT*	Units	TMPGAG	159
TTMPGLDV	Variable	New light truck MPG, by technology *IT*	MPG	TMPGAG	157
TTMPGSTK	Variable	Light truck stock MPG, by vintage and technology	Miles per gallon	TMPGSTK	135
VDF	Input Data (N)	Vehicle fuel efficiency degradation factor	Percent	TMPGSTK	135
VMTECH	Variable	Personal travel VMT by technology	Vehicle-miles	TVMT	145
VMTEE	Variable	VMT for personal travel	Vehicle-miles	TVMT	144
VMTLDV	Variable	Total VMT for light duty vehicles	Vehicle-miles	TVMT	143
VSPLDV	Variable	The light duty vehicle shares of each of the sixteen vehicle technologies	Percent	TSMOD	124
VT	Index	Index of vehicle type: 1 = cars, 2 = light trucks	—	TMPGAG	—
XLDVMT	Variable	Fractional change of VMT over base year (1990)	Percent	TVMT	146

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
APSHR55	Variable	Absolute regional market shares of adjusted vehicle sales	Percent	TLEGIS	102
APSHRFLTB	Variable	Market shares of business fleet by vehicle type and technology	Percent	TLEGIS	106
APSHRFLTB	Variable	Alternative technology shares for the business fleet	Percent	TLEGIS	84
APSHRFLTOT	Variable	Aggregate market shares of fleet vehicle technologies	Percent	TLEGIS	105
APSHRNC	Variable	Market shares of new cars by technology	Percent	TLEGIS	104
APSHRNT	Variable	Market shares of new light trucks by technology	Percent	TLEGIS	104
AVSALES	Variable	Regional adjusted vehicle sales by size class	Units	TLEGIS	97
AVSALEST	Variable	Total regional adjusted vehicle sales by size class	Units	TLEGIS	100
ELECVSAL	Variable	Regional electric vehicle sales	Units	TLEGIS	92
ELECVSALSC	Variable	Regional ZEV sales within corresponding regions	Units	TLEGIS	96
EPACT	Parameter (H)	Legislative mandates for AFV purchases, by fleet type	Percent	TEXOG	81
FLTALT	Variable	Number of AFV's purchased by each fleet type in a given year	Units	TFLTSTKS	81
FLTAPSHR1	Input Data (G)	Fraction of each fleets' purchases which are AFV's, from historical data	Percent	TEXOG	81
FLTCONV	Variable	Fleet purchases of conventional vehicles	Units	TFLTSTKS	82
FLTCRAT	Input Data (G)	Fraction of total car sales attributed to fleets	Percent	TEXOG	80
FLTCSHR	Input Data (G)	Fraction of fleet cars purchased by a given fleet type	Percent	TEXOG	80
FLTECH	Variable	Vehicle purchases by fleet type and technology	Units	TFLTSTKS	85
FLTECHSAL	Variable	Fleet sales by size, technology, and fleet type	unts	TFLTSTKS	84
FLTECHSHR	Input Data (G)	Alternative technology shares for the government and utility fleets	Percent	TEXOG	84
FLTFCLDVBTU	Variable	Fuel consumption by vehicle type and technology	MMBtu	TFLTCONS	117
FLTFCLDVBTUR	Variable	Regional fuel consumption by fleet vehicles, by technology	MMBtu	TFLTCONS	118
FLTLDVC	Variable	Fuel consumption by technology, vehicle and fleet type	MMBtu	TFLTCONS	116
FLTMPG	Variable	New fleet vehicle fuel efficiency, by fleet type and engine technology	Miles per Gallon	TFLTMPG	110
FLTMPGTOT	Variable	Overall fuel efficiency of new fleet cars and light trucks	MPG	TFLTMPG	112
FLTSAL	Variable	Sales to fleets by vehicle and fleet type	Units	TFLTSTKS	80
FLTSLSCA	Variable	Fleet purchases of AFV's, by size class	Units	TFLTSTKS	83
FLTSLSCC	Variable	Fleet purchases of conventional vehicles, by size class	Units	TFLTSTKS	83

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FLTSSHR	Input Data (G)	Percentage of fleet vehicles in each size class, from historical data	Percent	TEXOG	83
FLTSTKVN	Variable	Fleet stock by fleet type, technology, and vintage	Units	TFLTSTKS	86
FLTTOTMPG	Variable	Fleet vehicle average fuel efficiency for cars and light trucks	Miles per Gallon	TFLTMPG	115
FLTTRAT	Input Data (G)	Fraction of total truck sales attributed to fleets	Percent	TEXOG	80
FLTTSHR	Input Data (G)	Fraction of fleet trucks purchased by a given fleet type	Percent	TEXOG	80
FLTVMT	Variable	Total VMT driven by fleet vehicles	Vehicle Miles Traveled	TFLTVMTS	108
FLTVMTECH	Variable	Fleet VMT by technology, vehicle type, and fleet type	Vehicle Miles Traveled	TFLTVMTS	109
FLTVMTYR	Variable	Annual miles of travel per vehicle, by vehicle and fleet type	Miles	TFLTVMTS	108
FMSHC	Variable	The market share of fleet cars, from the AFV model	Percent	TFLTMPG	110
FMSHLT	Variable	The market share of fleet light trucks, from the AFV model	Percent	TFLTMPG	110
IR	Index	Corresponding regions: *ST* = CA, MA, NY; *IR* = 9,1,2	—	TLEGIS	—
IS	Index	Index of size classes: 1 = small, 2 = medium, 3 = large	—	TFLTSTKS	—
ITECH	Index	Index of engine technologies: 1-5 = alternative fuels (neat), 6 = gasoline	—	TFLTSTKS	—
ITF	Index	Index of fleet vehicle technologies, corresponding to *IT* = 3,5,7,8,9	—	TLEGIS	—
ITY	Index	Index of fleet type: 1 = business, 2 = government, 3 = utility	—	TFLTVMTS	—
MAXVINT	Index	Maximum *IVINT* index associated with a given vehicle and fleet type	—	TFLTMPG	—
MPGFLTSTK	Variable	Fleet MPG by vehicle and fleet type, and technology, across vintages	Miles per Gallon	TFLTMPG	114
MPGFSTK	Variable	Fleet MPG by vehicle and fleet type, technology, and vintage	Miles per Gallon	TFLTMPG	113
NAMPG	Variable	New AFV fuel efficiency, from the AFV model	Miles per Gallon	TALT3	110
NCSTECH	Variable	Regional new car sales by technology, within six size classes: *OSC* = 1-6; *IS* = 2,1,1,3,3,2	Units	TLEGIS	107
NLTECH	Variable	Regional light truck sales by technology, with six size classes: *OSC* = 1-6; *IS* = 1,2,1,3,2,3	Units	TLEGIS	107
OLDFSTK	Variable	Old fleet stocks of given types and vintages, transferred to the private sector	Units	TFLTSTKS	87
QBTU	Input Data (I)	Energy content of the fuel associated with each technology	Btu/Gal	TFLTCONS	117

LIGHT DUTY VEHICLE FLEET MODULE

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
RSHR	Variable	Regional VMT shares, from the Regional Sales Module	Percent	TREG	118
ST	Index	Index of participating state: CA, MA, NY	—	TLEGIS	—
STATESHR	Variable	Share of national vehicle sales attributed to a given state	Percent	TLEGIS	94
SURVFLTT	Input Data (G)	Survival rate of a given vintage	Percent	TFLTSTKS	86
TFLTECHSTK	Variable	Total stock within each technology and fleet type	Units	TFLTSTKS	88
TMC_SQDTRUCKSL	Variable	Total light truck sales in a given year	Units	TMAC	80
TMC_SQTRCARS	Variable	Total automobile sales in a given year	Units	TMAC	80
TOTFLTSTK	Variable	Total of all surviving fleet vehicles	Units	TFLTSTKS	89
ULEV	Data Input (J)	State-mandated minimum sales share of ULEV's	Percent	TLEGIS	94
ULEVST	Variable	State-mandated minimum sales of ULEV's	Units	TLEGIS	94
VFSTKPF	Variable	Share of fleet stock by vehicle type and technology	Percent	TFLTSTKS	90
VSALES	Variable	Total disaggregate vehicle sales	Units	TLEGIS	91
VSALESC16	Variable	Total new car sales by technology: *IS* = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5	Units	TLEGIS	103
VSALEST	Variable	Total regional vehicle sales, by size class	Units	TLEGIS	93
VSALEST16	Variable	Total new light truck sales by technology: *IS* = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6	Units	TLEGIS	103
VT	Index	Index of vehicle type: 1 = cars, 2 = light trucks	—	TFLTSTKS	—
ZEV	Data Input (J)	State-mandated minimum sales share of ZEV's	Percent	TLEGIS	94
ZEVST	Variable	State-mandated minimum sales of ZEV's	Units	TLEGIS	94
ZEVSTSC	Variable	Mandated ZEV sales by size class and state	Units	TLEGIS	95

AIR TRAVEL MODULE: Air Travel Demand Model

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
DFRT	Parameter (O)	Fraction of freight ton-miles transported on dedicated carriers.	Percent	TAIRT	199
DI	Parameter (O)	Demographic air travel index, reflecting public's propensity to fly	—	TAIRT	201
EQSM	Input Data (O)	Equivalent seat-miles conversion factor; used to transform freight RTMs to seat-miles	—	TAIRT	204
LFDOM	Parameter (O)	Load factor, the average fraction of seats which are occupied in domestic travel.	Percent	TAIRT	204
LFINTER	Parameter (O)	Load factor for international travel.	Percent	TAIRT	204

AIR TRAVEL MODULE: Air Travel Demand Model

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
OPCST	Input Data (O)	Airline operating costs.	Dollars per Aircraft-Mile	TAIRT	195
PCTINT	Parameter (O)	Proportionality factor relating international to domestic travel levels	—	TAIRT	198
RPMB	Variable	Revenue passenger miles of domestic travel for business purposes.	Passenger Miles	TAIRT	200
RPMBPC	Variable	Per capita domestic RPM for business travellers.	Miles per Capita	TAIRT	196
RPMD	Variable	Total domestic revenue passenger miles.	Passenger Miles	TAIRT	203
RPMI	Variable	Revenue passenger miles of international travel.	Passenger Miles	TAIRT	202
RPMIPC	Variable	Per capita international RPM	Miles per Capita	TAIRT	198
RPMP	Variable	Revenue passenger miles of domestic travel for personal purposes.	Passenger Miles	TAIRT	201
RPMPPC	Variable	Per capita domestic RPM for personal travel.	Miles per Capita	TAIRT	197
RTM	Variable	Revenue ton miles of cargo.	Ton Miles	TAIRT	199
ASMDEMD	Variable	Total seat-miles demanded for domestic and international travel	Seat Miles	TAIRT	204
TMC_GDP	Variable	Real gross domestic product	Dollars per Capita	TMAC	196
TMC_POPAFO	Variable	U.S. population	People	TMAC	196
TMC_YD	Variable	Real gross disposable personal income	Dollars per Capita	TMAC	197
TPJFTR	Variable	Price of Jet Fuel.	Dollars per Gallon	TMAC	195
YIELD	Variable	Airline revenue per passenger mile	Dollars per Passenger-Mile	TAIRT	195

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
AGD	Variable	Demand for aviation gasoline, in gallons	Gallons	TAIREFF	226
AGDBTU	Variable	Aviation gasoline demand, in Btu	Btu	TAIREFF	224
AIRHRS	Input Data (P)	Average number of airborne hours per aircraft, by type.	Hours per Year	TAIREFF	205
ASMDEMD	Variable	Demand for available seat-miles, by aircraft type	Seat Miles	TAIREFF	207
ASMP	Variable	The available seat-miles per plane, by type	Seat Miles	TAIREFF	205

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AVSPD	Input Data (P)	Average flight speed, by type.	Miles per Hour	TAIREFF	205
BASEAGD	Parameter	Baseline demand for aviation gasoline	Gallons	TAIREFF	223
BASECONST	Parameter	Baseline constant, used to anchor the technology penetration curve	—	TAIREFF	216
COSTFX	Parameter	Factor reflecting the magnitude of the difference between the price of jet fuel and the trigger price of the considered technology	—	TAIREFF	215
DELTA	Parameter	User-specified rate of passenger shifts between aircraft types	—	TAIREFF	206
EFFIMP	Input Data (P)	Fractional improvement associated with a given technology	Percent	TAIREFF	218
FRACIMP	Variable	Fractional improvement over base year (1990) fuel efficiency, by type	Percent	TAIREFF	218
GAMMA	Parameter (P)	Baseline adjustment factor	—	TAIREFF	223
IFX	Index	Index of technology improvements (1-6)	—	TAIREFF	—
IT	Index	Index of aircraft type: 1 = narrow body, 2 = wide body	—	TAIREFF	—
IVINT	Index	Index of aircraft vintage	—	TAIREFF	—
IYEAR	Index	Current year	—	TAIREFF	—
JFBTU	Variable	Jet fuel demand, in Btu	Btu	TAIREFF	224
JFGAL	Variable	Consumption of jet fuel, in gallons	Gallons	TAIREFF	222
KAPPA	Parameter (P)	Exogenously-specified decay constant	—	TAIREFF	223
NEWSMPG	Variable	Average seat-miles per gallon of new aircraft purchases	SMPG	TAIREFF	219
NPCHSE	Variable	Number of aircraft purchased, by body type.	Aircraft	TAIREFF	209
NSURV	Variable	Number of surviving aircraft, by body type.	Aircraft	TAIREFF	212
QAGR	Variable	Regional demand for aviation gasoline	Btu	TAIREFF	225
QJETR	Variable	Regional demand for jet fuel	Btu	TAIREFF	225
RHO	Parameter (P)	Average historic rate of growth of fuel efficiency	—	TAIREFF	220
SEAT	Input Data (P)	Average number of seats per aircraft, by type.	Seats per Aircraft	TAIREFF	205
SMFRACN	Variable	Fraction of seat-mile demand on narrow-body planes	Percent	TAIREFF	206
SMFRACN	Variable	Fraction of seat miles handled by surviving stock and new purchases, by type.	——	TAIREFF	221
SMPG	Variable	Average seat miles per gallon for new purchases and surviving fleet, by type.	Seat Miles per Gallon	TAIREFF	219
SMPGT	Variable	Overall fleet average seat-miles per gallon	SMPG	TAIREFF	221

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
SMSURV	Variable	Surviving travel capacity by body type.	Seat Miles	TAIREFF	209
SSURVPCT	Parameter (P)	Marginal survival rate of planes of a given vintage	Percent	TAIREFF	208
STKOLD	Variable	Fraction of planes older than one year, by aircraft type	Percent	TAIREFF	213
SURVK	Parameter (P)	User-specified proportionality constant	—	TAIREFF	208
SURVPCT	Input Data (P)	Survival rate of planes of a given vintage *IVINT*	Percent	TAIREFF	208
T50	Parameter (P)	User-specified vintage at which stock survival is 50%	Years	TAIREFF	208
TIMECONST	Parameter (P)	User-specified scaling constant, reflecting the importance of the passage of time	—	TAIREFF	214
TIMEFX	Parameter (P)	Factor reflecting the length of time an aircraft technology improvement has been commercially viable	—	TAIREFF	214
TOTALFX	Parameter (P)	Overall effect of fuel price and time on implementation of technology *IFX*	—	TAIREFF	216
TPJFGAL	Variable	Price of jet fuel	$ per Gallon	TAIREFF	215
TPN	Variable	Binary variable (0,1) which tests whether current fuel price exceeds the considered techology's trigger price	—	TAIREFF	214
TPZ	Variable	Binary variable which tests whether implementation of the considered technology is dependent on fuel price	—	TAIREFF	215
TRIGPRICE	Parameter (P)	Price of jet fuel above which the considered technology is assumed to be commercially viable	$ per Gallon	TAIREFF	215
TYRN	Variable	Binary variable which tests whether current year exceeds the considered technology's year of introduction	—	TAIREFF	215
XAIR	Variable	Fractional change in air travel from base year	Percent	TAIREFF	226
XAIREFF	Variable	Fractional change in aircraft fuel efficiency from base year	Percent	TAIREFF	226

FREIGHT TRANSPORT MODULE

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
FAC	Input Data (Q)	Freight Adjustment Coefficient—relates growth in value added in industry I to growth in freight transportation	—	TFREI	162
FBENCH	Parameter (I)	Benchmarking factor to ensure congruence with 1990 data	—	TFREI	168
FERAIL	Input Data (B)	Rail fuel efficiency	Miles per gallon	TRAIL	182

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FESHIP	Input Data (B)	Domestic freighter fuel efficiency		TSHIP	188
FFD	Variable	Truck Fuel Demand, by type of fuel and class of vehicle.	MMBtu	TFREI	176
FFDT	Variable	Total fuel demand, by technology, in MMBtu	Gallons	TFREI	178
FFMPG	Variable	Average truck fuel economy for second size class for use in TMISC	MPG	TFREI	177
FFVMT	Variable	Total freight truck vehicle-miles traveled in industry group *IX*	Vehicle-miles	TFREI	165
FLVMTSHR	Variable	Share of fuel technology in total truck VMT	Percent	TFREI	169
FMPG	Variable	Truck Fuel Efficiency, by class of truck.	Miles per Gallon	TFREI	174
FRLOAD	Parameter (Q)	Load factor associated with a given industry's output	—	TFREI	163
FSHR	Variable	Adjusted technology share of VMT demand	Percent	TFREI	169
FTMT	Variable	Total highway freight traffic, by industry	Ton Miles	TFREI	162
FTOTVMT	Variable	Total VMT demand for trucks	Vehicle miles	TFREI	166
FVMT	Variable	Freight transport demand by class of truck.	Vehicle Miles	TFREI	163
FVMTECHSC	Variable	Total highway freight VMT, by size class and fuel technology	Vehicle Miles	TFREI	172
FVMTSC	Variable	Total highway freight VMT, by size class	Vehicle Miles	TFREI	168
GROSST	Variable	Value of gross trade (imports + exports)	$	TSHIP	191
GROWTH	Parameter	Factor which specifies changes in truck VMT by each fuel technology over time	—	TFREI	169
IF	Index	Index of fuel type	—	TRAIL	—
IS	Index	Index of truck size class (1-3)	—	TFREI	—
ISFD	Variable	International freighter energy demand, by fuel	MMBtu	TSHIP	192
ISFDT	Variable	Total international shipping energy demand	MMBtu	TSHIP	191
ISFSHARE	Parameter (B)	International shipping fuel allocation factor	—	TSHIP	192
IX	Index	Place holder for industry group	—	TFREI	—
OUTPUT	Variable	Value of output of each industry in base year dollars.	Dollars	TFREI	162
QBTU	Input Data (I)	Heat content of fuel used by each technology	MMBtu per gallon	TFREI	176
RTMT	Variable	Total rail freight traffic, by industry	Ton Miles	TRAIL	180
RTMTT	Variable	Total rail ton-miles traveled	Ton Miles	TRAIL	181
SEDSHR	Parameter (K)	Regional shares of shipping fuel demand	Percent	TFREI	179
SFD	Variable	Domestic freighter energy demand, by fuel	MMBtu	TSHIP	189

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
SFDBENCH	Parameter (I)	Benchmark factor to ensure congruence with 1990 data	—	TSHIP	188
SFDT	Variable	Domestic freighter energy demand	MMBtu	TSHIP	188
SFSHARE	Parameter (B)	Domestic shipping fuel allocation factor	—	TSHIP	189
STMT	Variable	Total waterborne freight traffic, by industry	Ton Miles	TSHIP	186
STMTT	Variable	Total ship ton-miles traveled	Ton Miles	TSHIP	187
SUMFVMT	Variable	Total freight VMT for the second size class for use in TMISC	Vehicle Miles	TFREI	173
TBETA1	Parameter	Base rate of fuel economy growth, by size class	Percent	TFREI	174
TBETA2	Parameter	Fuel-price sensitive rate of fuel economy growth, by size class	Percent	TFREI	174
TECH	Index	Index of engine technology (1-5)	—	TFREI	—
TMC_YD	Variable	Disposable personal income, from the MACRO module	$	TFREI	165
TPMGTR	Variable	Price of motor gasoline used for highway transport	$ per Gallon	TFREI	174
TQFREIR	Variable	Total regional truck fuel consumption for each technology	MMBtu	TFREI	179
TQFREIRSC	Variable	Total regional freight energy demand by technology and size class	MMBtu	TFREI	179
TQISHIPR	Variable	Total regional energy demand by international freighters	MMBtu	TSHIP	193
TQRAIL	Variable	Total demand for each fuel by rail freight sector in year *T*	MMBtu	TRAIL	183
TQRAILR	Variable	Total regional rail fuel consumption for each technology	MMBtu	TRAIL	184
TQRAILT	Variable	Total energy consumption by freight trains in year *T*	MMBtu	TRAIL	182
TQSHIPR	Variable	Total regional energy demand by domestic freighters, by fuel type	MMBtu	TSHIP	190
TRSCSHR	Input Data (B)	Travel share distribution factors, held constant	—	TFREI	168
TSIC	Variable	Value of output of industry *I*, in base year (1990) dollars	$	TFREI	162
TSIC90	Input Data (I)	Base year value of industrial output	$	TFREI	165
TYD8290	Input Data (I)	Base year disposable personal income	$	TFREI	165
XFREFF	Variable	Fuel economy improvement over base year	Percent	TFREI	175
XRAIL	Variable	Growth in rail travel from base year	Percent	TRAIL	185
XRAILEFF	Variable	Growth in rail efficiency from base year	Percent	TRAIL	185
XSHIP	Variable	Growth in ship travel from base year	Percent	TSHIP	194

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
XSHIPEFF	Variable	Growth in ship efficiency from base year	Percent	TSHIP	194
XTOTVMT	Variable	Fractional growth in freight VMT over base year	Percent	TFREI	167

MISCELLANEOUS ENERGY DEMAND MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
BETALUB	Parameter (K)	Coefficient of proportionality, relating highway travel to lubricant demand	—	TMISC	238
BETAMS	Parameter (B)	Coefficient of proportionality, relating mass transit to LDV travel	—	TMISC	230
BETAREC	Parameter (B)	Coefficient of proportionality relating income to fuel demand for boats	—	TMISC	234
FLTVMT	Variable	Total fleet vehicle VMT, from the Fleet Module	Vehicle Miles	TFLTVMTS	237
FMPG	Variable	Fuel efficiency for mass transit vehicles, by vehicle type, from the Freight Module	Miles per gallon	TFREI	231
FMPG89	Data Input (B)	Base-year fuel efficiency for mass transit vehicles, by vehicle type, from the Freight Module	Miles per gallon	TEXOG	231
FTVMT	Variable	Total freight truck VMT, from the Freight Module	Vehicle Miles	TMISC	236
FVMTSC	Variable	Freight truck VMT, by size class		TMISC	236
HYWAY	Variable	Total highway VMT	Vehicle Miles	TMISC	237
IF	Index	Index of fuel type: 1=Distillate, 2=Naphtha, 3=Residual, 4=Kerosene	—	TMISC	—
IM	Index	Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail	—	TMISC	—
IM	Index	Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail		TMISC	—
LUBFD	Variable	Total demand for lubricants in year T	MMBtu	TMISC	238
MFD	Variable	Total military consumption of each fuel in year T	MMBtu	TMISC	228
MILTARGR	Variable	The growth in the military budget from the previous year	Percent	TMISC	227
MILTRSHR	Input Data (L)	Regional consumption shares, from 1991 data, held constant	Percent	TMISC	229
QLUBR	Variable	Regional demand for lubricants in year T	MMBtu	TMISC	239
QMILTR	Variable	Regional military fuel consumption, by fuel type	MMBtu	TMISC	229
QMODR	Variable	Regional consumption of fuel, by mode	MMBtu	TMISC	233
QRECR	Variable	Regional fuel consumption by recreational boats in year T	MMBtu	TMISC	235
RECFD	Variable	National recreational boat gasoline consumption in year T	MMBtu	TMISC	234
TMC_GFML87	Variable	Total defense budget in year T, from the macro economic segment of NEMS	$	TMAC	227
TMC_POPAFO	Variable	Regional population forecasts, from the Macro Module	People	TMAC	233
TMC_YD	Variable	Total disposable personal income, from the Macro Module	$	TMAC	234
TMEFF89	Input Data (B)	Base-year Btu per vehicle-mile, by mass transit mode	Btu per vehicle mile	TMISC	231

MISCELLANEOUS ENERGY DEMAND MODULE

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
TMEFFL	Variable	Btu per passenger-mile, by mass transit mode	Btu per passenger mile	TMISC	231
TMFD	Variable	Total mass-transit fuel consumption by mode	Gallons	TMISC	232
TMOD	Variable	Passenger-miles traveled, by mode	Passenger miles	TMISC	230
TMLOAD89	Data Input (B)	Average passengers per vehicle, by mode, held constant at 1989 values (1=LDV's)	Units	TMISC	230
TYPE	Index	Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail	—	TFREI	231
VMTEE	Variable	LDV vehicle-miles traveled, from the VMT module	Vehicle miles	TVMT	230

TRANSPORTATION EMISSIONS MODULE

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
EFACT	Parameter (M)	Emissions factor relating measures of travel to pollutant emissions	—	TEMISS	240
EMISS	Variable	Regional emissions of a given pollutant, by mode of travel	Tons per year	TEMISS	240
IE	Index	Index of pollutants: 1 = SO_x, 2 = NO_x, 3 = C, 4 = CO_2, 5 = CO, 6 = VOC	—	TEMISS	240
IM	Index	Index of travel mode: references individual vehicle types used in the preceding modules	—	TEMISS	240
IR	Index	Index identifying census region	—	TEMISS	240
U	Variable	Measure of travel demand, by mode: units in VMT for highway travel, gallons of fuel consumption for other modes	—	TEMISS	240

SOURCES OF DATA INPUTS AND PARAMETERS USED IN THE NEMS TRANSPORTATION MODEL

CODE	**SOURCE**
A	*Conventional Light-Duty Vehicle Fuel Economy*, Decision Analysis Corporation of Virginia and Energy and Environmental Analysis, Inc., Prepared For: Energy Information Administration, U.S. Department of Energy, Washington D.C., November, 1992.
B	*Transportation Energy Data Book: Edition 12*, Oak Ridge National Laboratory, Prepared For: Office of Transportation Technologies, U.S. Department of Energy, Washington, D.C., March 1992.
C	*Revised VMT Forecasting Model*, Unpublished Memorandum, U.S. Department of Energy, February 22, 1993.
D	*1990 National Personal Transportation Survey*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 1992.
E	*Alternative-Fuel Vehicle Module*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
F	*Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey*, D. S. Bunch, *et. al.*, University of California, Davis, UCD-ITS-RR-91-14, December 1991.
G	*Fleet Vehicles in the United States*, Oak Ridge National Laboratories, Prepared For: Office of Transportation Technologies and Office of Policy, Planning and Analysis, U.S. Department of Energy, Washington, D.C., March 1992.
H	*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*, Office of Domestic and International Energy Policy, U.S. Department of Energy, May 1992.
I	*Annual Energy Outlook 1993*, Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, D.C., January 1993.
J	*Proposed Regulations for Low-Emission Vehicles and Clean Fuels*, State of California Air Resources Board, August 13, 1990.
K	*State Energy Data Survey 1991*, Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, Washington, D.C., May 1993.
L	*Fuel Oil and Kerosene Sales 1991*, Energy Information Administration, Office of Oil and Gas, U.S. Department of Energy, Washington D.C., November 1992.
M	*Emissions Regulations, Inventories, and Emission Factor for the NEMS Transportation Energy and Research Forecasting Model*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
N	*Fuel Efficiency Degradation Factor*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1992.
O	*Proposed Methodology for Projecting Air Transportation Demand*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., July 1992.
P	*Preliminary Estimation of the NEMS Aircraft Fleet Efficiency Module*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
Q	*Freight Transportation Requirements Analysis for the NEMS Transportation Sector Model*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1992.

Table A-2. Light Duty Vehicle Market Classes

CLASS	DEFINITION	EXAMPLE MODEL
	AUTOMOBILES (Domestic and Import)	
Minicompact	Interior passenger volume < 79 ft^3	Geo Metro, Toyota Paseo (no domestic cars)
Subcompact	Passenger volume between 79 ft^3 and 89 ft^3	Nissan Sentra, Honda Civic, GM Saturn, Ford Escort
Sports	Two door high performance cars costing less than $25,000	VW Corrado, Honda Prelude, Chevy Camaro, Ford Mustang
Compact	Passenger volume between 89 and 95 ft^3	Honda Accord, Toyota Camry, Ford Tempo, Pontiac Grand Am
Intermediate	Passenger volume between 96 and 105 ft^3	Nissan Maxima, Ford Taurus, Chevy Lumina
Large	Passenger volume >105 ft^3	Ford Crown Victoria, Pontiac Bonneville (no imports)
Luxury	Cars over $25,000	Lincoln Continental, Cadillac, all Mercedes, Lexus LS400
	LIGHT TRUCKS (Domestic and Import)	
Compact Pickup	Trucks with inertia weight between 2750 and 4000 lbs.	All import trucks, Ford Ranger, GM S-10/15
Compact Van	Vans with inertia weight between 3000 and 4250 lbs.	All import vans, Plymouth, Voyager, Ford Aerostar
Compact Utility	Utility vehicles with inertia weight between 3000 and 4250 lbs.	Nissan Pathfinder, Toyota SR-5, Ford Bronco II, Jeep Cherokee
Standard Pickup	Trucks with inertia weight over 4000 lbs.	GM C-10, Ford F-150 (no imports)
Standard Van	Vans with inertia weight over 4250 lbs.	GM C15 van, Ford E-150 (no imports)
Standard Utility	Utility vehicles with inertia weight over 4250 lbs.	Toyota Land Cruiser, GM Suburban, Ford Blazer
Mini-truck	Utility/trucks below 2750 lbs. inertia weight	Suzuki Samurai (no domestics)

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

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

Table A-4. Aircraft Fleet Efficiency Model Adjustment Factors

Year	DI	PCTINT	DFRT
1979	0.974	0.27	0.509
1980	0.976	0.32	0.523
1981	0.978	0.30	0.514
1982	0.980	0.28	0.509
1983	0.982	0.27	0.508
1984	0.985	0.28	0.522
1985	0.988	0.28	0.518
1986	0.991	0.25	0.520
1987	0.994	0.28	0.540
1988	0.996	0.30	0.545
1989	0.998	0.33	0.551
1990	1.000	0.35	0.555
1991	1.003	0.38	0.564
1992	1.004	0.40	0.569
1993	1.005	0.41	0.573
1994	1.007	0.42	0.577
1995	1.008	0.43	0.579
1996	1.007	0.44	0.584
1997	1.007	0.45	0.585
1998	1.006	0.46	0.591
1999	1.006	0.46	0.593
2000	1.005	0.47	0.598
2001	1.003	0.47	0.601
2002	1.001	0.48	0.604
2003	0.998	0.48	0.604
2004	0.996	0.48	0.604
2005	0.994	0.48	0.604
2006	0.992	0.49	0.604
2007	0.989	0.49	0.604
2008	0.987	0.49	0.604
2009	0.985	0.49	0.604
2010	0.983	0.49	0.604
2011	0.980	0.49	0.604
2012	0.978	0.49	0.604
2013	0.975	0.50	0.604
2014	0.972	0.50	0.604
2015	0.970	0.50	0.604
2016	0.967	0.50	0.604
2017	0.965	0.50	0.604
2018	0.962	0.50	0.604
2019	0.960	0.50	0.604
2020	0.957	0.50	0.604
2021	0.956	0.50	0.604
2022	0.954	0.50	0.604
2023	0.952	0.50	0.604
2024	0.951	0.50	0.604
2025	0.949	0.50	0.604
2026	0.948	0.50	0.604
2027	0.946	0.50	0.604
2028	0.944	0.50	0.604
2029	0.943	0.50	0.604
2030	0.941	0.50	0.604

Table A-5. List of Expected Aircraft Technology Improvements

Proposed Technology	Intro. Year	Jet Fuel Price[1] ('87 $/Gal)	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%

[1] These figures represent the minimum jet fuel prices (1987 $) at which the corresponding technologies are assumed to become cost-effective.

Appendix B. Mathematical Representation

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Introduction

This appendix provides a detailed mathematical description of the transportation model. Equations are presented in the order in which they are encountered in the code, identified by subroutine and model component. 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.

In the interest of clarity, initialization statements, variable name reassignments, and error-trapping tests are omitted, except where such descriptions are essential to an understanding of the process. Representative equations are also employed in those instances where the model specifies numerous, but essentially identical, calculations (most notably in the emissions component).

FUEL ECONOMY MODEL Subroutine FEMCALC

1) Calculate the fuel cost slope, used to linearly extrapolate expected fuel cost over the desired payback period:

$$SLOPE = \frac{MAX\ (0\ , FUELCOST_{YEAR-3}\ -\ FUELCOST_{YEAR-5}}{2} \qquad \textbf{(B-1)}$$

where:

PSLOPE = The fuel cost slope
FUELCOST = The cost of fuel in the specified prior years

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

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

where:

$PRICE\$EX_i$ = The expected price of fuel

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

$$SAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{itc,YEAR-1}} - \frac{1}{(1 + DEL\$FE_{itc} * FE_{itc,YEA}} \right. * PRICE\$EX_i * (1 + DISCOUNT)^{-i} \qquad \textbf{(B-3)}$$

where:

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

4) Calculate the cost of technology *itc*:

$$ECHCOST_{itc} = DEL\$COSTABS_{itc} - \Big(DEL\$COSTWGT_{itc} * DEL\$WGTWGT_{itc} * WEIGHT_{BASEY} \qquad \text{(B-4)}$$

where:

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

5) Calculate the perceived value of performance associated with technology *itc*:

$$PERF_{itc} = VALUEPERF_{itc} * \frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} * \frac{FE_{YEAR-1} * (1 + DEL\$}{FE_{YEAR-1}} * \frac{FUELCOST_{YEAR-1}}{PRICE\$EX_1} * DEL\$HP_{itc} \qquad \text{(B-5)}$$

where:

VAL\$PERF = The dollar value of performance of technology *itc*
VALUEPERF = The value associated with an incremental change in performance
DEL\$HP = The fractional change in horsepower of technology *itc*
PRICE\$EX = The expected price of fuel
FUELCOST = The actual price of fuel (in the previous year)

6) Calculate the cost effectiveness of technology *itc*:

$$= \frac{FUELSAVE_{itc} - TECHCOST_{itc} + VAL\$PERF_{itc} + \Big(REGCOST * FE_{YEA}}{ABS\left(TECHCOST_{itc}\right)} \qquad \text{(B-6)}$$

where:

COSTEFFECT = A unitless measure of cost effectiveness
REGCOST = A factor representing regulatory pressure to increase fuel economy
TECHCOST = The cost of the considered technology
VAL\$PERF = The performance value associated with technology *itc*

7) Calculate the preliminary economic market share of technology *itc*:

$$UAL\$MKT_{itc} = MMAX_{itc} * PMAX_{itc} * \left(1 + e^{-2 * COSTEFFECT} \right. \quad \text{(B-7)}$$

where:

ACTUAL$MKT = The economic share, prior to consideration of engineering or regulatory constraints. The subsequent adjusted value is stored in the variable MKT$PEN.

MMAX = The maximum market share for technology *itc*, obtained from MKT$MAX

PMAX = The institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in the subroutine FUNCMAX.

8) Ensure that existing technologies maintain market share in the absence of competing technologies:

$$CTUAL\$MKT_{itc} = MAX\,(\,MKT\$PEN_{YEAR-1}\ ,\ ACTUAL\$MKT_{it} \quad \text{(B-8)}$$

where:

$MKT\$PEN_{Year-1}$ = The previous year's market share of technology *itc*

9) Apply mandatory constraints:

$$ACTUAL\$MKT_{itc} = MAX\left(ACTUAL\$MKT_{itc}\ ,\ MANDMKSH_{itc}\right. \quad \text{(B-9)}$$

where:

MANDMKSH = The minimum market share of technology *itc* required by legislative mandate.

10) Apply required engineering constraints (following a call to the subsequent subroutine NOTE$SUPER):

a) Sum the market shares of the required technologies (*req*):

$$REQ\$MKT = MIN\left(\sum_{req} ACTUAL\$MKT_{req}\ ,\ 1.0\right) \quad \text{(B-10)}$$

where:

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

b) Compare REQ$MKT to the market share of technology referred to by the engineering note, $ACTUAL\$MKT_{itc}$, selecting the smaller share:

$$ACTUAL\$MKT_{itc} = MIN\left(ACTUAL\$MKT_{itc}\ ,\ REQ\$MKT\right) \quad \textbf{(B-11)}$$

11) Assign the preliminary market share value to the permanent variable:

$$MKT\$PEN_{icl,igp,itc,year} = ACTUAL\$MKT_{itc} \quad \textbf{(B-12)}$$

where:

MKT$PEN = The market penetration of technology *itc* by vehicle group *igp* and vechilce class *icl*

12) Apply synergistic engineering constraints to those technologies whose combination provide non-additive benifits to fuel economy:

$$\text{-}E_{YEAR} + \left(MKT\$PEN_{itc1,YEAR} - MKT\$PEN_{itc1,YEAR-1}\right)$$
$$* \left(MKT\$PEN_{itc2,YEAR} - MKT\$PEN_{itc2,YEAR-1}\right) * SYNR \quad \textbf{(B-13)}$$

where:

itc1 = First synergistic technology

itc2 = Second synergistic technology

SYNR$DEL = The synergistic effect of the two technologies on fuel economy

13) Calculate the change in market share for a given technology:

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,YEAR} - MKT\$PEN_{itc,YEAR-1} \quad \textbf{(B-14)}$$

where:

$DELTA\$MKT_{itc}$ = The change in market share for technology *itc*

14) Calculate current fuel economy for the considered vehicle class:

$$FE_{YEAR} = FE_{YEAR-1} + \sum_{itc=1}^{NUMTECH} FE_{YEAR-1} * DELTA\$MKT_{itc} * DEL\$FE_{itc} \quad \textbf{(B-15)}$$

where:

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

15) Calculate average vehicle weight for the considered class:

$$GHT_{YEAR} = WEIGHT_{YEAR-1} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \left[DEL\$WGTABS_{i} \right. \\ \left. + \left(WEIGHT_{BASEYR} * DEL\$WGTWG \right.\right. \quad \textbf{(B-16)}$$

where:

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

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

$WEIGHT_{BASEYEAR}$ = The base year vehicle weight, absent the considered technology

16) Calculate the average vehicle price for the considered class:

$$PRICE_{YEAR} = PRICE_{YEAR-1} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \left[DEL\$COSTABS_{itc} \right. \\ \left. + (WEIGHT_{YEAR} - WEIGHT_{BASEYR}) * DEL\$COSTWGT_{itc} \right] \quad \textbf{(B-17)}$$

where:

DEL$COSTABS = The cost of technology *itc*

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

17) Calculate horsepower, assuming a constant weight to horsepower ratio:

$$HP_{YEAR} = HP_{BASEYR} * \frac{WEIGHT_{YEAR}}{WEIGHT_{BASEYR}} \quad \textbf{(B-18)}$$

where:

$HP_{BASEYEAR}$ = The base year average horseposer for the considered vehicle class

18) Calculate the horsepower adjustment factor:

$$\text{'ERFFACT} * \left[\left(\frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} \right)^{0.9} * \left(\frac{PRICE_{YEAR-1}}{PRICE_{YEAR}} \right)^{0.9} * \left(\cdot \right. \right.$$

$$* \left(\frac{FUELCOST_{YEAR-1}}{FUELCOST_{YEAR}} \right)^{0.} \qquad \textbf{(B-19)}$$

where:

ADJHP = The fractional change in horsepower from the previous year within a given vehicle class
INCOME = Household income
PRICE = Vehicle price
FE = Vehicle fuel economy
FUELCOST = Fuel price

19) Calculate current year horsepower, summing incremental changes from the initial year:

$$HP_{YEAR} = HP_{YEAR} * \left(1 + \sum_{1990}^{YEAR} ADJHP \right) \quad \textbf{(B-20)}$$

20) Calculate fractional change in fuel economy due to horsepower change:

$$FE = -0.22 * ADJHP - 0.560 * ADJHP^{2} \quad ; \quad ADJHP$$
$$FE = -0.22 * ADJHP + 0.560 * ADJHP^{2} \quad ; \quad ADJHP \quad \textbf{(B-21)}$$

where:

ADJFE = The fuel economy adjustment factor

21) Calculate the adjusted fuel economy:

$$FE = FE * (1 + ADJFE) \quad \textbf{(B-22)}$$

22) Calculate the vehicle price, adjusted for the change in performance:

$$PRICE = PRICE + ADJHP * VALUEPERF \quad \textbf{(B-23)}$$

FUEL ECONOMY MODEL Subroutine NOTE$SUPER

This subroutine is called from subroutine FEMCALC in order to check whether new technologies have superseded older ones. Affected technologies are grouped in a hierarchy, and market shares are adjusted so that the sum does not exceed the maximum market penetration of the group.

1) Calculate aggregate market share of superseding technologies:

$$TOT\$MKT = \sum_{ino=1}^{num\$sup} ACTUAL\$MKT_{ino} \qquad \textbf{(B-24)}$$

where:

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

2) Establish the maximum market share for the group:

$$MAX\$SHARE = MAX\ (\ MKT\$MAX_{ino}\ ) \qquad \textbf{(B-25)}$$

--where:

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

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

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

$$MKT = MIN\Big((\ TOT\$MKT - MAX\$SHARE\ )\ ,\ ACTUAL\$MI \qquad \textbf{(B-26)}$$

where:

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

b) Adjust total market share to reflect this decrement

$$TOT\$MKT = TOT\$MKT - DEL\$MKT \qquad \textbf{(B-27)}$$

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

$$ACTUAL\$MKT_{isno} = ACTUAL\$MKT_{isno} - DEL\$MKT \qquad \textbf{(B-28)}$$

These values are returned to the preceding subroutine.

FUEL ECONOMY MODEL Subroutine CMKSCALC

1) Calculate incremental change in class market share ratio:

a) For all vehicles except luxury cars:

$$\$LN = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR} - \$13,}{INCOME_{1990} - \$13,}\right. \qquad \textbf{(B-29)}$$

where:

DIFF$LN = The increment from the base year (1990) of the log of the market share ratio

b) For luxury cars:

$$* \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\right. \qquad \textbf{(B-30)}$$

2) Solve for the log-share ratio:

$$RATIO\$LN = DIFF\$LN + \ln\left(\frac{CLASS\$SHARE_{1990}}{1 - CLASS\$SHARE_{1990}}\right) \qquad \textbf{(B-31)}$$

where:

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

3) Solve for the class market share:

$$CMKS = \frac{EXP\ (RATIO\$LN)}{1 + EXP\ (RATIO\$LN)} \qquad \textbf{(B-32)}$$

where:

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

4) Normalize so that shares total 100% within each CAFE group:

$$CLASS\$SHARE_{icl,igp,YEAR} = \frac{CLASS\$SHARE_{icl,igp,YEAR}}{\sum_{icl=1}^{7} CLASS\$SHARE_{icl,igp,YEAR}} \qquad \textbf{(B-33)}$$

FUEL ECONOMY MODEL — Subroutine CAFECALC

1) Calculate the Corporate Average Fuel Economy for each of the four CAFE groups:

$$CAFE_{icl,igp,YEAR} = \frac{\sum_{icl=1}^{7} CLASS\$SHARE_{icl,igp,YEAR}}{\sum_{icl=1}^{7} \frac{CLASS\$SHARE_{icl,igp,YEAR}}{FE_{icl,igp,YEAR}}} \qquad \textbf{(B-34)}$$

where:

icl = FEM vehicle size class index (7)

igp = CAFE group index: 1 = domestic car, 2 = import car, 3 = domestic light truck, 4 = import light truck

REGIONAL SALES MODEL — Subroutine FEMSIZE

This subroutine maps vehicle sales and fuel economy generated for the seven size classes considered in the Fuel Economy Model (FEM) into the six vehicle size classes used in subsequent sectors.

1) Map vehicle sales from seven size classes to six:

$$MAPSALE_{igp,icl,osc,N} = NVS7SC_{igp,icl,N} * MAP_{igp,icl,osc} \quad \text{(B-35)}$$

where:

MAPSALE = Disaggregate vehicle sales
NVS7SC = New vehicle sales within the seven FEM size classes, calculated in subroutine TSIZE
MAP = Array of mapping constants, which converts FEM to ORNL size classes
osc = ORNL size class index (6)
N = Time period index (1990 = 1)

2) Sum across sales within each size class:

$$TOTNVS7 = \sum_{icl=1}^{7} MAPSALE_{igp,icl,osc,N} \quad \text{(B-36)}$$

where:

TOTNVS7 = Total new vehicle sales within the six ORNL size classes

3) Create a mapping share:

$$MAPSHR_{igp,icl,osc,N} = \frac{MAPSALE_{igp,icl,osc,N}}{TOTNVS7_{igp,osc,N}} \quad \text{(B-37)}$$

where:

MAPSHR = Sales shares within the disaggregate array

4) Multiply MPG by mapped sales share:

$$FEMPG_{igp,osc,N} = \sum_{icl=1}^{7} FE_{icl,igp,YEAR} * MAPSHR_{igp,icl,osc,N} \quad \text{(B-38)}$$

where:

FEMPG = Average fuel economy by six ORNL size classes
FE = Average fuel economy by seven FEM size classes
YEAR = Year index (*YEAR* = *N*+1)

5) Create benchmark factors for each CAFE group *igp*, held constant after 1992:

$$BENCHMPG_{igp,osc} = \frac{ORNLMPG_{igp,osc}}{FEMPG_{igp,osc,N=3}} \qquad \textbf{(B-39)}$$

where:

BENCHMPG = MPG benchmark factors to ensure congruence with most recent data from ORNL
ORNLMPG = Most recent (1992) fuel economy data from ORNL

6) Apply the benchmark factor to each size class, combining domestic and imported vehicles:

$$\ldots_{osc,N} = \sum_{igp=1}^{2} FEMPG_{igp,osc,N} * BENCHMPG_{igp,osc} * ORNLS\ldots$$

$$\ldots_{osc,N} = \sum_{igm=3}^{4} FEMPG_{igp,osc,N} * BENCHMPG_{igp,osc,} * ORNLS\ldots \qquad \textbf{(B-40)}$$

where:

FESIXC = Fuel economy for cars within six size classes
FESIXT = Fuel economy for light trucks within six size classes

REGIONAL SALES MODEL Subroutine TSIZE

1) Estimate non-fleet, non-commercial sales of cars and light-trucks within each of the seven size classes considered by FEM (subsequently passed to subroutine FEMSIZE):

a) For cars, *igp* = 1,2:

$$\ldots_{icl,N} = CLASS\$SHARE_{icl,igp,YEAR} * TMC\_SQTRCARS_N * \left(1 - FLTCRAT_{1990}\right) * SA\ldots \qquad \textbf{(B-41)}$$

where:

NVS7SC = New vehicle sales in the original seven FEM size classes, by CAFE group *igp*

TMC_SQTRCARS = Total new car sales (supplied by the MACRO module)
CLASS$SHARE = The market share for each automobile class, from FEM
FLTCRAT = Fraction of new cars purchased by fleets
SALESHR = Fraction of vehicle sales which are domestic/imported

b) For light trucks, *igp* = 3,4:

$$SC_{igp,icl,N} = CLASS\$SHARE_{icl,igp,YEAR} * TMC\_SQDTRUCKS_{N} * \left(1 - (FLTTRAT_{1990} + COMTSHR)\right) * SALESH \quad \text{(B-42)}$$

where:

TMC_SQDTRUCKS = Total new light truck sales (from the MACRO module)
FLTTRAT = Fraction of new light trucks purchased by fleets
COMTSHR = Fraction of new light trucks dedicated to commercial freight

2) Redistribute car and truck sales among six size classes, combining import and domestic:

a) For cars:

$$NCSTSCC_{osc,N} = \sum_{igp=1}^{2} \sum_{icl=1}^{7} \left(NVS7SC_{igp,icl,N}\right) * MAP_{igp,icl,osc} \quad \text{(B-43)}$$

where:

NCSTSCC = Total new car sales by size class *osc*
MAP = Array of constants which map sales from seven to six size classes

b) For light trucks:

$$NLTSTSCC_{osc,N} = \sum_{igp=3}^{4} \sum_{icl=1}^{7} \left(NVS7SC_{igp,icl,N}\right) * MAP_{igp,icl,osc} \quad \text{(B-44)}$$

where:

NLTSTSCC = Total new light truck sales by size class *osc*

3) Calculate the market shares of cars and light trucks by size class:

$$PASSHRR_{osc,N} = \frac{NCSTSCC_{osc,N}}{\sum_{osc=1}^{6} NCSTSCC_{osc,N}} \quad \textbf{(B-45)}$$

and:

$$LTSHRR_{osc,N} = \frac{NLTSTSCC_{osc,N}}{\sum_{osc=1}^{6} NLTSTSCC_{osc,N}} \quad \textbf{(B-46)}$$

where:

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

4) Reassign horsepower estimates to six size classes:

$$AR_{osc,N} = \sum_{igp=1}^{2} \sum_{icl=1}^{7} \left(HP_{icl,igp,YEAR}\right) * SALESHR_{igp} * MAP_{igp} \quad \textbf{(B-47)}$$

and:

$$UCK_{osc,N} = \sum_{igp=3}^{4} \sum_{icl=1}^{7} \left(HP_{icl,igp,YEAR}\right) * SALESHR_{igp} * MAP_{i} \quad \textbf{(B-48)}$$

where:

HPCAR = Average horsepower of automobiles, by size class *osc*
HPTRUCK = Average horsepower of light trucks, by size class *osc*
HP = Vehicle horsepower by FEM size class *icl* and CAFE group *igp*
SALESHR = Domestic vs. import market share for automobiles and light trucks, from ORNL

5) Calculate average horsepower of cars and light trucks, by size class *osc*:

$$AHPCAR_N = \sum_{osc=1}^{6} HPCAR_{osc,N} * PASSHRR_{osc,N} \qquad \textbf{(B-49)}$$

and:

$$AHPTRUCK_N = \sum_{osc=1}^{6} HPTRUCK_{osc,N} * LTSHRR_{osc,N} \qquad \textbf{(B-50)}$$

where:

AHPCAR = Average automobile horsepower
AHPTRUCK = Average light truck horsepower

REGIONAL SALES MODEL — Subroutine TREG

1) Calculate regional shares of fuel demand, and normalize:

$$HR_{FUEL,REG,T} = \frac{SEDSHR_{FUEL,REG,T-1} * \left(\dfrac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)}{\sum_{REG=1}^{9} SEDSHR_{FUEL,REG,T-1} * \left(\dfrac{TMC\_YD_{RE}}{TMC\_YD_{REG}} \right.} \qquad \textbf{(B-51)}$$

where:

SEDSHR = Regional share of the consumption of a given fuel in period *T*
TMC_YD = Estimated disposable personal income by region, *REG* (9)
FUEL = Index of fuel type (11)

2) Calculate regional cost of driving per mile:

$$COSTMIR_{REG,T} = 0.1251 * \left(\frac{TPMGTR_{REG,T}}{MPGFLT_{T-1}} \right) \quad \textbf{(B-52)}$$

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

3) Calculate regional income:

$$INCOMER_{REG,T} = \left(\frac{TMC\_YD_{REG,T}}{TMC\_POPAFO_{REG,T}} \right) \quad \textbf{(B-53)}$$

where:

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

4) Estimate regional driving demand:

$$\rho\, VMT16R_{REG,T-1} + \beta_0 (1 - \rho) + \beta_1 \left(COSTMIR_{REG,T} - \rho\, C \right.$$
$$\beta_2 \left(INCOMER_{REG,T} - \rho\, INCOMER_{REG,T-1} \right) + \beta_3 \left(PRFEM_T - \right. \quad \textbf{(B-54)}$$

and:

$$VMTEER_{REG,T} = VMT16R_{REG,T} * TMC\_POP16_{REG,T} * DAF_1 \quad \textbf{(B-55)}$$

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

5) Calculate regional VMT shares (RSHR):

$$RSHR_{REG,T} = \frac{VMTEER_{REG,T}}{\sum_{REG=1}^{9} VMTEER_{REG,T}} \quad \text{(B-56)}$$

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

$$NCS_{REG,SC,T} = NCSTSCC_{SC,T} * RSHR_{REG,T} \quad \text{(B-57)}$$

and:

$$NLTS_{REG,SC,T} = NLTSTSCC_{SC,T} * RSHR_{REG,T} \quad \text{(B-58)}$$

where:

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

ALTERNATIVE FUEL VEHICLE MODEL — Subroutine TALT3

1) Calculate commercial availability by technology:

$$COMAV_{IT,N} = \left[1 + EXP\left(\frac{TT50_{IT} - YEAR}{2} \right) \right]^{-1} \quad \text{(B-59)}$$

where:

COMAV = The fraction of market demand of a given technology which is commercially available
IT = Index of the sixteen engine technologies considered by the model
TT50 = The exogenously specified year in which 50% of the demand for technology *IT* can be met

2) Calculate the weighted average fuel price for each technology, by region:

$$AFCOST_{IT,IR,N} = \frac{\sum_{FUEL} (RFP_{FUEL,IR,N} \cdot FAVAIL_{FUEL,IR,N})}{\sum_{FUEL} FAVAIL_{FUEL,IR,N}} \quad \textbf{(B-60)}$$

where:

AFCOST = Weighted average fuel price, in 1990 cents/MMBTU, for each technology *IT*
RFP = Price of each fuel used by the corresponding technology
FAVAIL = Relative availability of the corresponding fuel

3) Map fuel economy for cars and light trucks from six to three size classes for use in the AFV model:

a) For cars:

$$FEC3SC_{ISC,N} = \left[\frac{\sum_{OSC} \left(\frac{NCSTSCC_{OSC,N}}{FESIXC_{OSC,N}} \right)}{\sum_{OSC} NCSTSCC_{OSC,N}} \right]^{-1} \quad \textbf{(B-61)}$$

where:

FEC3SC = Automobile fuel economy within the three reduced size classes
NCSTSCC = New car sales within the six size classes *OSC*
FESIXC = New car fuel economy within the six size classes *OSC*
ISC = Index of reduced size classes, mapped as follows for cars: *ISC* = 1, *OSC* = 2, 3; *ISC* = 2, *OSC* = 1, 6; *ISC* = 3, *OSC* = 4, 5

b) For light trucks:

$$FET3SC_{ISC,N} = \left[\frac{\sum_{OSC} \left(\frac{NLTSTSCC_{OSC,N}}{FESIXT_{OSC,N}} \right)}{\sum_{OSC} NLTSTSCC_{OSC,N}} \right]^{-1} \quad \textbf{(B-62)}$$

where:

FET3SC = Light truck fuel economy within the three reduced size classes
NLTSTSCC = New light truck sales within the six size classes *OSC*
FESIXT = New light truck fuel economy within the six size classes *OSC*

ISC = Index of reduced size classes, mapped as follows for trucks: *ISC* = 1, *OSC* = 1, 3; *ISC* = 2, *OSC* = 2, 5; *ISC* = 3, *OSC* = 4, 6

4) Convert fuel economy from miles per gallon to miles per MMBTU:

$$VEFFACT_{ISC,N} = \frac{FEC3SC_{ISC,N}}{0.125} \quad \textbf{(B-63)}$$

where:

VEFFACT = Gasoline vehicle fuel economy, used as a baseline

5) Calculate alternative vehicle fuel economy, using gasoline baseline:

$$VEFFBTU_{ISC,IT,N} = VEFF_{ISC,IT,N} * VEFFACT_{ISC,N} \quad \textbf{(B-64)}$$

where:

VEFFBTU = Fuel economy by technology *IT*, in miles per MMBTU

VEFF = Fuel economy of technology *IT*, relative to gasoline baseline

6) Calculate AFV operating cost, by region:

$$COPCOST_{IT,ISC,IR,N} = \frac{AFCOST_{IT,IT,N} * 100}{VEFFBTU_{ISC,IT,N}} \quad \textbf{(B-65)}$$

where:

COPCOST = Regional vehicle operating cost, in 1990$/mile

7) Calculate utility of electric and electric hybrid vehicles (*IT* = 7-10):

$$\begin{aligned} C3_{IT,IR} = \; & BETACONST_{IT} + BETAVP \cdot VPRICE3_{IS,IT,N} + BETAFC \cdot COPCOST3_{IT,IS,IR,N} \\ & + BETAVR \cdot VRANGE3_{IS,IT,N} + BETAVR2 \cdot VRANGE3^2_{IS,IT,N} + BETAEM \cdot EMISS3_{IS,I} \\ & + BETAEM2 \cdot EMISS3^2_{IS,IT,N} + BETAFA \cdot FAVAIL3_{IT,IR,N} + BETAFA2 \cdot FAVAIL3^2_{IT,IR,} \end{aligned} \quad \textbf{(B-66)}$$

where:

VC3 = Utility vector for electric vehicles

BETACONST = Constant associated with each considered technology *IT*

COPCOST3 = Fuel operating costs for electric vehicles

VPRICE3 = Price of each considered EV technology in 1990$
VRANGE3 = Vehicle range of the considered EV technology
EMISS3 = EV emissions levels relative to gasoline ICE's
FAVAIL33 = Fuel availability for EV technologies
BETAVP = Coefficient associated with vehicle price
VETAFC = Coefficient associated with fuel cost
BETAVR = Coefficient associated with vehicle range
BETAEM = Coefficient associated with vehicle emissions
BETAFA = Coefficient associated with fuel availability
BETAVR2 = Coefficient associated with the square of vehicle range
BETAEM2 = Coefficient associated with the square of vehicle emissions
BETAFA2 = Coefficient associated with the square of fuel availability

8) Exponentiate utility vector, and adjust by commercial availability factor:

$$EVC3_{IT,IS,IR,N} = EXP\left[VC3_{IT,IS,IR,N}\right] * COMAV_{IT,N} \quad \text{(B-67)}$$

where:

EVC3 = Exponentiated value of electric vehicle utility vector

9) Calculate electric vehicle market shares, by region:

$$APSHR33_{IS,IR,IT,N} = \frac{EVC3_{IT,IS,IR,N}}{\sum_{IT=7}^{10} EVC3_{IT,IS,IR,N}} \quad \text{(B-68)}$$

where:

APSHR33 = Relative market shares within the electric vehicle group

ALTERNATIVE FUEL VEHICLE MODEL Subroutine TALT2

1) Calculate weighted average characteristics of electric vehicles, and reconfigure technology indices to reflect the compression of four EV technologies into one prototype:

$$\Psi_{IS,IT,IR,N} = \sum_{IT=7}^{10} \Psi_{IS,IT,IR,N} \cdot APSHR33_{IS,IR,IT,N} \qquad \textbf{(B-69)}$$

where:

Ψ = VPRICE3, VEMISS3, VRANGE3, COMAV, COPCOST, FAVAIL33, and BETACONST

2) Calculate utility for alternative fuel vehicles (*IT* = 3-13):

$$\ldots ONST2_{IT} + BETAVP \cdot VPRICE2_{IS,IT,N} + BETAFC \cdot COPCO\ldots$$
$$\ldots VR \cdot VRANGE2_{IS,IT,N} + BETAVR2 \cdot VRANGE2^{2}_{IS,IT,N} + BETA\ldots \qquad \textbf{(B-70)}$$
$$\ldots EM2 \cdot EMISS2^{2}_{IS,IT,N} + BETAFA \cdot FAVAIL22_{IT,IR,N} + BETAFA\ldots$$

where:

VC2 = Utility vector for alternative vehicles
BETACONST2 = Constant associated with each considered AFV technology
COPCOST2 = Fuel operating costs for alternative vehicles
VPRICE2 = Price of each considered AFV technology in 1990$
VRANGE2 = Vehicle range of the considered AFV technology
EMISS2 = AFV emissions levels relative to gasoline ICE's
FAVAIL22 = Alternative fuel availability

3) Exponentiate utility vector, and adjust by commercial availability factor:

$$EVC2_{IT,IS,IR,N} = EXP\left[VC2_{IT,IS,IR,N}\right] * COMAV_{IT,N} \qquad \textbf{(B-71)}$$

where:

EVC2 = Exponentiated value of alternative vehicle utility vector

4) Calculate alternative vehicle market shares, by region:

$$APSHR22_{IS,IR,IT,N} = \frac{EVC2_{IT,IS,IR,N}}{\sum_{IT=3}^{13} EVC2_{IT,IS,IR,N}} \qquad \textbf{(B-72)}$$

where:

APSHR22 = Relative market shares within the alternative vehicle group

ALTERNATIVE FUEL VEHICLE MODEL — Subroutine TALT1

1) Calculate weighted average characteristics of alternative vehicles, and reconfigure technology indices to reflect the compression of eleven alternative technologies into one prototype:

$$\Psi_{IS,IT,IR,N} = \sum_{IT=3}^{13} \Psi_{IS,IT,IR,N} \cdot APSHR22_{IS,IR,IT,N} \qquad \textbf{(B-73)}$$

where:

Ψ = VPRICE2, VEMISS2, VRANGE2, COMAV, COPCOST2, FAVAIL22, and BETACONST2

2) Calculate utility for all vehicles (*IT* = 1-3):

$$\ldots CONST1_{IT} + BETAVP \cdot VPRICE1_{IS,IT,N} + BETAFC \cdot COPCO\ldots$$
$$\ldots VR \cdot VRANGE1_{IS,IT,N} + BETAVR2 \cdot VRANGE1^{2}_{IS,IT,N} + BETA\ldots \qquad \textbf{(B-74)}$$
$$\ldots EM2 \cdot EMISS1^{2}_{IS,IT,N} + BETAFA \cdot FAVAIL11_{IT,IR,N} + BETAFA\ldots$$

where:

VC1 = Utility vector for conventional and alternative vehicles
BETACONST1 = Constant associated with each considered technology
COPCOST1 = Fuel operating costs for conventional and alternative vehicles
VPRICE1 = Price of each considered technology in 1990$
VRANGE1 = Vehicle range of the considered technology
EMISS1 = Emissions levels relative to gasoline ICE's
FAVAIL11 = Fuel availability

3) Exponentiate utility vector, and adjust by commercial availability factor:

$$EVC1_{IT,IS,IR,N} = EXP\left[VC1_{IT,IS,IR,N}\right] * COMAV_{IT,N} \qquad \textbf{(B-75)}$$

where:

EVC1 = Exponentiated value of vehicle utility vector

4) Calculate vehicle market shares, by region:

$$APSHR11_{IS,IR,IT,N} = \frac{EVC1_{IT,IS,IR,N}}{\sum_{IT=1}^{3} EVC1_{IT,IS,IR,N}} \qquad \textbf{(B-76)}$$

where:

APSHR11 = Relative market shares of conventional and alternative vehicles

5) Expand market share estimates to generate absolute market shares for each of the sixteen conventional and alternative technologies:

a) For conventional vehicles (IT = 16,15; $IT1$ = 1,2):

$$APSHR44_{IS,IR,IT,N} = APSHR11_{IS,IR,IT1,N} * APSHR22_{IS,IR,IT2,N} \qquad \textbf{(B-77)}$$

where:

APSHR44 = Absolute market share of technology *IT*

b) For non-electric alternative vehicles (IT = 1-6,11-14; $IT1$ = 3; $IT2$ = 5,6,3,4,8-13):

$$APSHR44_{IS,IR,IT,N} = APSHR11_{IS,IR,IT1,N} \qquad \textbf{(B-78)}$$

c) For electric and electric hybrid vehicles (IT = 7-10; $IT1$ = 3; $IT2$ = 7; $IT3$ = 1-4):

$$4_{IS,IR,IT,N} = APSHR11_{IS,IR,IT1,N} * APSHR22_{IS,IR,IT2,N} * APSHR3 \qquad \textbf{(B-79)}$$

LIGHT DUTY VEHICLE FLEET MODULE

1) Calculate fleet acquisitions of cars and light trucks:

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

and: **(B-80)**

$$LTSAL_{VT=2,ITY,T} = FLTTRAT * SQDTRUCKSL_{T} * FLTTSHR$$

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
SQTRUCKSL = 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
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

2) Determine total alternative fuel fleet vehicle sales, using either the market-driven or legislatively mandated values :

$$T_{VT,ITY,T} = MAX\left[\left(FLTSAL_{VT,ITY,T} * FLTAPSHR1_{ITY}\right), EPAC$$ **(B-81)**

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

3) Calculate the difference between total sales and AFV sales (representing conventional sales):

$$FLTCONV_{VT,ITY,T} = FLTSAL_{VT,ITY,T} - FLTALT_{VT,ITY,T}$$ **(B-82)**

where:

FLTCONV = Fleet purchases of conventional vehicles

4) Distribute fleet purchases among three size classes:

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

and: **(B-83)**

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

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

5) Disaggregate AFV sales by engine technology:

$$AL_{VT,ITY=1,IS,ITECH,T} = FLTSLSCA_{VT,ITY=1,IS,T} * APSHRFLTB_{VT,.}$$

$$ISAL_{VT,ITY\neq 1,IS,ITECH,T} = FLTSLSCA_{VT,ITY\neq 1,IS,T} * FLTECHSHR$$

(B-84)

and:

$$FLTECHSAL_{VT,ITY,IS,ITECH=6,T} = FLTSLSCC_{VT,ITY,IS,T}$$

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

6) Sum sales across size classes:

$$FLTECH_{VT,ITY,ITECH,T} = \sum_{IS=1}^{3} FLTECHSAL_{VT,ITY,IS,ITECH,T} \quad \textbf{(B-85)}$$

where:

FLTECH = Vehicle purchases by fleet type and technology

7) Calculate survival of older vehicles, and modify vintage array:

$$N_{VT,ITY,ITECH,IVIN,T} = FLTSTKVN_{VT,ITY,ITECH,IVIN-1,T-1} * SURVFL$$

and: **(B-86)**

$$FLTSTKVN_{VT,ITY,ITECH,IVIN=1,T} = FLTECH_{VT,ITY,ITECH,T}$$

where:

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

8) Assign fleet vehicles of retirement vintage to another variable, prior to removal from the fleet:

$$OLDFSTK_{VT,ITY,ITECH,RVINT,T} = FLTSTKVN_{VT,ITY,ITECH,RVINT,T} \qquad \textbf{(B-87)}$$

where:

OLDFSTK = Old fleet stocks of given types and vintages, transferred to the private sector
RVINT = Retirement vintage of fleet vehicles: If *VT* = 1, *ITY* = 1,2,3, *RVINT* = 5,6,7; If *VT* = 2, *ITY* = 1,2,3, *RVINT* = 6,7,6

9) Calculate total surviving vehicles, by vehicle, fleet type, and engine technology:

$$TFLTECHSTK_{VT,ITY,ITECH,T} = \sum_{IVIN=1}^{6} FLTSTKVN_{VT,ITY,ITECH,IVIN,T} \qquad \textbf{(B-88)}$$

where:

TFLTECHSTK = Total stock within each technology and fleet type

10) Calculate grand total of surviving vehicles:

$$TOTFLTSTK_{T} = \sum_{VT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} TFLTECHSTK_{VT,ITY,ITECH,T} \qquad \textbf{(B-89)}$$

where:

TOTFLTSTK = Total of all surviving fleet vehicles

11) Calculate percentage of fleet stock represented by each of the vehicle, fleet types, and engine technologies:

$$VFSTKPF_{VT,ITY,ITECH,T} = \frac{TFLTECHSTK_{VT,ITY,ITECH,T}}{TOTFLTSTK_{T}} \quad \textbf{(B-90)}$$

where:

VFSTKPF = Share of fleet stock by vehicle type and technology

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TLEGIS

This subroutine adjusts vehicle sales and market shares to reflect California's legislative mandates on sales of zero-emission vehicles (ZEV's) and ultra-low emission vehicles (ULEV's), which have also been tentatively adopted by New York and Massachusetts.

1) Calculate regional vehicle sales, by technology, within three size classes:

$$ES_{IS,IR,IT,N} = \sum_{OSC} APSHR44_{IS,IR,IT,N} * \left(NCS_{IR,OSC,N} + NLTS_{IR,} \right. \quad \textbf{(B-91)}$$

where:

VSALES = Total disaggregate vehicle sales
APSHR44 = Absolute market share of new vehicles, by region, size, and technology
IS = Index of reduced size class (1-3)
OSC = Index of original size class (1-6)
NCS = Regional new car sales within corresponding size classes *OSC*:
IS = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5
NLTS = Regional new light truck sales within corresponding size classes *OSC*
IS = 1, *OSC* = 1,2; *IS* = 2, *OSC* = 3,4; *IS* = 3, *OSC* = 5,6

2) Calculate total regional sales of electric and electric hybrid vehicles:

$$ELECVSAL_{IR,N} = \sum_{IS=1}^{3} \sum_{IT=7}^{10} VSALES_{IS,IR,IT,N} \qquad \textbf{(B-92)}$$

where:

ELECVSAL = Regional electric vehicle sales

3) Calculate total vehicle sales across all technologies:

$$VSALEST_{IS,IR,N} = \sum_{IT=1}^{16} VSALES_{IS,IR,IT,N} \qquad \textbf{(B-93)}$$

where:

VSALEST = Total regional vehicle sales, by size class

4) Calculate mandated sales of ZEV's and ULEV's by participating state:

$$TMC\_SQTRCARS_N * STATESHR_{ST,VT=1,N} + TMC\_SQDTRUCKSL_N * STATESHR_{ST}$$

and **(B-94)**

$$TMC\_SQTRCARS_N * STATESHR_{ST,VT=1,N} + TMC\_SQDTRUCKSL_N * STATESHR_{ST}$$

where:

ZEVST = State-mandated minimum sales of ZEV's

ULEVST = State-mandated minimum sales of ULEV's

TMC_SQTRCARS = Total car sales, from the MACRO module

TMC_SQDTRUCKSL = Total light truck sales, from the MACRO module

STATESHR = Share of national vehicle sales attributed to a given state

ZEV = State-mandated minimum sales share of ZEV's

ULEV = State-mandated minimum sales share of ULEV's

ST = Index of participating state: CA, MA, NY

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

5) If mandated sales exceed actual sales, then adjust actual sales as follows:

a) Evenly distribute mandated sales among three size classes:

$$ZEVSTSC_{ST,IS,N} = \frac{ZEVST_{ST,N}}{3} \quad \textbf{(B-95)}$$

where:

ZEVSTSC = Mandated ZEV sales by size class and state

b) Evenly distribute actual electric vehicle sales among three size classes:

$$ELECVSALSC_{IR,IS,N} = \frac{ELECVSAL_{IR,N}}{3} \quad \textbf{(B-96)}$$

where:

ELECVSALSC = Regional ZEV sales within corresponding regions

IR = Corresponding regions: *ST* = CA, MA, NY; *IR* = 9,1,2

c) Calculate mandated ZEV sales by EV technology (*IT* = 7-10):

$$AVSALES_{IS,IR,IT,N} = ZEVSTSC_{ST,IS,N} * APSHR33_{IS,IR,IT,N} \quad \textbf{(B-97)}$$

where:

AVSALES = Regional adjusted vehicle sales by size class

APSHR33 = Relative market shares of electric vehicle technologies

d) Reduce sales of gasoline vehicles (*IT* = 16) to compensate for increased ZEV sales in the affected regions (*IR* = 1,2,9):

$$_{,IR,IT=16,N} = VSALES_{IS,IR,IT=16,N} - \left(ZEVSTSC_{ST,IS,N} - ELECVS \quad \textbf{(B-98)}$$

6) Reassign vehicle sales in unaffected regions (*IR* ≠ 1,2,9):

$$AVSALES_{IS,IR,IT,N} = VSALES_{IS,IR,IT,N} \quad \textbf{(B-99)}$$

7) Sum adjusted vehicle sales across technologies:

$$AVSALEST_{IS,IR,N} = \sum_{IT=1}^{16} AVSALES_{IS,IR,IT,N} \qquad \textbf{(B-100)}$$

where:

AVSALEST = Total regional adjusted vehicle sales by size class

8) Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{IS,IR,IT,N} = \frac{AVSALES_{IS,IR,IT,N}}{AVSALEST_{IS,IR,N}} \qquad \textbf{(B-101)}$$

where:

APSHR55 = Absolute regional market shares of adjusted vehicle sales

9) Reset conventional vehicle market shares so that diesel represents 2.5% of conventional vehicle sales:

$$APSHR55_{IS,IR,IT=15,N} = \sum_{IT=15}^{16} APSHR55_{IS,IR,IT,N} * 0.025$$

and **(B-102)**

$$APSHR55_{IS,IR,IT=16,N} = \sum_{IT=15}^{16} APSHR55_{IS,IR,IT,N} * 0.975$$

10) Calculate new fleet market shares for use with business fleets:

a) Calculate total vehicle sales by technology:

$$\text{ALESC16}_{IT,N} = \sum_{IR=1}^{9} \sum_{IS=1}^{3} APSHR55_{IS,IR,IT,N} * \left(\sum_{OSC} NCS_{IR,OSC,} \right.$$

and **(B-103)**

$$\text{LEST16}_{IT,N} = \sum_{IR=1}^{9} \sum_{IS=1}^{3} APSHR55_{IS,IR,IT,N} * \left(\sum_{OSC} NLTS_{IR,OSC} \right.$$

where:

VSALESC16 = Total new car sales by technology:

IS = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5

VSALEST16 = Total new light truck sales by technology

IS = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6

b) Calculate market shares by technology:

$$APSHRNC_{IT,N} = \frac{VSALESC16_{IT,N}}{\sum_{IT=1}^{16} VSALESC16_{IT,N}}$$

and **(B-104)**

$$APSHRNT_{IT,N} = \frac{VSALEST16_{IT,N}}{\sum_{IT=1}^{16} VSALEST16_{IT,N}}$$

where:

APSHRNC = Market shares of new cars by technology

APSHRNT = Market shares of new light trucks by technology

c) Sum market shares for affected fleet technologies:

$$APSHRFLTOT_{VT=1,N} = \sum_{ITF} APSHRNC_{ITF,N}$$

and **(B-105)**

$$APSHRFLTOT_{VT=2,N} = \sum_{ITF} APSHRNT_{ITF,N}$$

where:

APSHRFLTOT = Aggregate market shares of fleet vehicle technologies

VT = Index of vehicle type: 1 = cars; 2 = light trucks

ITF = Index of fleet vehicle technologies, corresponding to IT = 3,5,7,8,9

d) Normalize business fleet market shares:

$$APSHRFLTB_{VT=1,ITF,N} = \frac{APSHRNC_{IT,N}}{APSHRFLTOT_{VT=1,N}}$$

and **(B-106)**

$$APSHRFLTB_{VT=2,ITF,N} = \frac{APSHRNT_{IT,N}}{APSHRFLTOT_{VT=2,N}}$$

where:

APSHRFLTB = Market shares of business fleet by vehicle type and technology

11) Reset new car and light truck sales using market shares, mapped from three to six size classes:

$$NCSTECH_{IR,OSC,IT,N} = NCS_{IR,OSC,N} * APSHR55_{IS,IR,IT,N}$$

and **(B-107)**

$$NLTECH_{IR,OSC,IT,N} = NLTS_{IR,OSC,N} * APSHR55_{IS,IR,IT,N}$$

where:

NCSTECH = Regional new car sales by technology, within six size classes:
OSC = 1-6; IS = 2,1,1,3,3,2
NLTECH = Regional light truck sales by technology, with six size classes:
OSC = 1-6; IS = 1,2,1,3,2,3

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TFLTVMTS

This subroutine calculates VMT for fleets.

1) Use historical data on fleet vehicle travel to estimate total fleet VMT:

$$= \sum_{VT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \Big(TFLTECHSTK_{VT,ITY,ITECH,T} \ * \ FLTVMT \qquad \textbf{(B-108)}$$

where:

FLTVMT = Total VMT driven by fleet vehicles
FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = Index of fleet type: Business, Government, Utility
ITECH = Index of fleet engine technology, corresponding to *IT* = 3,5,9,7,8

2) Disaggregate total VMT by vehicle type and technology:

$$FLVMTECH_{VT,ITY,ITECH,T} = FLVMT_{T} \ * \ VFSTKPF_{VT,ITY,ITECH,T} \qquad \textbf{(B-109)}$$

where:

FLTVMTECH = Fleet VMT by technology, vehicle type, and fleet type
VFSTKPF = Share of fleet stock by vehicle type and technology

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TFLTMPG

This subroutine calculates fuel efficiency for the fleet stock

1) Calculate the average efficiencies of the five non-gasoline technologies (*ITECH* = 1-5):

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

and: **(B-110)**

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

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

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

ITECH = 1-5, *IT* = 4,2,7,5,6

IS = Index of reduced size class (1-3)

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

2) Calculate the average efficiencies of conventional vehicles:

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

and: **(B-111)**

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

where:

FEC3SC = New car MPG, by three size classes, from the FEM model

FET3SC = New light truck MPG, by three size classes, from the FEM model

3) Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{VT,T} = \left[\frac{\sum_{IS=1}^{3} \sum_{ITECH=1}^{6} \frac{FLTECH_{VT,IS,ITECH,N}}{FLTMPG_{VT,IS,ITECH,N}}}{\sum_{IS=1}^{3} \sum_{ITECH=1}^{6} FLTECH_{VT,IS,ITECH,N}} \right]^{-1} \qquad \textbf{(B-112)}$$

where:

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

4) Adjust vintage array of fleet stock efficiencies to account for new additions:

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

and: **(B-113)**

$$MPGFSTK_{VY,ITY,ITECH,IVIN=1,T} = FLTMPG_{VT,ITY,ITECH,T}$$

where:

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

IVIN = Index of fleet vintages

5) Calculate average fuel efficiency by vehicle and fleet type:

$$STK_{VT,ITY,ITECH,T} = \left[\sum_{IVIN=1}^{MAXVINT} \frac{\left(\frac{FLTSTKVN_{VT,ITY,ITECH,IVIN,T}}{MPGFSTK_{VT,ITY,ITECH,IVIN,T} * VI} \right.}{\left(TFLTECHSTK_{VT,ITY,ITECH,T} \right.} \right. \quad \text{(B-114)}$$

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

VDF = Vehicle degradation factor

TFLTECHSTK = Total fleet stocks by vehicle, fleet type, and technology

6) Calculate overall fleet average MPG for cars and light trucks:

$$FLTTOTMPG_{VT,T} = \left[\sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \frac{VFSTKPF_{VT,ITY,ITECH,T}}{MPGFLTSTK_{VT,ITY,ITECH,T}} \right]^{-} \quad \text{(B-115)}$$

where:

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

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TFLTCONS

This subroutine calculates fuel consumption of fleet vehicles.

1) Calculate fuel consumption:

$$FLTLDVC_{VT,ITY,ITECH,T} = \frac{FLTVMTECH_{VT,ITY,ITECH,T}}{MPGFLTSTK_{VT,ITY,ITECH,T}} \quad \text{(B-116)}$$

where:

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

2) Sum consumption across fleet types, and convert to Btu values:

$$FCLDVBTU_{VT,ITECH,T} = \sum_{ITY=1}^{3} FLTLDVC_{VT,ITY,ITECH,T} * QBTU_{I} \quad \textbf{(B-117)}$$

where:

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

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

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

$$FCLDVBTUR_{IR,ITECH,T} = \sum_{VT=1}^{2} FLTFCLDVBTU_{VT,ITECH,T} * RSI \quad \textbf{(B-118)}$$

where:

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology

RSHR = Regional VMT shares, from the Regional Sales Module

LIGHT DUTY VEHICLE STOCK ACCOUNTING MODEL Subroutine TSMOD

1) Sum across size classes and regions to obtain vehicle sales by technology:

$$TECHNCS_{IT,T} = \sum_{OSC=1}^{6} \sum_{IR=1}^{9} NCSTECH_{IR,OSC,IT,T}$$

and: **(B-119)**

$$TECHNLT_{IT,T} = \sum_{OSC=1}^{6} \sum_{IR=1}^{9} NLTECH_{IR,OSC,IT,T}$$

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 Module
NLTECH = New light truck sales, by region, size class, and technology
OSC = Index of size class (1-6)
IR = Index of region (1-9)
IT = Index of vehicle technology (1-16)

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

a) For *VINT* = 2-9:

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

and: **(B-120)**

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

b) For *VINT* = 10:

$$_{INT=10,T} = \left(PASSTK_{IT,VINT=9,T-1} * SSURVP_{VINT=9}\right)$$

$$+ \left(PASSTK_{IT,VINT=10,T-1} * SSU\right.$$

and **(B-121)**

$$_{INT=10,T} = \left(LTSTK_{IT,VINT=9,T-1} * SSURVLT_{VINT=10}\right)$$

$$+ \left(LTSTK_{IT,VINT=10,T-1} * SSURV\right.$$

where:

PASSTK = Surviving automobile stock, by technology and vintage
LTSTK = Surviving light truck stock, by technology and vintage
SSURVP = Fraction of a given vintage's automobiles which survive
SSURVLT = Fraction of a given vintage's light trucks which survive
VINT = Index of vehicle vintage (1-10)

3) Add retired fleet vehicles to the appropriate vintage of the non-fleet population:

$$ASSTK_{IT,TVINT} = PASSTK_{IT,TVINT} + OLDFSTK_{VT=1,TYPE,ITECH,TVI}$$

and: **(B-122)**

$$LTSTK_{IT,TVINT} = LTSTK_{IT,TVINT} + OLDFSTK_{VT=2,TYPE,ITECH,TVINT}$$

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

4) Sum over vintages and technologies to obtain total stocks of cars and light trucks:

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

and: **(B-123)**

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

where:

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

5) Calculate LDV shares of each technology:

$$VSPLDV_{IT,T} = \frac{\sum_{VINT=1}^{10} \left(PASSTK_{IT,VINT,T} + LTSTK_{IT,VINT,T} \right)}{STKCAR_T + STKTR_T} \tag{B-124}$$

where:

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

LIGHT DUTY VEHICLE STOCK ACCOUNTING MODEL Subroutine TMPGSTK

1) Map non-gasoline vehicle sales from six to three size classes (IT = 1-15):

$$NCS3A_{IS,IT,T} = \sum_{OSC} \sum_{IR=1}^{9} NCSTECH_{IR,OSC,IT,T}$$

and **(B-125)**

$$NLT3A_{IS,IT,T} = \sum_{OSC} \sum_{IR=1}^{9} NLTECH_{IR,OSC,IT,T}$$

where:

NCS3A = New car sales by reduced size class and engine technology:
IS = 1, OSC = 1,6; IS = 2, OSC = 2,3; IS = 3, OSC = 4,5
NLT3A = New light truck sales by reduced size class and technolgy:
IS = 1, OSC = 1,3; IS = 2, OSC = 2,5; IS = 3, OSC = 4,6
NCSTECH = New car sales by region, technology, and six size classes
NLTECH = New light truck sales by region, technology, and six size classes

2) Calculate total regional sales of vehicles by reduced size class:

$$NCSR_{IR,IS,T} = \sum_{OSC} NCS_{IR,OSC,T}$$

and **(B-126)**

$$NLTSR_{IR,IS,T} = \sum_{OSC} NLTS_{IR,OSC,T}$$

where:

NCSR = Regional new car sales by reduced size class

NLTSR = Regional new light truck sales by reduced size class

3) Sum across regions:

$$NCS3SC_{IS,T} = \sum_{IR=1}^{9} NCSR_{IR,IS,T}$$

and **(B-127)**

$$NLTS3SC_{IS,T} = \sum_{IR=1}^{9} NLTSR_{IR,IS,T}$$

where:

NCS3SC = Total new car sales by reduced size class

NLTS3SC = Total new light truck sales by reduced size class

4) Sum conventional vehicle sales across regions:

$$NNCSCA_{OSC,T} = \sum_{IR=1}^{9} NCSTECH_{IR,OSC,IT=16,T}$$

and **(B-128)**

$$NNLTCA_{OSC,T} = \sum_{IR=1}^{9} NLTECH_{IR,OSC,IT=16,T}$$

where:

NNCSCA = New conventional car sales by six size classes

NNLTCA = New conventional light truck sales by six size classes

5) Calculate average MPG within reduced size classes:

$$AMPGC_{IS,T} = \sum_{OSC} \frac{NCMPG_{VT=1,OSC,T}}{2}$$

and **(B-129)**

$$AMPGT_{IS,T} = \sum_{OSC} \frac{NCMPG_{VT=2,OSC,T}}{2}$$

where:

AMPGC = Average new car MPG mapped from six to three size classes:
IS = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5
AMPGT = Average new truck MPG mapped from six to three size classes:
IS = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6
VT = Index of vehicle type: 1 = cars, 2 = light trucks

6) Calculate ratio of truck to car MPG by size class:

$$RATIO_{IS,T} = \frac{AMPGT_{IS,T}}{AMPGC_{IS,T}} \quad \textbf{(B-130)}$$

where:

RATIO = Light truck MPG adjustment factor

7) Calculate the average efficiencies of the fifteen non-gasoline technologies:

$$MPGC_{IT,T} = \left[\frac{\sum_{IS=1}^{3} \frac{NCS3A_{IS,IT,T}}{NAMPG_{IT,IS,T}}}{\sum_{IS=1}^{3} NCS3A_{IS,IT,T}} \right]^{-1}$$

and: **(B-131)**

$$MPGT_{IT,T} = \left[\frac{\sum_{IS=1}^{3} \frac{NLT3A_{IS,IT,T}}{NAMPG_{IT,IS,T} * RATIO_{IS,T}}}{\sum_{IS=1}^{3} NLT3A_{IS,IT,T}} \right]^{-1}$$

where:

MPGC = New car fuel efficiency, by engine technology
MPGT = New light truck fuel efficiency, by engine technology
NAMPG = New AFV fuel efficiency, from the AFV model

8) Calculate new vehicle MPG for gasoline ICE's (*IT* = 16):

$$MPGC_{IT=16,T} = \left[\frac{\sum_{OSC=1}^{6} \frac{NNCSCA_{OSC,T}}{NCMPG_{OSC,T}}}{\sum_{OSC=1}^{6} NNCSCA_{OSC,T}} \right]^{-1}$$

and: **(B-132)**

$$MPGT_{IT=16,T} = \left[\frac{\sum_{OSC=1}^{6} \frac{NNLTCA_{OSC,T}}{NLTMPG_{OSC,T}}}{\sum_{OSC=1}^{6} NNLTCA_{OSC,T}} \right]^{-1}$$

where:

NCMPG = New car MPG, from the FEM model

NLTMPG = New light truck MPG, from the FEM model

9) Calculate average fuel efficiency across all technologies for cars and light trucks:

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

and: **(B-133)**

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

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

10) Calculate total miles driven by each type of vehicle:

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

and: **(B-134)**

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

where:

TOTMICT = Total miles driven by cars

TOTMITT = Total miles driven by light trucks

PVMT = Average automobile VMT, by vintage, from RTECS

LVMT = Average light truck VMT, by vintage, from RTECS

11) Calculate total energy consumption:

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

and: **(B-135)**

$$TMPGT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} \frac{LTSTK_{IT,IV,T} * LVMT_{IV}}{TTMPGSTK_{IT,IV,T} * VDF_{VT=2}}$$

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

VDF = Vehicle fuel efficiency degradation factor: *VT* = 1 for cars, *VT* = 2 for trucks

12) Calculate stock fuel efficiency:

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

and: **(B-136)**

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

where:

SCMPG = Stock MPG for automobiles

STMPG = Stock MPG for light trucks

13) Calculate average fuel efficiency of light duty vehicles:

$$MPGFLT_T = \frac{TOTMICT_T + TOTMITT_T}{CMPGT_T + TMPGT_T} \quad \textbf{(B-137)}$$

where:

MPGFLT = Stock MPG for all light duty vehicles

14) Calculate average fuel efficiency by technology:

$$ _{I} = \frac{\sum_{IV=1}^{10} \frac{PASSTK_{IT,IV,T} \; * \; PVMT_{IV}}{CMPGSTK_{IT,IV,T} \; * \; VDF_{VT=1}} \; + \; \sum_{IV=1}^{10} \frac{LTSTK_{IT,IV,T}}{TTMPGSTK_{IT,I}}}{TOTMICT_{T} \; + \; TOTMITT_{T}} \qquad \textbf{(B-138)} $$

where:

MPGTECH = Average stock MPG by technology

VEHICLE MILES TRAVELED MODEL Subroutine TVMT

1) Calculate the cost of driving per mile:

$$ COSTMI_{T} \; = \; \frac{TPMGTR_{T} \; * \; 0.125}{MPGFLT_{T}} \qquad \textbf{(B-139)} $$

where:

COSTMI = Cost of driving per mile
TPMGTR = Price of motor gasoline
MPGFLT = Fuel economy of the automobile fleet
0.125 = Conversion factor for gasoline, in MMBtu/gallon

2) Calculate per capita income:

$$ INCOME_{T} \; = \; \frac{TMC\_YD_{T}}{TMC\_POPAFO_{T}} \qquad \textbf{(B-140)} $$

where:

INCOME = Per capita disposable personal income

TMC_YD = Total disposable personal income, from MACRO module
TMC_POPAFO = Total population, from MACRO module

3) Calculate unadjusted VMT per capita:

$$
\begin{aligned}
VMT16_T = {} & RHO \cdot VMTPC_{T-1} + ALPHA\,(1 - RHO) \\
& - BETAPE\,(COSTMI_T - RHO \cdot COSTMI_{T-1}) \\
& + BETAIE\,(INCOME_T - RHO \cdot INCOME_{T-1}) \\
& + BETADEM\,(PrFem_T - RHO \cdot PrFem_{T-1})
\end{aligned}
\tag{B-141}
$$

where:

VMT16 = Per capita VMT for persons 16 and older
ALPHA = Constant parameter for the VMT difference equation
BETAPE = Parameter associated with the cost of driving
BETAIE = Parameter associated with disposable persoal income
BETADEM = Parameter associated with demographic influences
PrFem = Ratio of per capita female driving to per capita male driving.
RHO = Lag factor, estimated using the Cochrane-Orcutt iterative procedure to be 0.72.

4) Calculate adjusted VMT per capita:

$$
ADJVMTPC_T = VMT16_T \cdot DAF_T \tag{B-142}
$$

where:

ADJVMTPC = Demographically-adjusted per capita VMT
DAF = Demographic adjustment factor

5) Calculate total VMT:

$$VMTLDV_T = ADJVMTPC_T * TMC\_POP16_T \quad \textbf{(B-143)}$$

where:

VMTLDV = Total VMT for light duty vehicles

6) Calculate net VMT, subtracting off fleet and light truck freight VMT:

$$VMTEE_T = VMTLDV_T - \left(FLTVMT_T + FVMTSC_{IS=1,T}\right) \quad \textbf{(B-144)}$$

where:

VMTEE = VMT for personal travel
FLTVMT = Fleet VMT
FVMTSC = Freight VMT by size class

7) Calculate VMT by technology:

$$VMTECH_{IT,T} = VMTEE_T * VSPLDV_{IT,T} \quad \textbf{(B-145)}$$

where:

VMTECH = Personal travel VMT by technology
VSPLDV = Sales shares of vehicles by technology

8) Calculate fractional change of VMT:

$$XLDVMT_T = \frac{VMTEE_T}{VMTEE_{T=1}} \quad \textbf{(B-146)}$$

where:

XLDVMT = Fractional change of VMT over base year (1990)

VEHICLE MILES TRAVELED MODEL Subroutine TFREISMOD

1) Calculate light truck sales dedicated to freight:

$$TRSAL_T = 0.408427 * TMC\_SQDTRUCKSL_T \quad \textbf{(B-147)}$$

where:

TRSAL = Light truck sales for freight
TMC_SQDTRUCKSL = Total light truck sales, from MACRO module

2) Calculate sales by technology:

$$TRSALTECH_{IT,T} = TRSAL_T * FLVMTSHR_{IS=1,IT,T} \quad \textbf{(B-148)}$$

where:

TRSALTECH = Light truck sales by technology
FLVMTSHR = VMT-weighted shares by size class and technology

3) Add to vintage array and adjust stock survival:

$$TRSTKTECH_{IT,IV=1,T} = TRSALTECH_{IT,T}$$

$$ECH_{IT,IV,T} = TRSTKTECH_{IT,IV-1,T-1} * SSURVLT_{IV-1} \quad ; \quad IV$$

and **(B-149)**

$$V=10,T = \left(TRSTKTECH_{IT,IV=9,T-1} * SSURVLT_{IV=9}\right)$$

$$+ \left(TRSTKTECH_{IT,IV=10,T-1} *\right.$$

where:

TRSTKTECH = Light truck stock by technology
SSURVLT = Array of survival rates for light trucks

4) Sum over vintages:

$$TRSTKTOT_{IT,T} = \sum_{IV=1}^{10} TRSTKTECH_{IT,IV,T} \quad \textbf{(B-150)}$$

where:

TRSTKTOT = Total light truck stock by technology

5) Sum over technologies:

$$TRSTK_T = \sum_{IT=1}^{5} TRSTKTOT_{IT,T} \quad \textbf{(B-151)}$$

where:

TRSTK = Total light truck stock

6) Calculate average MPG for light trucks:

$$TRFLTMPG_T = \left[\frac{\sum_{IT=1}^{5} \left(\frac{TRSTKTOT_{IT,T}}{FMPG_{IS=1,IT,T}} \right)}{\sum_{IT=1}^{5} TRSTKTOT_{IT,T}} \right]^{-1} \quad \textbf{(B-152)}$$

where:

TRFLTMPG = Average light truck MPG

VEHICLE MILES TRAVELED MODEL Subroutine TMPGAG

This subroutine calculates aggregate fuel efficiencies for cars and light trucks.

1) Sum fleet vehicle sales over size class:

$$FLTECHSALT_{VT,ITY,ITECH,T} = \sum_{IS=1}^{3} FLTECHSAL_{VT,ITY,IS,ITECH,T} \quad \textbf{(B-153)}$$

where:

FLTECHSALT = Vehicle purchases by fleet type and technolgy
FLTECHSAL = Fleet sales by size, technology, and fleet type
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITECH = Index of engine technology (1-6)
ITY = Index of fleet type: Business, Government, Utility
IS = Index of size class (1-3)

2) Calculate new vehicle MPG:

$$FLTMPGNEW_{VT,ITECH,T} = \left[\frac{\sum_{ITY=1}^{3} \frac{FLTECHSALT_{VT,ITY,ITECH,T}}{FLTMPG_{VT,ITY,ITECH,T}}}{\sum_{ITY=1}^{3} FLTECHSALT_{VT,ITY,ITECH,T}} \right]^{-1} \quad \textbf{(B-154)}$$

where:

FLTMPGNEW = New fleet vehicle MPG by vehicle type and technology
FLTMPG = Fleet vehicle MPG by vehicle type, size class, and technology

3) Sum fleet stock across fleet types:

$$FLTSTOCK_{VT,ITECH,T} = \sum_{ITY=1}^{3} FLTECHSTK_{VT,ITY,ITECH,T} \quad \textbf{(B-155)}$$

where:

FLTSTOCK = Total fleet vehicle stock, by technology
FLTECHSTK = Total fleet vehicle stock, by technology and fleet type

4) Calculate average MPG of fleet and non-fleet vehicles, by technology:

a) For cars:

$$GLDV_{IT,T} = \left[\frac{\left(\frac{TECHNCS_{IT,T}}{MPGC_{IT,T}} \right) + \left(\frac{FLTSTOCK_{VT=1,ITECH,T}}{FLTMPGNEW_{VT=1,ITECH}} \right)}{TECHNCS_{IT,T} + FLTSTOCK_{VT=1,ITECH,T}} \right. \quad \textbf{(B-156)}$$

where:

CCMPGLDV = New car MPG, by technology *IT*
IT = Index of vehicle technology (1-16)
ITECH = Index of fleet vehicle technologies which correspond to the *IT* index
TECHNCS = Non-fleet new car sales, by technology *IT*
MPGC = New car MPG, by technology *IT*
FLTSTOCK = New fleet stock, by vehicle type and technology *ITECH*
FLTMPGNEW = New fleet vehicle MPG, by vehicle type and technology *ITECH*

b) For light trucks:

$$GLDV_{IT,T} = \left[\frac{\left(\dfrac{TECHNLT_{IT,T}}{MPGT_{IT,T}} \right) + \left(\dfrac{FLTSTOCK_{VT=2,ITECH,T}}{FLTMPGNEW_{VT=2,ITECH,}} \right)}{TECHNLT_{IT,T} + FLTSTOCK_{VT=2,ITECH,T}} \right. \qquad \textbf{(B-157)}$$

where:

TTMPGLDV = New light truck MPG, by technology *IT*

TECHNLT = Non-fleet new light truck sales, by technology *IT*

MPGT = New light truck MPG, by technology *IT*

5) Calculate total stock by vehicle type and technology:

$$STOCKLDV_{VT,IT2,T} = STKCT_{VT,IT,T} + FLTSTOCK_{VT,ITECH,T} \qquad \textbf{(B-158)}$$

where:

STOCKLDV = Total stock of fleet and non-fleet vehicles, by technology

STKCT = Stock of non-fleet vehicles, by technology

IT = Index of vehicle technology (1-16)

IT2 = Reassigned indices of vehicle technology *IT2* = 1-16; *IT* = 16,15,1-14

ITECH = Index of fleet technologies which map to corresponding *IT* and *IT2* as follows:

IT2 = 1,3,5,7,8,9; *IT* = 16,1,3,5,6,7; *ITECH* = 6,1,2,3,4,5

6) Calculate total stock across technologies:

$$TSTOCKLDV_{VT,T} = \sum_{IT2=1}^{16} STOCKLDV_{VT,IT2,T} \qquad \textbf{(B-159)}$$

where:

TSTOCKLDV = Total stock by vehicle type *VT*

7) Calculate average MPG of cars and light trucks:

$$TMPGLDVSTK_{VT=1,T} = \left[\frac{\sum_{IT2=1}^{16} \left(\frac{STOCKLDV_{VT=1,IT2,T}}{CCMPGLDV_{IT2,T}} \right)}{\sum_{IT2=1}^{16} STOCKLDV_{VT=1,IT2,T}} \right]^{-1}$$

and **(B-160)**

$$TMPGLDVSTK_{VT=2,T} = \left[\frac{\sum_{IT2=1}^{16} \left(\frac{STOCKLDV_{VT=2,IT2,T}}{TTMPGLDV_{IT2,T}} \right)}{\sum_{IT2=1}^{16} STOCKLDV_{VT=2,IT2,T}} \right]^{-1}$$

where:

TMPGLDVSTK = Average MPG by vehicle type *VT*

8) Calculate overall average MPG of light-duty vehicle fleet:

$$TLDVMPG_{T} = \left[\frac{\sum_{VT=1}^{2} \left(\frac{TSTOCKLDV_{VT,T}}{TMPGLDVSTK_{VT,T}} \right)}{\sum_{VT=1}^{2} TSTOCKLDV_{VT,T}} \right]^{-1} \quad \textbf{(B-161)}$$

where:

TLDVMPG = Average fuel economy of light-duty vehicles

HIGHWAY FREIGHT MODEL Subroutine TFREI

1) Calculate freight transport demand by trucks for manufacturing, agriculture and mining industries (I = 1-10):

$$FTMT_{I,T} = FTMT_{I,T_0} \cdot FAC_{I,Mode} \cdot \left[\frac{TSIC_{I,T}}{TSIC_{I,T_0}}\right] \quad \textbf{(B-162)}$$

where:

$FTMT_{I,T}$ = Total freight traffic (Ton-Miles) for a given industry, I, in year T
TSIC = Value of output of industry I, in base year (1990) dollars
$FAC_{I,Mode}$ = A freight adjustment coefficient
Mode = Index of freight mode: Truck, Rail, Marine

2) Convert ton-miles to vehicle miles:

$$FVMT_{I,T} = \frac{FTMT_{I,T}}{FRLOAD_I} \quad \textbf{(B-163)}$$

where:

FVMT = Freight vehicle-miles traveled
FRLOAD = Constant relating a given industry's ratio of ton-miles to vehicle-miles

3) Sum across industries:

$$FFVMT_{IX=1,T} = \sum_{I=1}^{10} FVMT_{I,T} \quad \textbf{(B-164)}$$

where:

FFVMT = Total freight truck vehicle-miles traveled in industry group IX
IX = Place holder for industry group

4) Estimate travel demand for construction and retail industries (I = 11, 12; IX = 2, 3):

$$FFVMT_{IX=2,T} = INTVMT90_{I=11} * \frac{TSIC_{I=11,T}}{TSIC90}$$

and **(B-165)**

$$FFVMT_{IX=3,T} = INTVMT90_{I=12} * \frac{TMC\_YD_T}{TYD8290}$$

where:

INTVMT90 = Base year (1990) travel demand for the considered industries
TSIC90 = Base year value of industrial output
TMC_YD = Disposable personal income, from the MACRO module
TYD8290 = Base year disposable personal income

5) Calculate total VMT for freight:

$$FTOTVMT_T = \sum_{IX=1}^{3} FFVMT_{IX,T} \quad \textbf{(B-166)}$$

where:

FTOTVMT = Total VMT demand for trucks

6) Calculate growth in VMT:

$$XTOTVMT_T = \frac{FTOTVMT_T}{FTOTVMT_1} \quad \textbf{(B-167)}$$

where:

XTOTVMT = Fractional growth in freight VMT over base year

7) Distribute freight VMT among three size classes:

$$FVMTSC_{IS,T} = FTOTVMT_T * FBENCH * TRSCSHR_{IS,N} \quad \textbf{(B-168)}$$

where:

FVMTSC = Freight VMT by size class

FBENCH = Benchmarking factor to ensure congruence with 1990 data
TRSCSHR = Travel share distribution factors, held constant
IS = Index of truck size class (1-3)

8) Distribute freight VMT among fuel technologies:

a) Calculate share growth adjustments:

$$FSHR_{IS,TECH,T} = FLVMTSHR_{IS,TECH,T-1} * GROWTH_{IS,TECH} \qquad \textbf{(B-169)}$$

where:

FSHR = Adjusted technology share of VMT demand
FLVMTSHR = Normalized technology share of VMT demand
GROWTH = Constant growth adjustment factor for each technology and size class:
GROWTH = 1.0 when *TECH* = 3,4,5
TECH = Index of engine technology (1-5)

b) Reassign variables for *TECH* = 3-5:

$$FLVMTSHR_{IS,TECH,T} = FSHR_{IS,TECH,T} \quad ; \quad TECH = 3,4,5 \qquad \textbf{(B-170)}$$

c) Normalize and reassign shares for *TECH* = 1,2:

$$HR_{IS,TECH,T} = \left(\frac{FSHR_{IS,TECH,T}}{\sum_{TECH=1}^{2} FSHR_{IS,TECH,T}} \right) * \left(1 - \sum_{TECH=3}^{5} FSHR \right. \qquad \textbf{(B-171)}$$

d) Calculate VMT by technology:

$$FVMTECHSC_{IS,TECH,T} = FVMTSC_{IS,T} * FLVMTSHR_{IS,TECH,T} \qquad \textbf{(B-172)}$$

where:

FVMTECHSC = Freight truck VMT by size class and technology

9) Sum VMT across technologies for second size class for use in subroutine TMISC:

$$SUMFVMT_{T} = \sum_{TECH=1}^{5} FVMTECHSC_{IS=2,IT,T} \qquad \textbf{(B-173)}$$

where:

SUMFVMT = Total freight VMT for the second size class

10) Calculate freight truck MPG:

$$'MPG_{IS,TECH,T-1} \; * \; (1 \; + \; TBETA1_{IS}) \; * \; \left(\; MAX \left\{ 1.0 \; , \; \left[\frac{TPM(}{TPMG} \right. \right. \right. \quad \textbf{(B-174)}$$

where:

FMPG = Freight truck MPG, by size class and technology
TPMGTR = Price of motor gasoline
TBETA1 = Base rate of fuel economy growth, by size class
TBETA2 = Fuel-price sensitive rate of fuel economy growth, by size class

11) Calculate fractional improvement of fuel economy for gasoline-fueled light trucks:

$$XFREFF_{T} \; = \; \frac{FMPG_{IS=1,TECH=1,T}}{FMPG_{IS=1,TECH=1,T=1}} \quad \textbf{(B-175)}$$

where:

XFREFF = Fuel economy improvement over base year

12) Calculate fuel consumption for each truck type:

$$FFD_{IS,TECH,T} \; = \; \left(\frac{FVMTECHSC_{IS,TECH,T}}{FMPG_{IS,TECH,T}} \right) \; * \; QBTU_{TECH} \quad \textbf{(B-176)}$$

where:

FFD = Freight fuel demand, in MMBtu
QBTU = Heat content of fuel used by the considered technology, in MMBtu/gallon

13) Calculate average fuel efficiency for second size class, for use in subroutine TMISC:

$$FFMPG_T = \sum_{TECH=1}^{5} \frac{FMPG_{IS=2,TECH,T}}{5} \quad \textbf{(B-177)}$$

where:

FFMPG = Average truck fuel economy for seconc size class

14) Calculate total fuel demand for trucks, by technology:

$$FFDT_{TECH,T} = \sum_{IS=1}^{3} FFD_{IS,TECH,T} \quad \textbf{(B-178)}$$

where:

FFDT = Total fuel demand, by technology, in MMBtu

15) Calculate regional consumption:

$$TQFREIR_{TECH,IR,T} = FDT_{TECH,T} * SEDSHR_{FUEL,IR,T}$$

and **(B-179)**

$$TQFREIRSC_{IS,TECH,IR,T} = FFD_{IS,TECH,T} * SEDSHR_{FUEL,IR,T}$$

where:

TQFREIR = Total regional freight energy demand by technology

TQFREIRSC = Total regional freight energy demand by technology and size class

SEDSHR = Regional shares of fuel consumption, from SEDS

RAIL FREIGHT MODEL — Subroutine TRAIL

1) Calcutate ton-miles traveled for rail, by industry:

$$RTMT_{I,T} = RTMT_{I,T_0} \cdot FAC_{I,MODE} \cdot \left[\frac{TSIC_{I,T}}{TSIC_{I,T_0}}\right] \quad \textbf{(B-180)}$$

where:

RTMT = Rail ton-miles traveled, by industry *I*
MODE = Index of freight mode: truck, rail, marine
TSIC = Value of industrial output, by industry
I = Index of NEMS industrial category
FAC = Freight adjustment coefficient, by industry and mode

2) Sum across industries:

$$RTMTT_T = \sum_{I=1}^{10} RTMT_{I,T} \qquad \textbf{(B-181)}$$

where:

RTMTT = Total rail ton-miles traveled

3) Estimate energy consumption by rail:

$$TQRAILT_T = FERAIL_T \cdot RTMTT_T \qquad \textbf{(B-182)}$$

where:

TQRAILT = Total energy demand by rail
FERAIL = Rail efficiency coefficient, in Btu/ton-mile

4) Increment rail demand for specific fuels:

$$TQRAIL_{IF,T} = TQRAIL_{IF,T-1} \cdot \left(\frac{TQRAILT_T}{TQRAILT_{T-1}} \right) \qquad \textbf{(B-183)}$$

where:

TQRAIL = Rail demand, by fuel *IF*
IF = Index of fuel type

5) Divide into regions:

$$TQRAILR_{IF,IR,T} = TQRAIL_{IF,T} * SEDSHR_{IF,IR,T} \qquad \textbf{(B-184)}$$

where:

TQRAILR = Regional demand by fuel type
SEDSHR = Regional shares of fuel demand, from SEDS
IR = Index of census region (1-9)

6) Calculate fractional change in rail travel and fuel efficiency:

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

and **(B-185)**

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

where:

XRAIL = Growth in rail travel from base year
XRAILEFF = Growth in rail efficiency from base year

WATERBORNE FREIGHT MODEL Subroutine TSHIP

1) Calcutate ton-miles traveled for domestic shipping, by industry:

$$STMT_{I,T} = STMT_{I,T_0} \cdot FAC_{I,MODE} \cdot \left[\frac{TSIC_{I,T}}{TSIC_{I,T_0}}\right] \qquad \textbf{(B-186)}$$

where:

STMT = Ship ton-miles traveled, by industry *I*

2) Sum across industries:

$$STMTT_T = \sum_{I=1}^{10} STMT_{I,T} \quad \textbf{(B-187)}$$

where:

STMTT = Total ship ton-miles traveled

3) Estimate energy consumption by ship:

$$SFDT_T = FESHIP_T \cdot STMTT_T \cdot SFDBENCH \quad \textbf{(B-188)}$$

where:

SFDT = Total energy demand by ship
FESHIP = Ship efficiency coefficient, in Btu/ton-mile
SFDBENCH = Benchmark factor to ensure congruence with 1990 data

4) Allocate energy demand among specific fuels:

$$SFD_{IF,T} = SFDT_T \cdot SFSHARE_{IF} \quad \textbf{(B-189)}$$

where:

SFD = Domestic ship energy demand, by fuel *IF*
SFSHARE = Constant allocation share for domestic shipping, by fuel

5) Divide into regions:

$$TQSHIPR_{IF,IR,T} = SFD_{IF,T} * SEDSHR_{IF,IR,T} \quad \textbf{(B-190)}$$

where:

TQSHIPR = Regional ship demand by fuel type
SEDSHR = Regional shares of fuel demand, from SEDS

6) Calculate international shipping fuel demand:

$$SFDT_T = ISFDT_{T-1} + \left[\frac{GROSST_T}{GROSST_{T-1}} - 1 \right] * 0.5 * ISFDT_{T-} \quad \textbf{(B-191)}$$

where:

ISFDT = Total international shipping fuel demand
GROSST = Value of gross trade (imports + exports)

7) Allocate among the considered fuels:

$$ISFD_{IF,T} = ISFDT_T \cdot ISFSHARE_{IF} \quad \textbf{(B-192)}$$

where:

ISFD = International ship energy demand, by fuel *IF*
ISFSAHRE = Constant allocation share for international shipping, by fuel

8) Divide into regions:

$$TQISHIPR_{IF,IR,T} = ISFD_{IF,T} * SEDSHR_{IF,IR,T} \quad \textbf{(B-193)}$$

where:

TQISHIPR = Regional international shipping demand by fuel type

9) Calculate fractional change in domestic ship travel and fuel efficiency:

$$XSHIP_T = \frac{STMTT_T}{STMTT_{T=1}}$$

and **(B-194)**

$$XSHIPEFF_T = \frac{FESHIP_T}{FESHIP_{T=1}}$$

where:

XSHIP = Growth in ship travel from base year

XSHIPEFF = Growth in ship efficiency from base year

AIR TRAVEL MODULE

AIR TRAVEL DEMAND MODEL Subroutine TAIRT

1) Calculate the cost of flying:

$$YIELD_T = 4.22 + .94\,TPJFTR_T + 65.42\,OPCST_T \qquad \textbf{(B-195)}$$

where:

YIELD = Cost of air travel, expressed in cents per RPM
TPJFTR = Price of jet fuel, in dollars per million Btu
OPCST = Non-fuel operating costs, in dollars per available seat-mile

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

a) For business travel:

$$RPMBPC_T = -126.8 + .050\left(\frac{TMC\_GDP_T}{TMC\_POPAFO_T}\right) - 12.80\,YIELD_T \qquad \textbf{(B-196)}$$

b) For personal travel:

$$RPMPPC_T = -587.8 + .118\left(\frac{TMC\_YD_T}{TMC\_POPAFO_T}\right) - 20.56\,YIELD_T \qquad \textbf{(B-197)}$$

c) For international travel:

$$RPMIPC_T = PCTINT_T \cdot (RPMBPC_T + RPMPPC_T) \qquad \textbf{(B-198)}$$

where:

RPMBPC = Per capita revenue passenger miles for business travel
RPMPPC = Per capita revenue passenger miles for personal travel
RPMIPC = Per capita revenue passenger miles for international travel
TMC_GDP = Gross domestic product, from MACRO module
TMC_YD = Disposable personal income, from MACRO module
TMC_POPAFO = Total domestic population, from MACRO module
PCTINT = Proportionality factor relating international to domestic travel levels

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

$$TM_T = \left(-18{,}165.6 + 22.35\ TMC\_EXDN87_T + 5.77\ TMC\_GDP_T\right) \cdot DFR' \qquad \textbf{(B-199)}$$

where:

TMC_EXDN87 = Value of merchandise exports, from MACRO module

DFRT = Fraction of freight ton-miles transported by dedicated carriers

4) Calculate total revenue passenger-miles flown for each category of travel:

a) For business travel:

$$RPMB_T = RPMBPC_T \cdot TMC\_POPAFO_T \qquad \textbf{(B-200)}$$

b) For personal travel:

$$RPMP_T = RPMPPC_T \cdot TMC\_POPAFO_T \cdot DI_T \qquad \textbf{(B-201)}$$

c) For international travel:

$$RPMI_T = RPMIPC_T \cdot TMC\_POPAFO_T \qquad \textbf{(B-202)}$$

where:

RPMB = Revenue passenger miles for business travel

RPMP = Revenue passenger miles for personal travel

RPMI = Revenue passenger miles for international travel

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

5) Calculate total domestic air travel:

$$RPMD_T = RPMB_T + RPMP_T \qquad \textbf{(B-203)}$$

where:

RPMD = Total domestic air travel

6) Calculate the total demand for available seat-miles:

$$ASMDEMD_T = \left(\frac{RPMD_T}{LFDOM_T} \right) + \left(\frac{RPMI_T}{2 \, * \, LFINTER_T} \right) + (RTM_T \cdot EQSM \qquad \textbf{(B-204)}$$

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

AIRCRAFT FLEET EFFICIENCY MODEL — Subroutine TAIREFF

1) Calculate available seat-miles per plane, by aircraft type:

$$ASMP_{IT,T} = AIRHRS_{IT,T} \, * \, AVSPD_{IT,T} \, * \, SEAT_{IT,T} \qquad \textbf{(B-205)}$$

where:

ASMP = The available seat-miles per plane, by type.
AIRHRS = The average number of airborne hours per aircraft.
AVSPD = The average flight speed.
SEAT = The average number of seats per aircraft.
IT = Index of aircraft type: 1 = narrow body, 2 = wide body

2) Calculate fraction of seat-mile demand accomodated by narrow-body aircraft:

$$\begin{aligned} CN_T &= \left[\left(\frac{ASMDEMD_{IT=1,T-1}}{SMDEMD_{T-1}} \right) + DELTA \cdot \left(\frac{ASMDEMD_{IT=2,T-1}}{SMDEMD_{T-1}} \right) \right] \; ; \; DE \\ &= \left[\left(\frac{ASMDEMD_{IT=1,T-1}}{SMDEMD_{T-1}} \right) \cdot (1 + DELTA) \right] \; ; \; DELTA < 0 \end{aligned} \qquad \textbf{(B-206)}$$

where:

SMFRACN = Fraction of seat-mile demand on narrow-body planes
ASMDEMD = Demand for available seat-miles, by aircraft type
DELTA = User-specified rate of passenger shifts between aircraft types

3) Calculate current seat-miles demanded by aircraft type:

$$ASMDEMD_{IT=1,T} = SMDEMD_{T} * SMFRACN_{T}$$

and **(B-207)**

$$ASDEMD_{IT=2,T} = SMDEMD_{T} * \left(1.0 - SMFRACN_{T}\right)$$

4) Calculate survival rates of aircraft:

$$URVPCT_{IVINT} = \left[\, 1 + EXP\ (\, SURVK * (\, T50 - IVINT\,)\,)\,\right]^{-}$$

and **(B-208)**

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

where:

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

5) Calculate surviving seat-miles from previous year:

$$RV_{IT,T} = \sum_{IVINT=2}^{60} NPCHSE_{IT,IVINT-1,T-1} * SSURVPCT_{IVINT} * AS$$ **(B-209)**

where:

SMSURV = Surviving available seat-miles, by aircraft type
NPCHSE = Surviving aircraft stock, by vintage and aircraft type

6) Calculate new aircraft purchases:

$$NPCHSE_{IT,IVINT=1,T} = \left[\frac{ASMDEMD_{IT,T} - SMSURV_{IT,T}}{ASMP_{IT,T}}\right]$$ **(B-210)**

7) Adjust array of aircraft stocks by vintage:

$$\ldots_{IT,IVINT,T} = NPCHSE_{IT,IVINT-1,T-1} * SSURVPCT_{IVINT} \quad ; \quad IVINT\ldots \qquad \textbf{(B-211)}$$

8) Calculate aircraft stock across vintages:

$$NSURV_{IT,T} = \sum_{IVINT=1}^{60} NPCHSE_{IT,IVINT,T} \qquad \textbf{(B-212)}$$

where:

NSURV = Number of surviving aircraft, by type

9) Calculate fraction of current year stock which is old (*IVINT* > 1):

$$STKOLD_{IT,T} = \frac{\left(NSURV_{IT,T} - NPCHSE_{IT,IVINT=1,T}\right)}{NSURV_{IT,T}} \qquad \textbf{(B-213)}$$

where:

STKOLD = Fraction of planes older than one year, by aircraft type

10) Calculate effect of technology improvements:

a) Calculate time effect:

$$\ldots FX_{IFX,T} = TIMEFX_{IFX,T-1} + \left(TIMECONST * TPN_{IFX} * TYR\ldots \qquad \textbf{(B-214)}$$

where:

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

IFX = Index of technology improvements (1-6)

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

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

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

b) Calculate the cost effect:

$$= 10 * \left(\frac{TPJFGAL_T - TRAGPRICE_{IFX}}{TPJFGAL_T} \right) * TPN_{IFX} * TYR \quad \textbf{(B-215)}$$

where:

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

TPJFGAL = Price of jet fuel

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

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

c) Calculate the total effect:

$$'OTALFX_{IFX,T} = TIMEFX_{IFX,T} + COSTFX_{IFX,T} - BASECONS \quad \textbf{(B-216)}$$

where:

TOTALFX = Overall effect of fuel price and time on implementation of technology *IFX*

BASECONST = Baseline constant, used to anchor the technology penetration curve

d) Calculate the penetration of new technologies:

$$TECHFRAC_{IFX,T} = \left[1 + EXP \left(-TOTALFX_{IFX,T} \right) \right]^{-1} \quad \textbf{(B-217)}$$

where:

TECHFRAC = Fration of new aircraft purchases which incorporate a given technology

11) Calculate fractional fuel efficiency improvement for new aircraft, by type:

$$+ \sum_{IFX=2}^{6} EFFIMP_{IFX}$$

and

$$MP_{IT=2,T} = 1.0 + \sum^{6} EFFIMP_{IFX} * TECHFRAC_{IFX,T} \quad ; \quad I \tag{B-218}$$

where:

FRACIMP = Fractional improvement over base year (1990) fuel efficiency, by type
EFFIMP = Fractional improvement associated with a given technology

12) Ensure that technical improvements provide at least as much efficiency gain as average growth in remainder of air fleet:

$$NEWSMPG_{IT,T} = MAX \left[(FRACIMP_{IT,T} * SMPG_{IT,T=1}) \; , \; ((1.0 + P_{IT,T}) * SMPGIT,T-1 * 1.05) \right] \tag{B-219}$$

where:

NEWSMPG = Average seat-miles per gallon of new aircraft purchases
SMPG = Surviving fleet average seat-miles per gallon, by aircraft type
RHO = Average historic rate of growth of fuel efficiency

13) Calculate average fuel economy of aircraft fleet, by type:

$$_{T,T} = \left[\left(\frac{STKOLD_{IT,T}}{(1 + RHO_{IT}) \cdot (SMPG_{IT,T-1})} \right) + \left(\frac{1 - STKOLD_{I}}{NEWSMPG_{IT,}} \right. \right. \tag{B-220}$$

14) Calculate average fuel economy of aircraft fleet:

$$SMPGT_T = \left[\left(\frac{SMFRACN_T}{SMPG_{IT=1,T}} \right) + \left(\frac{(1 - SMFRACN_T)}{SMPG_{IT=2,T}} \right) \right]^{-1} \tag{B-221}$$

where:

SMPGT = Overall fleet average seat-miles per gallon

15) Calculate demand for jet fuel, incrementing by 5% to reflect consumption by private aircraft:

$$JFGAL_T = \left(\frac{SMDEMD_T}{SMPGT_T} \right) * 1.05 \qquad \textbf{(B-222)}$$

where:

JFGAL = Consumption of jet fuel, in gallons

16) Calculate demand for aviation gasoline:

$$= BASEAGD + GAMMA * EXP \left[- KAPPA * (IYEAR - \right. \qquad \textbf{(B-223)}$$

where:

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

17) Convert from gallons to Btu:

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

and **(B-224)**

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

where:

JFBTU = Jet fuel demand, in Btu
AGDBTU = Aviation gasoline demand, in Btu

18) Regionalize demand:

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

and **(B-225)**

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

where:

QJETR = Regional demand for jet fuel
QAGR = Regional demand for aviation gasoline
SEDSHR = Regional shares of fuel demand, from SEDS

19) Calculate fractional changes in air travel and aircraft efficiency:

$$XAIR_T = \frac{SMDEMD_T}{SMDEMD_{T-1}}$$

and **(B-226)**

$$XAIREFF_T = \frac{SMPGT_T}{SMPGT_{T-1}}$$

where:

XAIR = Fractional change in air travel from base year
XAIREFF = Fractional change in aircraft fuel efficiency from base year

MILITARY DEMAND MODEL Subroutine TMISC

Calculate military energy use:

1) Calculate growth in military budget:

$$MILTARGR_T = \frac{TMC\_GRML87_T}{TMC\_GFML87_{T-1}} \quad \text{(B-227)}$$

where:

MILTARGR = Fractional growth of military budget
TMC_GRML87 = Military budget, from MACRO module

2) Calculate fuel demand:

$$MFD_{IF,T} = MFD_{IF,T-1} * MILTARGR_T \quad \text{(B-228)}$$

where:

MFD = Demand for fuel by military
IF = Index of fuel type

3) Regionalize demand:

$$QMILTR_{IF,IR,T} = MFD_{IF,T} * MILTRSHR_{IF,IR,T} \quad \text{(B-229)}$$

where:

QMILTR = Regional military demand for fuel
MILTRSHR = Regional shares of military demand for fuel

Calculate mass-transit consumption:

1) Calculate passenger-miles by mode:

$$TMOD_{IM=1,T} = VMTEE_T * TMLOAD89_{IM=1}$$

and:

$$TMOD_{IM,T} = TMOD_{IM,T-1} * \left[\frac{TMOD_{1,T}}{TMOD_{1,T-1}}\right]^{BETAMS} \quad \textbf{(B-230)}$$

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

2) Calculate mass transit efficiencies, in Btu per passenger-mile:

$$TMEFFL_{IM,T} = \frac{\left[TMEFF89_{IM} * \left(\frac{FMPG_{TYPE,T}}{FMPG89_{TYPE}}\right)\right]}{TMLOAD89_{IM}} \quad \textbf{(B-231)}$$

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

3) Calculate fuel consumption by mode:

$$TMFD_{IM,T} = TMOD_{IM,T} * TMEFFL_{IM,T} \quad \textbf{(B-232)}$$

where:

TMFD = Total mass-transit fuel consumption by mode

4) Regionalize consumption:

$$QMODR_{IM,IR,T} = TMFD_{IM,T} * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \quad \textbf{(B-233)}$$

where:

QMODR = Regional consumption of fuel, by mode

TMC_POPAFO = Regional population forecasts, from the Macro Module

RECREATIONAL BOATING DEMAND MODEL Subroutine TMISC

Calculate recreational boat fuel use:

1) Calculate fuel demand:

$$RECFD_{T} = RECFD_{T-1} * \left[\frac{TMC\_YD_{T}}{TMC\_YD_{T-1}} \right]^{BETAREC} \quad \textbf{(B-234)}$$

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

2) Regionalize consumption according to population:

$$QRECR_{IR,T} = RECFD_{T} * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \quad \textbf{(B-235)}$$

where:

QRECR = Regional fuel consumption by recreational boats in year T

Calculate lubricant demand:

1) Sum freight truck VMT across size classes:

$$FTVMT_T = \sum_{SC=1}^{3} FVMTSC_{SC,T} \tag{B-236}$$

where:

FTVMT = Total freight truck VMT
FVMTSC = Freight truck VMT, by size class

2) Calculate total highway travel:

$$HYWAY_T = VMTEE_T + FTVMT_T + FLTVMT_T \tag{B-237}$$

where:

HYWAY = Total highway VMT
FLTVMT = Total fleet vehicle VMT, from the Fleet Module

3) Calculate lubricant demand:

$$LUBFD_T = LUBFD_{T-1} * \left[\frac{HYWAY_T}{HYWAY_{T-1}}\right]^{BETALUB} \tag{B-238}$$

where:

LUBFD = Total demand for lubricants in year T
BETALUB = Constant of proportionality, relating highway travel to lubricant demand

4) Regionalize lubricant demand:

$$_{,T} = LUBFD_T * \left[\frac{((VMTEE_T + FLTVMT_T) * SEDSHR_{IF,IR,T}) + (FTVMT_T * SE}{HYWAY_T} \right. \quad \textbf{(B-239)}$$

where:

QLUBR = Regional demand for lubricants in year T, in Btu

SEDSHR = Regional share of fuel consumption, from SEDS

IF = Index of fuel type: gasoline for light-duty vehicles, diesel for freight trucks

VEHICLE EMISSIONS MODULE Subroutine TEMISS

This subroutine calculates the emissions of six airborne pollutants, at every conceivable level of aggregation. A single, representative equation is provided.

1) Calculate disaggregate emissions of airborne pollutants:

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T} \tag{B-240}$$

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, and may be further subdivided by size class, vehicle technology, and vehicle type
IE = Index of pollutants: 1 = SO_x, 2 = NO_x, 3 = C, 4 = CO_2, 5 = CO, 6 = VOC
IR = Index identifying census region

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Appendix D. Model Abstract

Model Name:

Transportation Sector Model

Model Acronym:

TRAN

Description:

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

Purpose of the Model:

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

Most Recent Model Update:

December, 1993.

Part of Another Model?

National Energy Modeling system (NEMS).

Model Interfaces:

Receives inputs from the Electricity Market Module, Oil and Gas Market Module, Renewable Fuels Module, and the Macroeconomic Activity Module.

Official Model Representative:

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Documentation:

Model Documentation Report: Transportation Sector Model of the National Energy Modeling System, March 1994.

Archive Media and Installation Manual(s):

The model will be archived on IBM 3380 tape compatible with the IBM 3090 mainframe system upon completion of the NEMS production runs to generate the Annual Energy Outlook 1994.

Energy System Described:

Domestic transportation sector energy consumption.

Coverage:

- Geographic: Nine Census Divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific.
- Time Unit/Frequency: Annual, 1990 through 2010.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants.
- Economic Sectors: Forecasts are produced for personal travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Model Interfaces:

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

Model Structure:

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

Special Feautres:

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

Modeling Techniques:

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

Computing Environment:

- Hardware Used: IBM 3090
- Operating System: MVS
- Language/Software Used: VS FORTRAN, Ver 2.05
- Memory Requirement: 4098 K
- Storage Requirement: Model has not yet been archived. It will require an as-yet undetermined number of tracks of an IBM 3380 disk pack.
- Estimated Run Time: 2 minutes for a 1990-2015 run on non-iterating NEMS Mode on IBM 3090 mainframe
- Special Features: None.

Independent Expert Reviews Conducted:

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

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- State Energy Data System (SEDS), 1991, May 1993.
- Residential Transportation Energy Consumption Survey (RTECS), 1991, December 1993
- U.S. Department of Energy, Office of Policy, Planning and Analysis, "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector", Technical Report Ten: Alternative Fuel Requirements, 1992.

Non-DOE Input Sources:

- National Energy Accounts
- Federal Highway Administration, Highway Statistics, 1991, 1992
- Department of Transportation Air Travel Statistics
- Air Transport Association of America, 1990 Air Travel Survey
- Oak Ridge National Laboratory, Energy Data Book: 13, March 1993.
- Oak Ridge National Laboratory, Light-Duty Vehicle MPG and Market Report: Model Year 1992, February, 1992.
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Appendix E. Data Quality and Estimation

LIST OF TABLES

Appendix E. Data Quality and Estimation

This appendix presents results of the statistical tests conducted for those componenents of the transportation model which rely on econometric estimations. These components include: The Fuel Economy Model, the Alternative Fuel Vehicle Model, the Vehicle-Miles Traveled Model, and the Air Travel Demand Model. To date, no data quality studies have been conducted in order to validitate the transportation model's input data.

Fuel Economy Model

The methodology employed to assess the influence of macroeconomic and time-dependent variables on the mix of size classes and performance was log-linear regression analysis using historical data on car and light truck sales over the 1979-1990 period. Greater detail is provided in Attachment 1 of Appendix F.

The following equations were used to estimate the class market shares of new vehicle purchases:

All Vehicle Classes Except Luxury Cars:[1]

$$\left(\frac{\text{ARE}_i}{\text{HARE}_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\ldots \right.$$
$$+ B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOM\ldots}{INCOM\ldots}\right. \qquad \textbf{(E-1)}$$

where:

$CLASS\$SHARE_i$ = The market share of the i[th] vehicle class
FUELCOST = The price of gasoline
INCOME = Per capita disposable income

[1]Note: Market shares for Mini and Sub-Compact cars are solved jointly. 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.

Luxury Cars:

$$\left(\frac{SHARE_i}{\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln$$

$$+ B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\Bigg(\qquad \text{(E-2)}$$

The values of the coefficients with their associated T-statistics are provided below in Table E-1.

Table E-1. Regression Results From The Market Share Model

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

Alternative Fuel Vehicle Model

The AFV model uses a multinomial nested logit approach to estimate market shares of sixteen vehicle technologies. Model coefficients are taken from a study sponsored by the California Energy Commission, using a stated preference survey of California residents. The applicability of this study to a nationwide model has not been tested. Market shares are based on the exponentiated value of the consumer utility function, represented as follows:

$$
\begin{aligned}
{}_{IT,IR} = \quad & CONST_{IT} + \beta_1 \, VPRI_{IS,IT,N} + \beta_2 \, COPCOST_{IT,IS,IR,N} \\
& + \beta_3 \, VRANGE_{IS,IT,N} + \beta_4 \, VRANGE^2_{IS,IT,N} + \beta_5 \, EMISS_{IS} \\
& + \beta_6 \, EMISS^2_{IS,IT,N} + \beta_7 \, FAVAIL_{IT,IR,N} + \beta_8 \, FAVAIL^2_{IT,IR}
\end{aligned}
\qquad \textbf{(E-3)}
$$

where:

VC1 = Utility vector for conventional and alternative vehicles
CONST = Constant associated with each considered technology *IT*
VPRI = Price of each considered technology in 1990$
VRANGE = Vehicle range of the considered technology
EMISS = Emissions levels relative to gasoline ICE's
FAVAIL = Relative availability of the considered fuel

Model coefficients and relevant T-statistics are provided in Table E-2, on the following page. An extensive description of the data base development process is provided as an attachment in Appendix F.

Table E-2. Alternative Fuel Vehicle Model Coefficients

VARIABLE	COEFFICIENT	T-STATISTIC
VPRI	-.134	10.1
COPCOST	-.190	16.4
VRANGE	2.52	11.4
VRANGE^2	-.408	7.4
EMISS	-2.45	7.0
EMISS^2	0.855	2.7
FAVAIL	2.96	5.7
FAVAIL^2	-1.63	3.5
CONST (Technology-Specific, as Follows)		
Gasoline	0.0	—
Diesel	0.0	—
Ethanol Flex	0.693	6.7
Ethanol Neat	0.0979	0.9
Methanol Flex	0.693	6.7
Methanol Neat	0.0979	0.9
Electric	-.0240	0.1
Electric Hybrid/Large ICE	-.257	1.5
Electric Hybrid/Small ICE	-.257	1.5
Electric Hybrid/Turbine	-.257	1.5
CNG	0.0979	0.9
LPG	0.0979	0.9
Turbine/Gasoline	0.0	—
Turbine/CNG	0.0979	0.9
Fuel Cell/Methanol	0.0979	0.9
Fuel Cell/Hydrogen	0.0979	0.9

Vehicle-Miles Traveled Model

Vehicle-miles traveled is estimated on a per capita basis using a generalized difference equation, estimated using the Cochrane-Orcutt iterative procedure:

$$
\begin{aligned}
&= \rho\, VMTPC_{T-1} + 0.28\,(1-\rho) - 7.50\,(CPM_T - \rho\, CPM_{T-1} \\
&\quad + 3.6x10^{-4}\,(YPC_T - \rho\, YPC_{T-1}) + 8.36\,(PrFem_T - \rho\, Pr
\end{aligned}
\qquad \textbf{(E-4)}
$$

where:

CPM = The cost of driving a mile
YPC = Disposable personal income per capita
PrFem = The ratio of per capita female driving to per capita male driving.

The parameters and relevant T-statistics are provided in Table E-3, below.

Table E-3. Model of VMT per Capita

	$\hat{\rho}$	Constant	CPM	YPC	PrFem	Adj. R-Sq
Parameter	0.72	0.28	-7.50	3.6e-04	8.36	0.841
T-Statistic			-2.32	2.46	2.99	

Air Travel Demand Model

The following tables (E-4 - E-8) provide the data used in the air travel demand regressions. All data manipulation is described in the accompanying notes.

Table E-4. Fuel Consumption and Real (1982) Operating Costs

YEAR	DOMESTIC			INTERNATIONAL		
	Fuel Cons. (10^6 Gal.) (JFD_D)	Cost/Gal (PJF_D)	Non-Fuel Costs/ASM ($OPCST_D$)	Fuel Cons. (10^6 Gal.) ($JFD_{I,US}$)	Cost/Gal (PJF_I)	Non-Fuel Costs/ASM ($OPCST_I$)
1979	8,866	72	6.23	1,828	82	6.28
1980	8,519	101	6.34	1,747	119	5.94
1981	8,555	109	6.17	2,033	122	5.07
1982	8,432	97	5.85	1,968	108	4.72
1983	8,673	85	5.87	1,998	93	4.90
1984	9,626	78	5.51	2,286	83	4.97
1985	10,115	72	5.65	2,488	76	4.79
1986	11,137	48	5.89	2,545	54	5.17
1987	11,587	47	6.00	2,894	51	5.25
1988	11,918	43	6.28	3,263	47	5.72
1989	11,905	47	6.69	3,557	50	6.02
1990	12,429	58	6.60	3,963	64	6.48

Sources:

JFD & PJF: U.S. Department of Transportation, Research and Special Programs Administration (RSPA), *Fuel Cost And Consumption Tables*, annual summaries, 1979-1990.

OPCST: Non-Fuel operating costs derived from U.S. Department of Transportation, Research and Special Programs Administration, *Air Carrier Financial Statistics Quarterly, December 1990/1989*, and prior issues, "Total Operating Expenses", Line 28, minus Fuel Costs from RSPA fuel consumption tables, *op. cit.* The result is subsequently divided by Available Seat Miles, from U.S. Department of Transportation, Research and Special Programs Administration, *Air Carrier Traffic Statistics Monthly, December 1990/1989*, and prior issues, Lines 12, 42.

Table E-5. Domestic Passenger Travel Demand—Preliminary Data

YEAR	Total Travel (RPM_D)	Business Fraction (BFRAC)	Available Seat-Miles (ASM_D)
1979	212,701	0.55	337,668
1980	204,367	0.54	350,716
1981	201,435	0.52	349,824
1982	213,631	0.52	364,301
1983	232,165	0.51	386,138
1984	250,686	0.48	432,781
1985	277,836	0.50	455,099
1986	307,884	0.46	505,734
1987	329,214	0.48	533,169
1988	334,290	0.50	544,737
1989	335,213	0.49	537,133
1990	345,763	0.48	570,387

Sources:

(1) **RPM:** U.S. Department of Transportation, Research and Special Projects Administration (RSPA),*Air Carrier Traffic Statistics Monthly, December 1990/1989*, and prior issues. Lines 9, 41.
Passenger Revenue: U.S. Department of Transportation, Research and Special Projects Administration (RSPA), *Air Carrier Financial Statistics Quarterly, December 1990/1989*, and prior issues. Lines 1, 2, 12.

(2) **RTM:** U.S. Department of Transportation, Research and Special Projects Administration (RSPA),*Air Carrier Traffic Statistics Monthly, December 1990/1989*, and prior issues. Lines 18-21, 46.
Freight Revenue: U.S. Department of Transportation, Research and Special Projects Administration (RSPA), *Air Carrier Financial Statistics Quarterly, December 1990/1989*, and prior issues. Lines 6, 7, 13.

Table E-6. International Passenger Travel Demand—Preliminary Data

YEAR	Total, U.S. Carrier ($RPM_{I,US}$)	Available Seat-Miles ($ASM_{I,US}$)	Departures, U.S. Carrier (DEP_{US})	Departures, Foreign Carrier (DEP_{FOR})	Miles per Int. Departure (MPID)
1979	57,017	87,743	9,124	8,958	3,125
1980	63,355	97,762	9,369	9,886	3,381
1981	58,629	89,013	9,581	10,330	3,060
1982	58,803	91,637	9,485	9,837	3,100
1983	61,823	93,510	9,888	9,837	3,126
1984	68,818	101,324	10,531	11,076	3,267
1985	73,237	110,578	10,696	11,791	3,424
1986	71,038	117,339	10,711	12,464	3,316
1987	88,615	137,701	12,853	13,811	3,447
1988	103,358	151,601	14,981	14,440	3,450
1989	112,266	166,755	15,687	15,466	3,578
1990	126,392	182,724	17,628	16,418	3,585

Sources:

Fraction of Business Travel: Air Transport Association of America, *Air TravelSurvey, 1990,* Washington D.C.
International Passenger Departures: U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA, *U.S. International Air Travel Statistics,* annual issues, Table Id/IId.

Table E-7. Passenger and Freight Travel Demand

YEAR	DOMESTIC			INTERNATIONAL		FREIGHT
	Business ($RPM_{D,B}$)	Personal ($RPM_{D,P}$)	Load Fac (LF_D)	Total (RPM_I)	Load Fac (LF_I)	D & I (RTM)
1979	116,986	95,715	0.63	56,498	0.65	8,350
1980	109,336	95,031	0.58	65,103	0.65	9,136
1981	104,746	96,689	0.58	60,921	0.66	9,033
1982	110,020	103,611	0.59	59,894	0.64	9,086
1983	118,404	113,761	0.60	61,664	0.66	9,713
1984	120,329	130,357	0.58	70,599	0.68	10,766
1985	138,918	138,918	0.61	76,986	0.66	10,515
1986	141,627	166,257	0.61	76,851	0.61	12,228
1987	158,023	171,191	0.62	91,917	0.64	14,466
1988	167,145	167,145	0.61	101,492	0.68	16,066
1989	164,254	170,959	0.62	111,475	0.67	17,824
1990	165,966	179,797	0.61	122,054	0.69	17,922

International RPM associated with passengers departing the United States is inferred from available data, as follows:

1) The Department of Transportation estimates total (departures and arrivals) international RPM for only U.S. carriers. This estimate is divided by two to estimate the RPM associated with international departures.
2) This figure (RPM for U.S. carrier departures) is divided by the number of passengers departing on U.S. carriers to obtain miles per departure.
3) Assuming that this quotient (miles per departure) also characterizes foreign carriers' trips, and further assuming equal load factors, passenger departures of both U.S. and foreign carriers are added, then multiplied by the above factor to get an estimate of total international RPM.
4) Yields will be estimated using only data for U.S. carriers' international operations and will be attributed to foreign carriers, as well.

Table E-8. Total Yields (1982 Cents Per Passenger or Ton Mile)

YEAR	PASSENGER[1]			FREIGHT[2]
	Domestic		International	
	Business ($YIELD_B$)	Personal ($YIELD_P$)	($YIELD_I$)	($YIELD_F$)
1979	11.32	11.32	9.53	43.23
1980	13.29	13.29	9.18	41.76
1981	13.47	13.47	8.72	39.64
1982	11.91	11.91	8.43	35.90
1983	11.41	11.41	8.73	33.14
1984	11.64	11.64	8.20	31.84
1985	10.82	10.82	7.94	31.82
1986	9.66	9.66	8.11	47.97
1987	9.70	9.70	8.05	45.45
1988	10.11	10.11	8.26	46.38
1989	10.31	10.31	7.89	39.52
1990	10.18	10.18	8.09	33.86

Sources:

(1) **RPM:** U.S. Department of Transportation, Research and Special Projects Administration (RSPA),*Air Carrier Traffic Statistics Monthly, December 1990/1989,* and prior issues. Lines 9, 41.
Passenger Revenue: U.S. Department of Transportation, Research and Special Projects Administration (RSPA), *Air Carrier Financial Statistics Quarterly, December 1990/1989,* and prior issues. Lines 1, 2, 12.

(2) **RTM:** U.S. Department of Transportation, Research and Special Projects Administration (RSPA),*Air Carrier Traffic Statistics Monthly, December 1990/1989,* and prior issues. Lines 18-21, 46.
Freight Revenue: U.S. Department of Transportation, Research and Special Projects Administration (RSPA), *Air Carrier Financial Statistics Quarterly, December 1990/1989,* and prior issues. Lines 6, 7, 13.

Parameter Estimation Details

The equations used to forecast air travel demand are presented below, along with relevant statistical information.

1. Calculate the cost per mile of air travel (the following equation corresponds to Equation 103 in Volume I):

$$YIELD = 4.22 + .94\,PJF + 65.42\,OPCST$$

Std. Err.	(.016)	(7.59)
T−Statistic	58.95	8.62

(E-5)

Adj. $R^2 = .997$; D−W = 1.06

where:

YIELD = Cost of air travel, expressed in cents per RPM
PJF = Price of jet fuel, in dollars per million Btu
OPCST = Non-fuel operating costs, in dollars per available seat-mile

2. Calculate annual the revenue passenger miles for business travel (the following equation corresponds to Equation 104 in Volume I):

$$RPMBPC = -587.8 + .118\,\frac{TMC\_GDP}{TMC\_POPAFO} - 20.56\,YIELD$$

Std. Err.	(.010)	(5.90)
T−Statistic	5.0	−2.17

(E-6)

Adj. $R^2 = .947$; D−W = 2.42

where:

RPMBPC = Revenue passenger miles for business travel
TMC_GDP = Gross domestic product, in 1987 dollars.
TMC_POPAFO = U.S. population

3. Calculate the revenue passenger miles for personal travel (the following equation corresponds to Equation 105 in Volume I):

$$RPMPPC = -126.8 + .050 \frac{TMC\_YD}{TMC\_POPAFO} - 12.80\,YIELD \qquad \textbf{(E-7)}$$

Std. Err.	(.027)	(10.51)
T-Statistic	4.32	-1.96

Adj. R^2 = .940 ; D-W = 1.44

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

4. Calculate the revenue ton-miles of air freight (the following equation corresponds to Equation 107 in Volume I):

$$RTM = \left(-18{,}165.6 + 22.35\,EXDN87 + 5.77\,GDP\right) \cdot DFRT \qquad \textbf{(E-8)}$$

Std. Err.	(6.04)	(.740)
T-Statistic	3.70	7.79

Adj. R^2 = .940 ; D-W = 1.44

where:

RTM = Revenue ton-miles of freight
TMC_EXDN87 = Value of merchandise exports, in 1987 dollars
TMC_GDP = Gross domestic product, in 1987 dollars.
DFRT = Fraction of freight ton-miles transported by dedicated carriers

Appendix F. Attachments to the Transportation Model

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Appendix F. Attachments to the Transportation Model

The attachments contained within this appendix provide additional details about the model development and estimation process which do not easily lend themselves to incorporation in the main body of the model documentation report. The information provided in these attachments is not integral to the understanding of the model's operation, but provides the reader with to opportunity to gain a deeper understanding of some of the model's underlying assumptions. There will be a slight degree of replication of materials found elsewhere in the documentation, made unavoidable by the dictates of internal consistency. Each attachment is associated with a specific component of the transportation model; the presentation follows the same sequence of modules employed in Volume I.

The following attachments are contained in Appendix F:

Attachment 1: Fuel Economy Model (FEM): Provides a discussion of the FEM vehicle demand and performance by size class models.

Attachment 2: Alternative Fuel Vehicle (AFV) Model: Describes data input sources and extrapolation methodologies.

Attachment 3: Light-Duty Vehicle (LDV) Stock Model: Discusses the fuel economy gap estimation methodology.

Attachment 4: Vehicle-Miles Traveled (VMT) Model: Presents the development of the updated VMT forecasting methodology.

Attachment 5: Air Travel Demand Model: Presents the derivation of the demographic index, used to modify estimates of personal travel demand.

Attachment 6: Airborne Emissions Model: Describes the derivation of emissions factors used to associate transportation measures to levels of airborne emissions of several pollutants.

Attachment 1: Fuel Economy Model

Demand Models for Vehicle Size Class Mix
and Performance by Size Class

INTRODUCTION

Estimates of the future mix of vehicle classes sold and the performance level by size class requires a detailed econometric demand model of vehicle choice by size class and vehicle performance within size class. There are a few publicly available models that forecast vehicle demand by size class, but those models have proved inaccurate in the past, and do not use a class structure that is compatible with the one used in the FEM. Demand for performance has not been assessed to date in any publicly available study. Both the size mix and performance levels are difficult to estimate because the car purchase decision is complex and consumer choice depends not only on the macroeconomic conditions but also on the attributes of individual products in the marketplace. Some of these attributes are based on the styling of the car, its perceived quality, the manufacturer's image and the status conveyed by owning a specific model, and cannot be easily quantified. Although these variables affect choice of individual models, they can also affect the choice of vehicle sizes or performance levels. For example, many consumers appeared to willing to buy a Japanese car for its quality and reliability even if it's size was smaller than the size actually desired by consumers. There have also been changes in consumer performance that may be linked to demographic variables, e.g., older consumers prefer larger cars.

These factors have made the automotive market notoriously difficult to forecast. The models incorporated in the FEM do not represent an attempt to provide a comprehensive forecast of future shifts in size class mix or performance levels by size class in response to the potentially large range of influencing or causal variables. Rather, the models attempt to capture the response to broad macroeconomic forces or behavioral (time) trends based on the experience of the last 15 years. It is recognized that these models are relatively simplistic, and it is anticipated that future versions of the FEM will incorporate more advanced models.

METHODOLOGY

The methodology employed to assess the influence of macroeconomic and time dependent variables on the mix of size classes and performance was by regression analysis of historical data.

EEA has compiled a very large data base on car and light truck sales over the 1979-1990 period. These data are based on the official CAFE files from EPA, augmented by the addition of vehicle and engine descriptor variables. All of the vehicles were classified by market class according to the scheme utilized in the FEM. Vehicle performance levels were measured by the horsepower to weight ratio (HP/WT) that is well correlated to objective measures such as the 0 to 60 mph acceleration time. Detailed weight data was unavailable for light trucks, and horsepower alone was used as a surrogate for performance. (Fortunately, truck weight within market class did not change significantly in the 12 year period analyzed).

The models for size class mix and performance utilized the same set of independent variables

- Disposable income per capita (in 1990 dollars)
- Price of gasoline (1990 dollars)
- Vehicle price average by class
- Vehicle fuel economy
- Rate of change of gas price over two years
- Cost of driving per mile
- Number of nameplates (models) in a class

The last variable is really a composite of fuel cost/fuel economy and not a new independent variable.

Performance was defined as the average HP/WT ratio by class for cars, and the average HP by class for trucks. Market share was defined as the sales fraction of the class relative to entire car and light truck market. This definition was chosen to incorporate the effects of consumers switching from cars to light trucks.

In general, the models were linear regressions of the logarithm of all variables, so that the co-efficients represented "elasticity" estimates. However, the market share model was modified to utilize the variable (m/1-m) as the independent variable in the regression, for two reasons. First, the elasticity of market share appears to be dependent on how large a share of the market a size class has. This reflects the fact that at very low market shares, buyers of a particular class are reduced to the diehard consumers who are less likely to switch due to macroeconomic forces, and the market is inelastic. Second the log(m/1-m) form converts a 0 to 1 variable to one that spans the -infinity to +infinity range. As a result of this variable change the model cannot be driven to m=1 for any input set, so that no one market class takes over the entire market for any combination of inputs. Such a variable form has been utilized in prior analysis by Wheaton Econometric Forecasting Associates (WEFA).

RESULTS

A stepwise linear regression of performance by market class and of class market share was performed to aid in the selection of independent variables with the greatest statistical significance. In addition, the co-efficients were required to be

- directionally consistent with intuitive expectations
- consistent in absolute magnitude across market classes that are similar

For the market share regressions, the variables that were statistically significant included: model year (time), price of gasoline, disposable income, number of nameplates (in some classes). In particular, number of nameplates was significant in those classes where only one or two makes existed in the early 1980’s but new makes were introduced in the mid-to-late 1980’s; compact vans are a good example of this phenomenon.

Table F-1 shows the results of the regressions of (m_i/1-m_i) against the variables MDLY (model year), LPGAS (price of gasoline), LYD (per capita disposable income), and LNPLT (number of nameplates). The following conclusions are appropriate:

- Subcompact and minicompact market share benefits from a time trend towards smaller cars. Market share increases with increasing gasoline prices (1.33 co-efficient) but decreases with increasing income.
- Sports cars market share appears to be declining with time but is insensitive to price of gasoline or income.
- Compact car market share increase with time and increasing price of gasoline, but is insensitive to income trends.

Table F-1. Regression Results From LDV Market Share Model

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

- Intermediate car market share is decreasing with time but is largely insensitive to either the price of gasoline or income.
- Large car market share decreases with time, but increases with income.
- Luxury car market share increases with time, income and the price of gasoline.
- Minitruck market share is very sensitive to the price of gasoline, and decreases with increasing gasoline prices and income.
- Compact trucks and utilities market share are negatively influenced by time trends and price of gas, but positively by income.
- Compact vans have a unique trend relative to all trucks in showing increasing market share with increasing gasoline prices. It is also positively influenced by increasing income.
- Full size trucks (pickup, van and utility) show relatively stable market shares, with a modestly declining time trend. Only utility vehicles' market share appear to be sensitive to income, while market shares of all full size trucks are insensitive to the price of gasoline.

Some of these trends initially appear to be counterintuitive, but one must consider the impact of a particular variable on sales of the class as well as the total fleet sales. For example, while sales of luxury cars decreases with increasing gasoline prices, the market share increases since sales of all other cars decline by a greater amount for the same change in the price of gasoline. Sales of minitrucks and compact pickup and utility vehicles, most of which are used for personal transportation or recreation, are also more strongly affected by increasing price of gasoline, and their market share drops. On the other hand, standard size vehicles are used more commonly in the light commercial sector or for hauling rather than personal transportation and their market shares are relatively stable in response to gasoline prices.

It should be noted that the co-efficients in Table F-1 are not elasticities as the dependent variable is $m_i/1\text{-}m_i$, not m_i alone. In general, the values of m_i range from 0.05 to 0.20. The correct "elasticity" co-efficient is the actual co-efficient times $1\text{-}m_i/2$, so that multiplying the co-efficients in Table F-1 by 0.4 ~ 0.475 will provide an estimate of elasticity.

The performance model utilized a similar procedure, but the dependent variable was average HP/WT (or HP for trucks) by class. The most significant variables were found to be LFC (fuel consumption), personal income (LYD) and price of gas (LPGAS) in most cases. In some cases, cost per mile (LCPM) provided a better regression when substituted for LFC and LPGAS. The results of the regression are shown in Table F-2. In general, the regressions yield the elasticities presented in Table F-3.

The results indicate that virtually all classes respond similarly to the cost of driving, although for small cars (mini-, sub-, and compact cars) an equivalent result was obtained for fuel economy rather than cost per mile. Performance demand is more sensitive to disposable income, with the large trucks showing very high sensitivity. This particular finding is suspect and may be due to the fact that significant engine improvements in the late 1980's (which increased rated HP) occurred in the same time frame when incomes were rising.

Table F-2. Regression Results From LDV Performance Model

Group	F Val	R^2	Intercept	LFC	LYD	LPGAS
Mini and Subcompact	14.819	0.848	13.893	-0.238 (1.706)	1.012 (-2.270)	0.11 (-.811)
Sports	7.675	0.742	-1.104	-0.311 (1.299)	-0.533 (.666)	-0.364 (1.616)
Compact	11.613	0.813	20.709	-0.252 (3.094)	1.721 (-3.308)	0.403 (-2.679)
Intermediate	57.101	0.956	14.252	-0.099 (.845)	1.114 (-3.296)	-0.0051 (.050)
Large	72.509	0.964	10.429	-0.168 (1.380)	0.704 (-1.902)	-0.171 (1.535)
Luxury	151.145	0.983	11.085	-0.124 (1.859)	0.79 (-2.704)	-0.248 (2.912)
Mini Truck	0.219	0.076	0.88	0.378 (.550)	0.483 (.230)	0.035 (.056)

Compact Pickup	35.043	0.929	-9.264	-0.119 (-.646)	1.409 (3.045)	0.03 (.228)
Compact Van	57.789	0.956	-33.712	-0.853 (-2.375)	3.722 (2.960)	-0.0044 (-.012)
Compact Utility	21.804	0.891	-10.507	0.586 (2.824)	1.785 (2.149)	-0.063 (-.264)
Standard Pickup	16.854	0.863	-17.358	0.276 (1.315)	2.41 (3.182)	0.271 (1.257)
Standard Van	37.117	0.933	-14.171	0.142 (1.061)	2.038 (4.393)	0.195 (1.72)
Standard Utility	21.177	0.888	-19.425	0.331 (2.144)	2.54 (3.398)	0.253 (1.176)

Table F-3: LDV Performance Model Elasticities

	LFC	**LYD**	**LPGAS**	**LCPM**
Small Cars	-0.23 ~ -0.30	+1 to +1.7	N.S.	--
Large Cars	-0.10 ~ -0.17	0.7 to 1.0	Variable	-0.1 to -0.20
Small Trucks	N.S.	+1.4 to +1.7	N.S.	-0.24 to -0.33
Standard Trucks	N.S.	-2.0 to 2.5	N.S.	-0.23 to -0.35

N.S. - Not Specified

VALUE OF PERFORMANCE AND FUEL ECONOMY ADJUSTMENT

The value of performance is defined as the dollar amount that consumers are willing to pay for horsepower. This value was estimated from the actual list price for the vehicles in the 1988-1990 period and was based on the engine option prices. This method assumes that the manufacturers are pricing horsepower at levels that consumers are willing to pay. Most domestic models offer an optional engine with higher HP, while several import models offer optional turbocharged engines or 4-valve engine versions. In each case the cost of the engine option alone was identified from manufacturer price lists for 1989/1990 models (very often, the engine option is available with other features such as performance tires, aerodynamic devices etc. so that the vehicle price is higher than the cost of the engine option). Based on the prices of engine options, the following averages are applicable for all cars except sports and luxury cars:

Table F-4. LDV Performance and Price Options

Engine Option	HP Gain (%)	Price	Price/% HP
4-Valve vs. 2-Valve	30 to 35	$400 to 500	13.30 to 16.66
V-6 vs. I-4	25 to 30	$300 to 400	12 to 16
V-8 vs. V-6	30 to 35	$400 to 500	13.30 to 16.66
Turbo vs. Nat Aspirated	45 to 60	$650 to 850	14.44 to 18.88

Based on these data, an approximate average value of performance is $15 per percent increase in HP. Most sports and several luxury cars charge prices that are 15 to 25 percent higher than the values quoted above (although some very high priced luxury cars such as Mercedes, Porsche, and BMW charge more than twice the values quoted above). Accordingly, the value of performance for these classes has been set to $18 per percent increase in HP.

Increasing performance also decreases fuel economy and this relationship is derived from a regression analysis of fuel economy data that provides the sensitivity of fuel economy to factors that increase performance. In general, performance can be increased by four methods:

- by increasing the axle ratio
- by installing a larger engine with the same number of cylinders
- by installing a larger engine with more cylinders
- by utilizing 4-valve heads or turbocharging

The first method is suitable only for small changes in performance (less than 10 percent). The second method is useful for changes in the range of 10 to 25 percent. The use of engines with more cylinders can result in HP gains of 30 to 60 percent (4 cylinder to 6 cylinder, or 6 cylinder to 8 cylinder). 4-valve engines generally provide HP gains of 20 to 25 percent relative to a 2-valve engine of equal displacement, while turbocharging can provide an HP increase of 40 to 45 percent relative to a naturally aspirated engine of equal displacement. These technologies can be combined with displacement increases or decreases to achieve any desired result.

Based on engineering and regression analysis (see Appendix G, Supplement 1), the fuel economy sensitivity for axles ratio changes is -0.22 (i.e., a 10 percent axle ratio increase decreases fuel economy by 2.2 percent). The fuel economy sensitivity for displacement changes without changing the number of cylinders is -0.35 (i.e. a 25 percent change in displacement decreases fuel economy by nine percent, including the effect of increased engine weight). Substituting a V-6 for a 4-cylinder or a V-8 for a V-8 significantly increases the vehicle weight, and a fifty percent HP increase decreases fuel economy by about 25 percent.

A non-linear equation that captures these effects is given by

$$\begin{aligned} \Delta FE &= -0.22\,\Delta HP - 0.56\,\Delta HP^2 \;; \quad \Delta HP > 0 \\ &= -0.22\,\Delta HP + 0.56\,\Delta HP^2 \;; \quad \Delta HP < 0 \end{aligned} \tag{1}$$

where both ΔHP and ΔFE are expressed as *percent changes*. The equation is valid for ΔHP values between 0 and 60 percent.

Attachment 2: Alternative Fuel Vehicle Model

Data Input Sources and Extrapolation Methodology

INTRODUCTION

This Attachment documents the AFV database used in the National Energy Modeling System Transportation Sector Model. The database includes the present values and forecast methodologies of six attributes for three classes of light-duty vehicles. These attributes apply to sixteen vehicle-technology types and three scenarios for nine regions of the United States.

DEFINITIONS

The vehicle classes are:

1. Small light-duty
2. Medium light-duty
3. Large light-duty

The attributes are:

1. Purchase price (1990$, including the NPV of periodic battery and fuel cell replacements)
2. Fuel Operating Cost (1990$/MMBtu)
3. Fuel Availability (Fraction of stations)
4. Vehicle Efficiency (Miles/MMBtu)
5. Emissions (impact-weighted index to gasoline in each year)
6. Vehicle Range (miles between refueling)

The vehicle-technology types are:

1. Gasoline
2. Methanol Flex
3. Methanol Neat
4. Ethanol Flex
5. Ethanol Neat
6. CNG
7. LPG
8. Electric
9. Electric Hybrid - Large ICE
10. Electric Hybrid - Small ICE
11. Electric Hybrid Gas Turbine
12. Gas Turbine Gasoline
13. Gas Turbine CNG
14. Fuel Cell Methanol
15. Fuel Cell Hydrogen
16. Diesel

OTHER TECHNOLOGIES

There are two limitations in the database in terms of other technologies. The technologies that could have been included in the database but were not are:

- hydrogen i.c.e.-- near-conventional engines that burn hydrogen as opposed to electrochemical generation of power in fuel cells (as was considered in the database). Hydrogen-burning engines have been manufactured for some time and outperform gasoline engines in terms of emissions. As with fuel cells, their main drawback is fuel price, as tremendous amounts of energy are needed for the production of hydrogen from water.

- hydrogen-CNG mix (hythane)-- also burned in i.c.e.'s and already in use. Offers great advantages in terms of emissions at a more reasonable price than pure hydrogen.

The technologies in the database that are misspecified are:

- Fuel cells/hydrogen & methanol-- at this early stage of development it would be more practical to consider these two as one technology. Each rely on essentially the same power train and electrochemical energy conversion technology, the only difference being the way the fuel is stored. Hydrogen is extremely unwieldy due to its low mass, which means that to fit in a fuel tank of manageable size it must be liquified or bonded to other substances. Methanol, with its high hydrogen content, falls within the latter category as the hydrogen in it is the only participant in the electrochemical conversion.

APPROACH

The approach to the database development is as follows:

1. Identify data sources in the open literature and through industry contacts.

2. Obtain the data and organize it for use in the database.

3. Define and design the database to characterize the data usefully.

FORECASTING METHOD

The data base is provided in a spreadsheet format. The basic forecasting method is to identify current values for fuel prices, vehicle prices, fuel availability, etc. and one or more forecast values. The current data are entered in the 1990 column of cells for each attribute and extrapolated exponentially to and through the other data points. (In some cases, the 1990 values are assigned so that the curve fit through the 1992 values is based on 1992 actual data.) Each of the eight sections for vehicle attributes contains a detailed log of relationships and data sources.

DATABASE LIMITATIONS

Three main types of limitations apply to the database and to its usage within a transportation choice model. They are discussed below.

GENERAL DATA AND MODELING ISSUES

- Model and data do not distinguish fleet and non-fleet users. Fleet criteria include the availability of a central station, set and known use patterns, large cargo requirements (taxi, delivery, etc.), longer permissible refueling times, and limited luxury features. Non-fleet users need public stations, much longer range, luggage space, luxury features, better performance, and higher reliability. These markets are on different legislative paths and ATF adoption schedules. They cannot be mixed and cannot be modeled using the Bunch approach.

- Model and data do not recognize non-economic forces currently distorting markets. In 1991, SAIC contacted the owners of every CNG vehicle refueling station in the country. We found that the number and use of CNG vehicles is exaggerated by about 200% and that current usage patterns and interests by non-utility users are biased by artificially low-cost CNG (e.g., no compression costs). Moreover, many of the public refueling stations have very limited refueling capability. These stations are operated mostly as demonstrations rather than as commercial stations. A similar deficiency exists at the LPG outlets, most of which are not equipped to refuel vehicles. The Bunch approach, which is geared to open-market, non-fleet purchase decisions, requires an accurate and economic (i.e., non-interventionist) baseline tied specifically to private vehicles. This baseline does not exist.

- Model specifies six decision variables cited in Bunch. SAIC work suggests that actual technology choice depends on additional variables. The following variables omitted from the model significantly affect consumer choice: reliability, maintenance cost, certainty of maintenance availability, salvage or resale value, performance, utility (trunk space in CNG vehicles, A/C in electric vehicles, etc.), safety issues (real or perceived), ease of refueling, and refueling time. A few of these omitted variables appear in other work by the Transportation Modeling committee but were not requested of SAIC. The omission of these variables is highly significant when large differences exist but are not well-understood by survey participants (e.g., 5-minute refueling for gasoline vs. 8-hour refueling for electric).

MACROECONOMIC ISSUES

The database model is generally optimistic about the current rate of technological progress and innovation and assumes it will continue to grow progressively faster. Limitations in the database suggest that these forecasts may be overly optimistic in a macroeconomic sense.

- Diversion of Resources — the diversion of government and private sector resources toward alternative investments is not considered, i.e., large sums could go into infrastructure and mass transportation systems that are more efficient than any passenger vehicle alternative.

- Institutional Barriers — the created interests of significant economic or political actors, or groups of actors, could override market considerations for the benefit or detriment of any alternative technology or fuel.

- Environmental Barriers — one or more AFVs may receive significant opposition or backing purely for its environmental impact; moreover, public opinion as well as the environmental movement's preferences may shift in the near future, i.e., the environmental movement currently supports methanol-fueled vehicles, but that could change if a cleaner way to produce hydrogen for hydrogen-burning vehicles was found.

- Psychological Barriers — acceptance by the public is also a function of misperceptions and psychological factors, e.g., CNG, LNG, LPG and hydrogen may be perceived as dangerous to handle and thus avoided even if their safety records are objectively similar to that of gasoline.

- Information Barriers — accurate data do not exist for most of the exotic vehicle-fuel combinations (fuel cells, hybrid electric, etc.). Also cost and performance estimates for many of the emerging alternatives, especially electric vehicles, differ by a factor of 2-10 from source to source. In many cases, there is no clear basis for distinguishing among such inconsistencies.

DESCRIPTION OF VEHICLE TECHNOLOGIES

The AFV module currently analyzes 15 alternative-fuel technologies against a single conventional gasoline powered vehicle[1] in the spreadsheet analysis. Additional conventional and non-conventional technologies can be added to the analysis; however, for simplicity, conventional technologies are represented as a single category. This section of the report describes the characteristics of the alternative-fuel technologies as well as the criteria used in selection of alternative fuel-vehicle types.

Four primary technology selection criteria are employed for this study. The four criteria are the following:

- Vehicle operates utilizing a non-gasoline fuel or a significantly new engine technology.
- Technology holds the potential to penetrate the light-duty vehicle market by the year 2030.
- Technology possesses distinct fuel use, performance and/or cost characteristics relative to all other technologies considered.
- Data is available on important attributes for the vehicle technology.

Variations within each technology class based on vehicle subclass are not being analyzed as a distinct category but are incorporated into the collective category for the technology[2]. Future work in estimating market share growth for alternative-fuel technology may breakdown technology classes by engine and combustion technology; however, the complexity of such an

[1] This study assumes all gasoline powered internal combustion engines under a single technology category even though there is significant variation within gasoline fueled engines.

[2] Significant variations exist in the gasoline powered technology such as fuel injected engines versus carbureting engines; however, for simplicity all technologies utilizing a single fuel mix will be categorized together.

analysis is unwarranted at the present time.

This study has identified 15 alternative-fuel technologies which have met the four criteria previously stated. Conventional gasoline technology has been grouped into one single category using average vehicle attributes taken across all conventional vehicles. Following is a list of the sixteen vehicle technologies incorporated in this study. The advantages and disadvantages of each of the individual technologies will be briefly described in the following sections.

Gasoline Internal Combustion Engine Vehicles

Presently, the vast majority of transportation vehicles utilize an internal combustion engine (ICE) which was first patented in 1876 by Nikolaus Otto. The ICE is a heat driven engine which operates by mixing air and fuel vapor together, compressing the fuel mix in a cylinder, and igniting the fuel mix by means of an electric spark. The ignited fuel mix pushes a piston which in turn drives the vehicle[3]. Since the invention of the internal combustion engine the primary power source has been gasoline, although, many other fuels such as alcohols, natural gas and diesel can be utilized. It is speculated that if the discoveries of enormous petroleum deposits in Texas had not occurred during the early development years, the automobile would have developed as an alcohol vehicle rather than gasoline.

One of the primary advantages of conventional ICE vehicles is that economically these vehicles are inexpensive to operate due to the large development and refining infrastructure established for petroleum products. An abundance of petroleum deposits occur throughout the world and transportation of petroleum is not difficult in comparison to methanol and natural gas.

The conventional gasoline ICE vehicles are more harmful to the environment than the majority of alternative-fuel vehicles. Environmental concerns is one of the leading incentives for the development of alternative-fuel vehicles due to the problems associated with greenhouse gasses and urban ozone formation problems.

Diesel Vehicles

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[3] Glasstone, S., *Energy Deskbook*, Van Nostrand Reinhold Company, New York, 1983, pp. 364-368.

The diesel engine, like the gasoline engine, is an internal combustion engine which is heat driven from the ignition of diesel fuel in the cylinder which in turn drives the pistons. Unlike the gasoline ICE, a spark plug is not used to ignite the fuel mix but rather the combination of the compression and heat of the cylinder causes ignition of the fuel mix.

Ethanol Vehicles

Ethanol is a fuel which is currently being used to supply ethanol powered vehicles in a ratio of approximately 85 percent ethanol to 15 percent gasoline as well as a gasoline supply extender for conventional gasoline powered engines in a ratio of approximately 5 percent ethanol and 95 percent gasoline. This study is considering only ethanol vehicles (vehicles using the 85/15 percent mix) as a category separate from conventional vehicles. Two technology categories exist under the ethanol fuel heading. Ethanol Neat Vehicles which use only ethanol fuel and Ethanol Flex Vehicles which have the ability to switch between gasoline and ethanol fuels.

Ethanol can be produced from food sources such as corn and sugar cane or from non-food biomass such as trees, grass, waste paper, and cardboard. Presently, approximately 95 percent of ethanol fuel being produced in the United States comes from corn. Neat ethanol engines are expected to produce a 30 percent increase in efficiency over conventional gasoline engines; however, ethanol fuel has a lower energy content of only 67 percent of gasoline. A variation in cost estimates for ethanol fuel production exist depending on the source material and the distillation process. The EPA estimates that the "gasoline equivalent" ethanol price using corn stock is between $1.47 and $2.07 per gallon[4].

Ethanol fuel provides several important environmental benefits over gasoline in both the consumption and production stages. Ethanol is produced from a renewable energy source such as corn or sugar cane, where as petroleum is a non-renewable energy source which could be depleted in the future. Ethanol fueled vehicles emit a lower amount of carbon dioxide, nitrogen oxide and hydrocarbons than gasoline[5]. The Environmental Protection Agency estimates that

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[4] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel*, April, 1990, pp. 15-22.

[5] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, pp. 20-21.

carbon dioxide emissions, the major component of "greenhouse gases", are reduced to zero using ethanol produced from corn or sugar cane when considering the carbon reabsorption factor of corn during the growing stage[6].

Methanol Vehicles

Methanol fuel is similar in some respects to ethanol since it also is used as a gasoline extender in conventional gasoline engines and as a fuel in methanol engines. Presently methanol is mixed with gasoline in an 85 percent methanol/ 15 percent gasoline (M85) ratio and is consumed in a methanol engine. Two technologies exist for this analysis under the methanol heading; Methanol Neat which operates on M85 and Methanol Flex which has the ability to switch between M85 and gasoline depending on economic and availability factors.

Currently natural gas is the primary source of methanol although other materials such as coal, biomass and cellulose can be used. Methanol allows countries with excess natural gas supplies to export fuel without the expense of pipelines and LNG process. It is estimated that the wholesale price of methanol produced from natural gas is approximately $.40/gallon. However, because methanol has only about one half of the energy per gallon of gasoline, the cost per gasoline equivalent gallon is estimated at $.75[7].

Environmental advantages of methanol fueled vehicles are reductions in ozone formation, volatile organic compounds (VOC) and "greenhouse gas" emissions[8]. Ozone formation is a significant problem in urban areas linked to the emission of gasoline vehicles. Methanol emissions produce a lower photochemical reactivity than gasoline emissions; therefore, reducing the urban ozone formation problem. It is estimated that methanol vehicles emit 80 percent less VOC emissions than gasoline vehicles. Methanol vehicles emit increased volumes of formaldehyde and methanol gas which can be harmful in concentrated amounts. Further research is being conducted on the

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[6] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel,* April, 1990, pp. 49-50.

[7] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels,* 1991, p. 28.

[8] Energy Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automobile Fuel,* April, 1990, pp. 15-18.

health risks associated with methanol and formaldehyde emissions.

Electric Vehicles

Extensive alternative fuel vehicle research is now being done to improve electric vehicle performance. The primary obstacle of electric car development is battery technology. Various automobile manufacturers and research groups are concentrating on improving battery capabilities; however, at the present time battery technology limits electric vehicle range and performance attributes. For this reason electric vehicle motors have been combined with other conventional and non-conventional technologies in order to enhance vehicle performance. Technologies combined with electric motors include the internal combustion engine and gas turbine engine. This study will consider four technologies under the electric vehicle heading; electric, electric hybrid, electric hybrid/small ICE, and electric hybrid/gas turbine.

The primary advantage of electric-powered vehicles is that they produce virtually no direct emissions at the point of consumption. Direct emissions produced by electric vehicles are largely hydrogen emissions released during the battery recharging stage. Although hydrogen is an explosive emission in high concentration, hydrogen poses no problem to atmospheric air pollution[9]. While electric vehicles produce almost no direct emissions there are emissions associated with the electricity production stage depending on the power source of the electricity generation. Centralized power plants located away from urban centers eliminate urban ozone formation problems and can effectively control emissions associated with fossil fuel consumption. Electric motors have the advantage over internal combustion engines (ICE) because electric motors do not idle when the motion is stopped as ICEs do thus eliminating the idling power loss which can be significant in urban transportation settings.

Considering present electricity prices, exclusive electric vehicles as an alternative to gasoline vehicles are not as cost effective as ethanol, methanol, and natural gas vehicles. Even though electricity as a transportation fuel delivers 50 percent more miles per Btu than other fuels, the current price of electricity makes electric fuel transportation notably more expensive than

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[9] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 21.

conventional vehicles[10].

Compressed Natural Gas/Liquid Petroleum Gas Vehicles

Compressed Natural Gas (CNG) and Liquid Petroleum Gas (LPG) vehicles are grouped together in this summary because the engine technology is similar for the two vehicles utilizing different fuel sources. CNG vehicles have been in use for several decades in the United States while in other parts of the world they have been in operation since the 1930's[11]. The largest application of CNG vehicles has been in heavy-duty fleet vehicles because of the bulky natural gas storage tanks.

The CNG/LPG technology consists of a modified internal combustion engine connected to the fuel source in a closed system[12]. Because the fuel supply is in a gaseous state the entire storage engine system must be a closed system which eliminates the emissions problem of evaporating fuel during storage and refueling. The CNG/LPG engine produces higher thermal efficiencies than conventional gasoline engines; however, because of the additional weight involved with the fuel storage tanks the additional energy efficiencies are almost negated[13]. However; presently it is reported that natural gas vehicle operation is less expensive than conventional gasoline vehicles. A survey of gas utilities taken by the Gas Research Institute indicated that the CNG price per gallon-equivalent of gasoline is $.85-$1.10. GRI reports that it's analysis indicates that CNG prices including compression costs and fuel taxes are 13 percent lower than gasoline cost for conventional vehicles[14].

Compressed natural gas and liquid petroleum gas vehicles are considered clean fuel vehicles because the fuel burns cleaner than conventional gasoline vehicles. Natural gas vehicles do not

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[10] Ibid, p.30.

[11] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel,* Volume II Heavy-Duty Vehicles, April 1990, pp. 1-2.4.

[12] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy,* December 21, 1990, pp. 90-91.

[13] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy,* December 21, 1990, pp. 90-91.

[14] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 29.

emit ozone formation emissions, however, these vehicles do emit a high amount of NO_x and methane which is an important contributor to greenhouse gases.

Gas Turbine Vehicles

Gas turbine engines have been in existence for several decades and presently have several significant applications such as aircraft engines and electricity generation. Gas turbine technology is a significant variation from ICE technology. A gas turbine engine consists of three principle components; a compressor which compresses outside air to be mixed with fuel, a combustion chamber where the compressed air and fuel are ignited, and turbine which is turned by the exhaust of the ignited fuel mix[15].

Gas turbine vehicles potentially could be up to 50 percent more efficient than conventional internal combustion engine vehicles[16]. The increased efficiency is due to the fact that a turbine engine utilizes a larger percentage of the work being performed by the fuel than ICE's. Small turbine engines suitable for use in transportation vehicles are not being produced now on a large scale; therefore, the current cost of turbine engines are prohibitive for vehicle use.

Gas turbine engines could be designed to burn different fuels ranging from alcohols to diesel fuel. This study will consider two technologies under the gas turbine engine, compressed natural gas and conventional gasoline.

Fuel Cell Vehicles

The concept of fuel cells as a power source for transportation vehicles is similar to electric vehicle technology because an electric current powers a motor which drives the vehicle. The difference is that an electric vehicle runs off of a battery which is recharged periodically while a fuel cell is charged by a separate power source such as methanol or hydrogen. The first large scale applications of fuel cell technology were the Apollo and Gemini space missions which sparked interest in fuel cell technology in vehicle transportation.

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[15] Glasstone, S. *Energy Deskbook,* Van Nostrand Reinhold Company, New York, 1983, pp. 152-156.

[16] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy,* December 21, 1990, pp. 90-91.

Fuel cell technology has the advantage of higher conversion efficiency from the fuel source into electricity than a combustion engine. A large portion of the energy derived in a heat driven internal combustion engine is lost in the form of external heat which does not occur in the fuel cell technology. Fuel cell technology remains in the development stage and cost projections of transportation vehicles are extremely high. Further research may lower the costs of fuel cell technology; however, for now fuel cell technology seems unrealistic for large scale adoption.

VEHICLE PRICES

This section documents vehicle purchase prices in the database. The output of the database is a vehicle price for sixteen technologies for three vehicle sizes and three penetration scenarios, from 1990 through 2030, in thousands of 1990 dollars.

The general approach is to establish current and ultimate price premia for AFV's (alternative fuel vehicles) over the price of a gasoline I.C.E. (internal combustion engine) vehicle, and to use an exponential decay function (expressed as a compound percentage decline rate) to project each price premium towards its ultimate value. The shape of the curve implied by the price decay is based on forecasted future price levels or SAIC's judgment where no data are available. A non-fuel escalation rate was used to establish future prices of gasoline vehicles for each of three vehicle sizes (small, medium, and large)[17] through the year 2030.

Vehicle prices were obtained from the following inputs:

- Current price of gasoline vehicles by size (S, M, L).

- Current price premia for 15 other vehicle types independent of size (i.e., fuel-related premium or discount to base gasoline vehicle).

[17] Size categories are defined primarily by weight, and secondarily by passenger cabin volume. These definitions are consistent with usage in all of the literature, and in terms of weight are: below 2600 lbs for small vehicles, between 2600 and 3200 lbs for mid size, and above 3200 for large.

- Ultimate long-run price premia for 15 other vehicle types independent of size.

- Non-fuel escalation rate independent of vehicle type.

- Annual, compound percentage decline in current premium towards ultimate premium, or premium decay, for 15 vehicle types for three scenarios (B, H, L).

The approach has the following advantages:

- Projected AFV prices should be relatively consistent vis a vis conventional gasoline and other AFV prices.

- Incorporating the price of gasoline vehicles into AFV prices ensures that the non-fuel escalation rate is taken into account for all technologies.

- Updating and revising figures based on future developments are facilitated.

CURRENT VEHICLE PRICES

Determining current vehicle prices required two steps: finding the price for gasoline vehicles of three sizes (small, medium, and large), and obtaining current AFV purchase prices by adding a premium to the gasoline vehicle price for each technology.

GASOLINE VEHICLE PRICES

Prices for gasoline vehicles were established by averaging the prices of three representative vehicles for each size category. The vehicles were selected on the basis of market share[18]. All prices are manufacturer's suggested retail prices obtained from the National Automobile Dealers Association (NADA) used vehicle price guide. Table F-5 below provides detailed information on the selected gasoline vehicles.

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[18] Market share source: NADA, August 1992, p.32.

Table F-5. Gasoline Vehicle Characteristics (1990)

SIZE	VEHICLE MAKE, MODEL, BODY & STYLE	PRICE (1990 $)	WEIGHT (LBS)
LARGE	Ford Ltd Crown Victoria V8/ 4D Sedan	$17,257	3821 lbs
	Cadillac DeVille/ 4D Sedan	$27,540	3546 lbs
	Dodge B250/ Van	$12,575	NA
MID-SIZE	Beretta Corsica/ 2D coupe GT2	$13,750	2839 lbs
	Ford Taurus/ 4D sedan, GL	$13,834	3089 lbs
	Honda Accord/ 4D sedan LX	$14,895	2857 lbs
SMALL	Honda Civic/ 3D hatchback DX	$8695	2165 lbs
	Chevrolet Cavalier L4/ 4D sedan	$8820	2471 lbs
	Ford Escort/ 2D hatchback LX	$7806	c2312 lbs

Sources for price and weight:

Large: (NADA, July-August, 1992, ps.23, 75, 271)
Mid-sized: (NADA, July-August, 1992, ps.29, 74, 174)
Small: (NADA, July-August, 1992, ps.29, 73, 173)

CURRENT PRICE PREMIA FOR AFV'S

Current price premia are the premia paid in the market today over conventional gasoline vehicle prices for each technology in the database. All current AFV prices are calculated by adding these premia to the current gasoline vehicle price values for each category. The premia are added to the current gasoline vehicle price to obtain the current AFV prices for each vehicle size, type, or scenario. All premia and SAIC's assumptions, rationales, and comments for each technology are provided below. Each entry also contains the citations consulted by SAIC; abbreviations are more fully defined at the end of this report.

- **Diesel — $1000.** Average premia for representative diesel passenger vehicles; figure was slightly higher in the past.
  Sources: (NADA, July-August, 1992 & SAIC).

- **Ethanol Flex — $4,500.** Figure was set at the upper end of the range in the literature because of recent DOE data that places a much higher premium on flexible fuel vehicles.
  Sources: FFV range $2000-5000 (Cogan, August 1992, p.94); average of $6,400 for DOE AFV's (including ethanol, methanol and CNG) procured in 1990 (G.A.O, May 1991, p.20).

- **Ethanol Neat — $2000.** As is the case with ethanol flex, estimate is at the upper end of the range to make it more consistent with recent DOE data.
  Sources: $300-2000 (Cogan, August 1992, p.94), DOE AFV's data (G.A.O., May 1991, p.20).

- **Methanol Flex — $4,700.** Premium is equal to that of ethanol flex plus $200 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine. Figure is consistent with the literature consensus and recent DOE data.
  Sources: Fully optimized vehicle not engineered yet (CRS, 1989, p.17); higher corrosiveness (Rouse, 1991).

- **Methanol Neat — $2,200.** Premium is equal to that of ethanol neat plus $200 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine. Figure is consistent with the literature consensus and recent DOE data.
  Sources: $2000 1992 Ford econoline van (NREL, 1992); FFV range $2000-5000 (Cogan, August 1992, p.94); average of $6,400 for DOE AFV's (includes ethanol, methanol and CNG) procured in 1990 (G.A.O, May 1991, p.20); $210-340 by 1995 (D.O.E., August 1990, p.ix); higher corrosiveness (Rouse, 1991).

- **Electric — $45,000.** This figure includes an estimate of the net present value of battery replacements. It is consistent with most recent sources and manufacturer-quoted prices of soon-to-be released vehicles.
  Sources: 1989 GM G vans priced at $32,500 in 1989 (SAIC/report, 1991, p.25); 1993 Ford small van priced at $100,000 (NREL, 1992, on-line); batteries premium $6,000 by 1995; 1993 GM Impact production cost range $15-20,000 (O.T.A., 1990, p.119); GM Impact price range $20,000-30,000 (Woodruff, 1991, p.58); batteries premium $2,600-8,200 for advanced lead-acid battery (ICAMF, 1990, 1.16); Fiat Electra priced at $22,000 or twice the price of its I.C.E. twin (Woodruff, 1991, p.57); current battery price $1,500, replaced every 20,000 miles (Woodruff, 1991, p.58).

- **Electric Hybrid/Large I.C.E. — $50,000.** Figure includes the price of a regular electric vehicle (EV) plus a premium for the large I.C.E. The premium accounts for the fact that two engines would be costly and inefficient in terms of maintenance and use of space. A large I.C.E. acts as a range extender in the same way as a conventional gasoline I.C.E. The difference in price between a small and large I.C.E. is deemed to be insignificant at any stage. The figure is consistent with manufacturer prices of soon-to-be released vehicles and the consensus of the literature.
  Sources: 1993 Ford small hybrid van priced at $100,000 (NREL, 1992, on-line); high cost of adding batteries and electric motors to the engine of an I.C.E. (Woodruff, 1991, p.59).

- **Electric Hybrid/Small I.C.E. — $50,000.** See Electric Hybrid/Large I.C.E. above. A small I.C.E. only serves as a generator to recharge the batteries for the electric engine to operate. The difference in price between a small and large I.C.E. is insignificant at any stage.
  Sources: 1993 Ford small hybrid van priced at $100,000 (NREL, 1992, on-line); high cost of adding batteries and electric motors to the engine of an I.C.E. (Woodruff, 1991, p.59).

- **Electric Hybrid/Turbine — $125,000.** Figure includes the price of an electric hybrid/I.C.E. plus a high premium that reflects the absence of a viable prototype

at this time. Gas turbine vehicles were manufactured in the fifties without success due to lack of competitively-priced, heat-resistant materials; however, new developments may solve such obstacles and a prototype vehicle may be successfully produced by 1998.
Source: (The Economist, September 28, 1991).

- **CNG — $2,750.** Although some economies of scale are already present, all CNG vehicles are essentially retrofitted rather than optimized, therefore a significant premium (and potential for improvement) remains. The selected figure is consistent with the middle to the higher end of the 1992 literature ranges.
  Sources: Range of $2000-5000 (Cogan, August 1992, p.94); 1992 Chrysler Dodge B-Series Van Wagon $5000 (NREL, 1992, on-line); $2,550-3,250 (EPA, 1990, p.10); $2550-3250 for light-duty automobile (large), $1650-2250 (small-medium), $2350-3050 light duty truck; mass-produced dual-fuel $1600 (ICAMF, 1990, p.5.7); average of $6,400 for DOE AFV's (includes ethanol, methanol and CNG) procured in 1990 (G.A.O, May 1991, p.20); $800 by 1995 (D.O.E., August 1990, p.ix).

- **LPG — $1,500.** Although some economies of scale are already present, all LPG vehicles are essentially retrofitted rather than optimized, therefore a significant premium (and potential for improvement) remains. The selected figure is consistent with the middle to the higher end of the 1992 literature ranges.
  Sources: $1,200-2,200, (ICAMF, 1990, p.1.15.); 1992 Ford F-700 medium duty truck conversion option at $800 (NREL, 1992, on-line).

- **Turbine/Gasoline — $125,000.** Figure includes a high premium that reflects the absence of a viable prototype at this time. Gas turbine vehicles were manufactured in the fifties without success due to lack of competitively-priced, heat-resistant materials; however, new developments may solve such obstacles and a prototype vehicle may be successfully produced by 1998. The figure is consistent with the electric hybrid/turbine vehicle premium. No significant estimated price differential between CNG and gasoline technologies at this time.
  Source: (The Economist, September 28, 1991).

- **Turbine/CNG — $125,000.** See Turbine/Gasoline above. No significant estimated price differential between CNG and gasoline technologies at this time.

  Source: (The Economist, September 28, 1991).

- **Fuel Cell/Hydrogen — $150,000.** Figure includes a high premium for fuel cells because they are far more expensive than conventional batteries; there is also a premium included for fuel storage. Production prices in the literature diverge widely. Both hydrogen and methanol technologies rely on hydrogen for their electrochemical reactions and differ only in the way it is stored, i.e., as a component of methanol, or independently; therefore, no significant difference between them exists at this stage. Hydrogen-burning (as opposed to fuel cell) vehicles are far more feasible and less costly at this time.
  Sources: Fuel cells cost and premium for fuel storage (McCosh, 1992, p.29); 1995 prototype's price: drive system and engine $225,000, plus a fuel storage tank with a price range of $2,253 to $7,709, for a subtotal of $225,203 to $232,659 not including chassis (C.E.C., June 1991, pp.25-30).

  Hydrogen I.C.E. Sources: feasibility; prototypes in Japan, i.e., Nissan's joint effort with Musashi Institute of Technology (Maruyama, 1991); Mazda hopes to sell a few hydrogen-burning cars in California within ten years; current models are not optimized; premium for hydrogen tank is $26,000 (Templeman, 1991, p.59).

- **Fuel Cell/Methanol — $150,000.** See Fuel Cell/Hydrogen above. Both hydrogen and methanol technologies rely on hydrogen for their electrochemical reactions and differ only in the way it is stored, i.e., as a component of methanol, or independently; therefore, no significant difference between them exists at this stage.
  Sources: See Fuel Cell/Hydrogen.

FUTURE VEHICLE PRICES

Ultimate price premia are defined as the minimum future price differentials between gasoline and ATF vehicles. An extensive literature search and SAIC's own resources yielded forecast future prices, which were used to set ultimate price premia and the approximate expected year they will be reached. All ATF vehicle prices falling between the ultimate and the current price premia are calculated by using the price premia decay rate described in the subsequent section.

FUTURE GASOLINE VEHICLE PRICES

For all gasoline models, the prices beyond 1992 escalated at 2% per year. Non-fuel escalation factors include:

- The historical tendency of options to become standard equipment through time.

- Progressively higher additional costs for emissions controls and efficiency requirements. These are estimated to be $70 for a TLEV and $170 for LEV/ULEV (CARB, August 1990, p.IX.13).

- Increased investment in more efficient, lighter engines such as the 2-stoke engine (The Economist, September 28, 1991) and higher cost super-light body materials such as carbon composites (GM, 1992, pp.14,15).

DEVELOPMENT OF ULTIMATE PRICE PREMIA

Minimum price differentials are reached once all criteria for improvement relative to conventional prices have been met. The criteria include the maximization of well-known economic principles such as economies of scale, returns to scale, and learning curves. The future year and value assigned to AFV premia were found by applying the above criteria to the current status of the technology, the short-term and future projected gains, and relevant theoretical limitations.

Once values for ultimate cost and associated year were calculated, the premia were added to the corresponding year's conventional gasoline price. After an AFV has reached its ultimate premium, price differentials between that AFV and a conventional vehicle remain constant except for non-fuel escalation. Assumptions, rationales and comments for each technology are provided below.

- **Diesel — $1,000.** Average premia for representative diesel passenger vehicles; figure was slightly higher in the past, but is not expected to decline further.
  Sources: (NADA, July-August, 1992 & SAIC).

- **Ethanol Flex — $0.** Near-zero ultimate price premium assumes economies of scale and optimization achieved prior to switch to ethanol neat vehicles. Figure consistent with EPA and most recent literature.
  Source: (EPA/ethanol, 1990, Appendix C, p.2).

- **Ethanol Neat — $0.** Near-zero ultimate price premium assumes economies of scale and optimization of both ethanol types. Prior development of flex vehicle would provide learning curve feedback. Figure consistent with EPA and most recent literature.
  Source: (EPA/ethanol, 1990, Appendix C, p.2).

- **Methanol Flex — $200.** Premium is equal to that of ethanol flex plus $200 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine.
  Sources: Premia for corrosion-resistant materials, fuel sensing and control systems, and larger fuel tank for a total range of $150-500 in the late nineties, down to near-zero premium after that (CRS,1989,p.17); $150-300 at high volume production (EPA, April 1990, p.35); $300 with large scale production (ICAMF, 1990, p.1.14).

- **Methanol Flex — $100.** Premium is equal to that of ethanol neat plus $100 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine. Such a premium would be smaller for a dedicated neat vehicle due to greater economies of scale, optimization, and transfer of knowledge from flexible fuel vehicles.
  Sources: (EPA, 1990, Appendix C, p.2, & CRS, 1989, p.17).

- **Electric — $6,500.** Figure includes an estimate of the ultimate price premium of a battery, assuming steady improvements in battery technology and mass production taking place as zero-emission vehicle laws take effect. Advanced batteries now in an infant stage of development could considerably extend the range of the vehicle without the need for replacement. Differences between EV and EH vehicles are unimportant, as their most expensive component, the batteries, is the same. The figure is consistent with the consensus of the literature.

Sources: Premium for ZEV $1350 (SAIC/report, 1991, p.35); advanced batteries, such as sodium-sulfur, with a 100,000-mile life may be available by 1994 (Woodruff, 1991, p.58).

- **Electric Hybrid/Large I.C.E. — $6,500.** See Electric above. Differences between EV and EH vehicles are unimportant, as their most expensive component, the batteries, is the same. The additional cost of a range-extender I.C.E. (regardless of size) ultimately approaches zero as economies of scale, transfer of knowledge and innovation arrive. The figure is consistent with the consensus of the literature.
  Sources: See Electric above.

- **Electric Hybrid/Small I.C.E. — $6,500.** See Electric and Electric Hybrid/Large I.C.E. above. The additional cost of a range-extender I.C.E. (regardless of size) ultimately approaches zero as economies of scale, transfer of knowledge, and innovation arrive. The figure is consistent with the consensus of the literature.
  Sources: See Electric Hybrid/Large I.C.E. above.

- **Electric Hybrid/Turbine — $6,500.** See Electric above. Differences between EV and EH vehicles are unimportant, as their most expensive component, the batteries, is the same. The additional cost of a range-extender turbine ultimately approaches zero as economies of scale, transfer of knowledge, and innovation arrive. The figure is consistent with the consensus of the literature.
  Sources: See Electric Vehicle above, and Turbine/Gasoline & CNG below.

- **CNG — $750.** Assumes mass-production of optimized dedicated vehicle. The figure is consistent with the consensus of the literature.
  Sources: $700-800 for optimized and dedicated vehicle (O.T.A., 1990, p.101); $800 for optimized large-scale production, less for dedicated vehicle (ICAMF,

1990, p.1.14).

- **LPG — $500.** Assumes mass-production of optimized dedicated vehicle. The figure is consistent with current price differences between LPG and CNG vehicles, and assumes such differences will persist.
  Source: $500 (SAIC judgment).

- **Turbines/Gasoline — $1,500.** Assumes likely advances in high temperature ceramics and electronic combustion controls will take place by the end of the decade and eventually make this technology cost-competitive with conventional technology.
  Source: (The Economist, September 28, 1991, p.95).

- **Turbines/CNG — $1,500.** See Turbine/Gasoline above. Assumes there will be no significant price differential between CNG and gasoline technologies.
  Source: (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen — $6,500.** Assumes significant advances in storage technology and fuel cell manufacturing are accomplished due to high demand.
  Sources: storage technique breakthroughs: liquid hydrogen, or hydrogen bonded with powdered metals or stored in metal alloy balls may render it as safe as gasoline (Templeman, 1991, pp.59, 60); by 2010 the fuel cell hybrid will be $6,562 plus chassis (C.E.C., June 1991, pp.25-30).

- **Fuel Cell/Methanol — $6,500.** Assumes significant advances in storage technology and fuel cell manufacturing are accomplished due to high demand.
  Sources: Hydrogen-rich methanol would allow a fuel cell vehicle to refuel as rapidly as an I.C.E. vehicle (Economist, September 1991, p.75); storage technique breakthroughs: liquid hydrogen, or hydrogen bonded with powdered metals or stored in metal alloy balls may render it as safe as gasoline (Templeman, 1991, pp.59, 60); by 2010 the fuel cell hybrid will be $6,562 plus chassis (C.E.C., June 1991, pp.25-30).

A comparison of the current and ultimate price premia discussed above is provided in the following table.

Table F-6. AFV Price Premia by Technology

TECHNOLOGY	PRICE PREMIA	
	CURRENT	ULTIMATE
Diesel	1,000	1,000
Ethanol Flex	4,500	0
Ethanol Neat	2,000	0
Methanol Flex	4,700	200
Methanol Neat	2,200	100
Electric	45,000	6,500
Electric Hybrid/Large ICE	50,000	6,500
Electric Hybrid/Small ICE	50,000	6,500
Electric Hybrid/Turbine	50,000	6,500
CNG	2,750	750
LPG	1,500	500
Turbine/Gasoline	125,000	1,500
Turbine/CNG	125,000	1,500
Fuel Cell/Methanol	150,000	6,500
Fuel Cell/Hydrogen	150,000	6,500

APPLICATION OF THE DECAY FUNCTION

This rate is the annual, compound percentage decline in the current premium towards the ultimate premium for all AFV technologies. AFV prices are assumed to fall along a curve between the current and the ultimate price premia. The curve's shape is determined by the decay rate. If the exponential decay rate is rapid, the vehicle price reached its ultimate price well before 2030 (e.g., ethanol and methanol). If the decay rate is slow, the ultimate price may not be reached in the 40-year period.

Table F-7. LDV and AFV Cost Decay Rates

FUEL TYPE	LOW	BASE	HIGH	EXPLANATION
Diesel ICE	10%	1%	1%	Diesel engines are advantageous only for medium and heavy-duty vehicles. Unsuccessful previous attempt to penetrate the passenger car market.
Ethanol & Methanol Flex	5%	10%	15%	Similar technologies are assumed to have near identical decay rates and constitute the alcohols flexible fuel market segment. Because of initial fuel availability advantages over neat vehicles and already existing technology (retrofitted gasoline engines), flex ones are expected to be mass-produced much sooner than optimized neat vehicles. Consistent with the consensus of the literature.
Ethanol & Methanol Neat	2.5%	5%	7.5%	Because optimized neat vehicles necessitate more engineering, they will take longer to develop and be mass-produced than flex vehicles. It is assumed that there will be a trend towards optimization and that flex vehicles will not be available in significant numbers by the end of the next decade. The rates were rounded off to figures equal to half of those for flex vehicles and are consistent with the consensus of the literature.
Electric & Electric Hybrids (ICE & Turbine)	7.5%	12.5%	15%	Assuming steady improvements in battery technology and the expansion of zero emissions state limit programs, the overall advantages of electric and hybrid vehicles will translate into the fastest annual increase in production for any AFV. The rates seem even faster because initial production is much lower than other competing technologies, i.e., CNG, LPG, and alcohol flex.
CNG	5%	10%	15%	Assuming retrofit conversion through 2000; dedicated mass-produced optimized vehicle after that year.
LPG	2%	4%	6%	Dedicated mass-production will come later than CNG vehicles, due to the latter's greater advantages vis a vis the non-fleet passenger vehicle market segment.
Turbines: Gasoline & CNG	5%	10%	15%	Rates consistent with, and slightly lower than, those for electrical vehicles. Both technologies are in their infancy but are also very promising. Assuming technology is operational by the end of the century, costs should decrease rapidly after that due to high initial learning curve position (e.g., turbine technology) and use of conventional fuel.

Table F-7. LDV and AFV Cost Decay Rates

FUEL TYPE	LOW	BASE	HIGH	EXPLANATION
Fuel Cells: Methanol & Hydrogen	5%	10%	15%	Rates are consistent with electrical vehicles and rounded off to equal those of turbine vehicles. The development of this technology presents more obstacles than turbines but offers more potential rewards, i.e., lower emissions and seemingly limitless fuel supply.

SOURCES:

- **Diesel —** Rate tied to gasoline rate; the price premium is assumed to remain constant through time. The usefulness of this technology is limited to large vehicles.

- **Ethanol Flex —** $300 premium with large production in the future (EPA, April 1990, p.2); limited production by 1993, full by 2000 (C.E.C., 1989, p.7).

- **Methanol Flex —** Costs dropping since Chrysler began selling its Dodge Spirit and Plymouth Acclaim without a price premium, other auto makers will presumably follow (Cogan, August 1992, p.94); limited production by 1993, full by 2000 (C.E.C., August 1989, p.6); Federal fleet assumptions for cost premia: 1993=$2,500, 1994=$1500, 1995=$1000, 1996=$275, 2001=$150 (D.O.E., May 1992, p.26).

- **Methanol Neat —** No significant production for dedicated vehicles before 2007-2010 (CRS, 1989, p.17-18).

- **Electric —** Large resources from Detroit's consortium going into EV research (Woodruff, 1991); estimated manufacturing cost versus annual production volume (no. of vehicles manufactured/EV cost in 1988$): 30/$48,200, 100/$40,000, 1000/$29,500, 10,000/$21,000, 50,000/$18,100 (C.E.C., August 1989, p.6); limited production 1993-2000 (C.E.C., 1989, p.7); economies of scale after 1998 (60,000-100,000 units) and replacement of DCEV (direct current electric vehicle) by ACEV (alternating current e.v.); NiFe batteries and advanced battery use beginning 2003 and 2005 respectively, by 2009 1/2 of the EV and EV/hybrid market captured (A.F., 1990, p.18-22); GM Impact plant production will be 25,000/year (Woodruff, 1991, p.54, p.58); it takes production runs of at least 50,000/year to make a profit on a reasonably priced vehicle (Woodruff, 1991, p.59).

- **Electric Hybrid/Large I.C.E. —** NiFe battery car by 2003; by 2010 half of the EV's may be EV/hybrid (A.F., 1990, p.18-22). See other applicable references above under Electric.

- **Electric Hybrid/Small I.C.E. —** NiFe battery car by 2003; by 2010 half of the EV's may be EV/hybrid (A.F., 1990, p.18-22). See other applicable references above under Electric.

- **Electric Hybrid/Turbine —** NiFe battery car by 2003; by 2010 half of the EV's may be EV/hybrid (A.F., 1990, p.18-22). See other applicable references above under Electric, and under Turbine.

- **CNG —** Retrofit conversion 1993-2000 (C.E.C., 1989, p.7).

- **LPG —** Retrofit conversion 1993-2000 (C.E.C., 1989, p.7).

- **Turbine/Gasoline —** (The Economist, September 28, 1991, p.95).

- **Turbine/CNG —** (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen —** Prototype vehicle by 1993, demonstration vehicle by 2000 (C.E.C., 1989, p.7); prototype by 1995 possible, limited production 1000 to 10,000 units/year by 2002 (C.E.C., June 1991, p.20); main current obstacles are safety, compact storage, and competitive production costs; factory site vehicles by 2000, road vehicles beyond that (Tyler, 1990, p.20).

- **Fuel Cell/Methanol —** See references for Fuel Cell/Hydrogen above.

VEHICLE EFFICIENCY

This section documents vehicle efficiency in the database. The output of the database is the efficiency rate for sixteen technologies for three vehicle sizes, from 1990 to 2030. The rate is given in miles per MMBtu.

The general approach consists of establishing the current mid-size vehicle mileage per MMBtu for each fuel. The mileage figures are then adjusted for differences in vehicle size (e.g., small and large) using an index of mileage by size, as a function of mid-size mileage, while holding fuel constant. A fuel-use adjustment is needed to correct the miles/MMBtu estimates for pure fuel use vs. hybrid fuel use (e.g., electric vs. electric hybrid).

To obtain future vehicle efficiency, an annual simple percentage efficiency gain by vehicle type was developed. Fuels with greater potential for engine efficiency improvements were assigned greater estimated efficiency gains over time (e.g., gasoline I.C.E. vs. EV.).

Thus, the vehicle efficiency inputs are:

- Current mileage per MMBtu for each fuel.
- Mileage by vehicle size (small, large) as a function of mid-size vehicle mileage.
- A fuel-use efficiency adjustment to correct the miles/MMBtu estimates for pure fuel use vs. hybrid fuel use.
- Annual simple percentage efficiency gain by vehicle type for all vehicle types.

The approach has the following advantages:

- Projected efficiency rates should be relatively consistent vis a vis conventional gasoline I.C.E. and other technology efficiency rates.
- Updating and revising figures based on future developments are facilitated.

CURRENT VEHICLE EFFICIENCY

This section describes the process of obtaining current efficiency rates and adjusting for size and fuel use. As explained in the previous section, current mileages per MMBtu for each vehicle technology were initially obtained for a mid-size vehicle only. The following table shows these current efficiency rates. The sources consulted and the specific references and/or figures used are given immediately after the table.[19] Efficiencies for the other two vehicle sizes were obtained by applying an adjustment factor of +10% for small, and -10% for large, to the base mid-size vehicle efficiency rate shown in the following table.

Table F-8. Current Mid-Sized Vehicle Fuel Efficiencies

FUEL TYPE	Miles/MMBtu
Gasoline	265
Diesel	280
Ethanol	190
Methanol	270
CNG	230
LPG	405
Electricity	695
Hydrogen	250

SOURCES AND REFERENCES:

- **Gasoline —** Efficiency rates of 24 MPG for Buick Park Avenue V6; 25 MPG for a Buick LeSabre; 24 MPG for Toyota Camry (G.M.,1992, pp.14, 15, 36); Clean, highly efficient engines already developed in Japan, i.e., M-Miller cycle engine

[19] Some improvements in the efficiency of gasoline vehicles also apply to AFV's, i.e., super-light materials and on-board computers, while others do not, i.e., two-stroke engines. Those that do apply do so differently from one technology to another, i.e., it will be easier to reduce air drag in a vehicle that has a small, powerful engine and does not require large fuel storage capacity.

(Japan 21st, 1992); recent impressive gains in mileage, i.e., 65 MPG for a 1992 Honda Civic hatchback VX (Woodruff, 1991, p.56).

- **Ethanol Flex —** Efficiency of 0.0505 ethanol gallons per mile (EPA, April 1990, p.53).

- **Ethanol Neat —** Efficiency of 0.0418 ethanol gallons per mile (EPA, April 1990, p.53).

- **Methanol Flex —** Efficiency of 11.4 MPG for 1992 Ford Econoline Van (NREL, 1992, On line).

- **Methanol Neat —** Dedicated vehicle improvement over gasoline vehicle (CRS, 1989, p.18); dedicated vehicle is 4-15% better in energy input due to higher compression ratios (Oil & Gas, Dec 1991, p.59).

- **Electric —** SAIC data.

- **Electric Hybrid —** SAIC data.

- **CNG —** SAIC data.

- **LPG —** Efficiency for a 1992-1993 Ford F-700 Medium Duty Truck is 15 to 20% less than its gasoline equivalent (N.R.E.L., 1992, On-line).

- **Turbine/Gasoline —** SAIC data.

- **Turbine/CNG —** SAIC data.

- **Fuel Cell/Hydrogen —** Energy density is about 3.8 watts per pound, or less than that of an EV's lead-acid batteries (McCosh, August 1992, p.29); the theoretical limit to energy conversion is 80-85% (Templeman, 1991, p.59).

- **Fuel Cell/Methanol —** See Fuel Cell/Hydrogen above. Both hydrogen and methanol technologies consume hydrogen as a fuel, so they are essentially the same technology, differing only in the way the fuel is stored.

FUTURE EFFICIENCY RATES

Future efficiency rates were obtained by applying an annual percentage gain by technology type, for each of the three penetration scenarios. This section describes how the gain rates were determined and provides the sources used.

ANNUAL PERCENTAGE GAIN IN EFFICIENCY

The following table shows the efficiency gain rates by vehicle technology for three penetration scenarios. Each vehicle technology entry is accompanied by comments or an explanation of assumptions where applicable.

Table F-9. Annual LDV & AFV Efficiency Gain, by Technology (Three Scenarios)

TECHNOLOGY	SCENARIO			EXPLANATION
	BASE	HIGH	LOW	
Gasoline & Diesel	1.00%	0.00%	2.00%	Based on historical rate, i.e., since 1974 GM vehicles have improved efficiency by 125%, and assuming current trends continue, i.e., increased investment in order to meet policy goals and competitive challenges of AFV's. The efficiency escalation rate cannot remain constant, because the easier gains have been already achieved. Nevertheless, even the auto-makers themselves have set ambitious goals, i.e., Chrysler's 29 MPG by 1996. Diesel rate parallels gasoline's and is consistent with the historical record.[20]

[20] Regardless of fuel choice, all ICE's are limited by the Carnot cycle's theoretical maximum of 40 to 50%.

Table F-9. Annual LDV & AFV Efficiency Gain, by Technology (Three Scenarios)

TECHNOLOGY	SCENARIO			EXPLANATION
	BASE	HIGH	LOW	
Alcohol Fuels	1.00%	2.00%	0.50%	5-10% operation efficiency increase through technological improvements in the near future. Since ethanol and methanol have higher heat content than gasoline or diesel, higher efficiency can be expected from a vehicle that runs on neat fuel, but the annual gains in efficiency would be almost the same for both neat and flex fuels.
Electric & Electric Hybrids	0.50%	0.75%	0.00%	Much higher initial efficiency, but fast improvements in battery and/or engine technology are unlikely, resulting in a relatively low efficiency gains rate. Note that this technology is not affected by the Carnot cycle's theoretical limit. Similar rates are projected for all types of hybrids, as their respective complementary technologies are secondary to the electric technology.
CNG & LPG	1.00%	2.00%	0.50%	Gain rates equivalent to those of alcohol fuels assumed.
Turbine/ Gasoline	1.25%	0.00%	2.00%	Based on existing technology applied to other types of vehicles, i.e., Abrahms M1 tank, hovercraft, and assuming the technology will fulfill its theoretical expectations once applied to passenger vehicles. Efficiency gains should parallel those of conventional gasoline vehicles to a large extent.
Turbine/CNG	1.25%	2.00%	0.50%	See TURBINE/GASOLINE entry above. Efficiency gains should parallel those of conventional CNG vehicles to a large extent.
Fuel Cell/ Methanol & Hydrogen	1.25%	2.00%	0.00%	Although the technology is in its infancy, because of its vast potential a fast gain rate similar to that of turbines is expected, i.e., it has a theoretical efficiency of 80 to 85% when the heat of the process is recovered for use elsewhere. It is assumed that there will be continuous technical breakthroughs as projected today, i.e., proton exchange membrane, or other advanced systems fully developed.

SOURCES AND REFERENCES:

- **Gasoline —** Carnot cycle's theoretical maximum (Romano, 1989, p.75); 2-stroke engine (The Economist, September 28, 1991 & Scientific American, October 1992, pp. 112-113); super-light materials (GM, 1992, p.14, 15); reduced air drag, upgraded on-board computers (Woodruff, 1991, p.56); reformulation (Unzelman, 1991,p.64). Since 1974 GM vehicles have improved efficiency by 125% (GM, 1992, p.14, 15); Chrysler's efficiency goal is to achieve an average 29 MPG by

1996 (Woodruff, 1991, p.54).

Already existing promising prototypes (Maruyama, 1991); policy and industry goals in the U.S. and elsewhere (Woodruff, 1991, p.54); CAFE's standards by 2001; the historical efficiency escalation rate, defined as a reduction in gallons/year per vehicle, is 4.95% (Oil & Gas, Dec 1991, p.58).

- **Diesel —** Carnot cycle's theoretical maximum (Romano, 1989, p.75); super-light materials (GM, 1992, p.14, 15); reduced air drag, upgraded on-board computers (Woodruff, 1991, p.56); reformulation (Unzelman, 1991,p.64).

- **Ethanol Flex —** 5-10% operational efficiency increase (Oil & Gas, Dec 1991, p.59); Carnot cycle's theoretical maximum (Romano, 1989, p.75).

- **Ethanol Neat —** Higher heat content and efficiency rates; learning curve gains of 20 to 30% over gasoline by the time dedicated vehicles enter the market (CRS, 1989, p.18); Carnot cycle's theoretical maximum (Romano, 1989, p.75).

- **Methanol Flex —** 5-10% operational efficiency increase over gasoline (Oil & Gas, Dec 1991, p.59); Carnot cycle's theoretical maximum (Romano, 1989, p.75); improvement over gasoline: low case 4%, base 6%, and high 13% (CRS, 1989, p.18).

- **Methanol Neat —** Higher heat content and efficiency rate; learning curve gains of 20 to 30% over gasoline by the time dedicated vehicles enter the market (CRS, 1989, p.18); Carnot cycle's theoretical maximum (Romano, 1989, p.75).

- **Electric —** SAIC data.

- **Electric Hybrid/Large I.C.E. —** Efficiency rates of 36 MPG for an average passenger vehicle, and 21 MPG for a light truck (A.F., 1990, p.18-22).

- **Electric Hybrid/Small I.C.E. —** Efficiency rates of 36 MPG for an average passenger vehicle, and 21 MPG for a light truck (A.F., 1990, p.18-22).

- **Electric Hybrid/Turbine —** (The Economist, September 28, 1991, p.95).
- **CNG —** Carnot cycle's theoretical maximum (Romano, 1989, p.75).
- **LPG —** Carnot cycle's theoretical maximum (Romano, 1989, p.75).
- **Turbine/Gasoline —** (The Economist, September 28, 1991, p.95).
- **Turbine/CNG —** (The Economist, September 28, 1991, p.95).
- **Fuel Cell/Hydrogen —** (Templeman, 1991, pp.59-60).
- **Fuel Cell/Methanol —** (Templeman, 1991, pp.59-60).

VEHICLE EMISSIONS

This section describes vehicle emissions from conventional and ATF vehicles over time.

INDEX APPROACH

The general approach uses an index value tied to the impact-weighted emissions from mid-size gasoline vehicles. In each year from 1990-2030, the emissions impact from the base-case gasoline vehicle is estimated. As gasoline vehicle emissions decline (e.g., due to reformulation), the absolute emissions level declines but the index value remains constant (at 1.0). The emissions impact of the alternative fuels is benchmarked against the absolute level to create the index value for the alternatives. If the emissions of an AFV declines faster than that of the gasoline vehicle, the emissions index for that AFV will decline. If the emissions of an AFV increases or declines less rapidly than that of the gasoline vehicle, the emissions index for that AFV will increase. The technology choice module can make use of this relative indexing in annually selecting vehicle types.

The weight given to emissions and emissions indexing in the technology choice module is outside the scope of this database. Whether decisions will ultimately be made with respect to some threshold emissions level is also not considered.

The emissions index is constructed from the following inputs:

- Current emissions from a mid-size car for five pollutants (CO, CO_2, NO_x, methane, and NMHC) in grams/mile for 16 vehicle types. See Table F-10.
- Minimum possible emissions by 2030 for the same pollutants for the same vehicle types. See Table F-11.
- Annual simple percentage decline in emissions towards the minima, same vehicle types.
- Impact-weighting of the five pollutants on health and environmental criteria.

The index constructed from these data is necessary because the impact on human health and the environment from a gram of one pollutant is not equivalent to the impact of another pollutant. This non-equivalence is particularly apparent when one compares the typical emissions of NO_x (about 1 gram/mile) to that of CO_2 (about 450 grams/mile). Clearly, CO_2 is not 450 times more hazardous to health or the environment than NO_x. Thus, a weighting scheme (i.e., an index) must be constructed to properly compare the overall emissions index.

Table F-10. Base Mid-Sized Vehicle Emissions (Grams/Mile, 1990)

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2	ASSUMPTIONS AND EXPLANATIONS
Gasoline	9.00	1.00	0.00	1.03	452	Representative vehicle for size category. Standard catalytic converter.[21]
Diesel	3.40	0.41	0.00	1.00	450	Representative vehicle for size category. Consistent with data entered under gasoline. Standard catalytic converter.
Ethanol Flex	2.00	0.60	0.00	1.10	435	Consistent with data entered under gasoline and diesel. Retrofitted representative vehicle for size category. Generally higher NO_x than gasoline and diesel due to higher combustion temperature. Formaldehyde not included for methanol emissions.
Ethanol Neat	1.57	0.36	0.00	1.10	429	
Methanol Flex	1.75	0.29	0.00	1.10	447	
Methanol Neat	1.50	0.20	0.00	1.10	450	
Electric	0.00	0.00	0.00	0.00	0.00	Near zero emissions. Rounded off for manageability.
Electric Hybrid/ Large ICE	2.00	0.10	0.00	0.20	90	Due to smaller size and less use, i.c.e.'s emissions are ¼ or less of a conventional engine.
Electric Hybrid/ Small ICE	1.00	0.05	0.00	0.10	45	Due to smaller size and less use, i.c.e's emissions are ½ of large i.c.e.'s
Electric Hybrid/ Gasoline Turbine	0.50	0.03	0.00	0.06	25	Near zero for electric part. See TURBINE entry below. Due to less use and smaller size emission's are about ¼ of conventional turbine's.
CNG	0.30	0.23	1.20	0.97	419	Representative vehicle, consistent with alcohol and gasoline vehicles selected above.
LPG	0.28	0.29	0.00	0.59	437	
Turbine/Gasoline	2.00	0.10	0.00	0.25	100	Theoretically very low emissions, around ¼ of conventional fuel (gasoline or CNG respectively) vehicle.
Turbine/CNG	0.08	0.06	0.35	0.40	95	
Fuel Cell/Methanol	0.00	0.00	0.20	0.01	0.01	Near zero emissions. Small methane figure for methanol vehicle.
Fuel Cell/Hydrogen	0.00	0.00	0.00	0.01	0.01	

[21] For all technologies, pollution produced by the power source or fuel production process is not included.

Table F-11. Minimum Possible Emissions, Mid-Size Vehicle (Grams/Mile, 2030)

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2	ASSUMPTIONS
Gasoline	1.70	0.04	0.00	0.20	250	Advanced catalytic converters and reformulation.[22]
Diesel	1.25	0.04	0.00	0.20	250	
Alcohol Fuels: Flex & Neat	1.00	0.04	0.00	0.20	250	Advanced catalytic converters.[23]
Electric	0.00	0.00	0.00	0.00	0.00	Power source and accidental leakage not included.
Electric Hybrid/ Large ICE	0.40	0.01	0.00	0.04	60	Due to less use and smaller size, ICE's emissions are ¼ or less of conventional engine.
Electric Hybrid/ Small ICE	0.20	0.01	0.00	0.02	30	Due to smaller size, ICE's emissions are ½ of large ICE hybrid.
Electric Hybrid/ Gasoline Turbine	0.01	0.00	0.00	0.01	12	Advanced catalytic converter and reformulation.
CNG	0.20	0.01	0.20	0.20	250	Advanced catalytic converter.
LPG	0.10	0.04	0.00	0.20	250	
Turbine/Gasoline	0.50	0.02	0.00	0.05	25	Advanced catalytic converter and reformulation.
Turbine/CNG	0.05	0.00	0.05	0.05	25	Advanced catalytic converter.
Fuel Cell/Methanol & Hydrogen	0.00	0.00	0.00	0.01	0.01	Negligible emissions.

[22] For all technologies, emissions from fuel source and accidental leakage is not included.

[23] For ethanol, the 30 to 50% emissions reduction must be weighed against the considerable CO, CO_2 and nitrogen compounds produced by growing, fertilizing, harvesting, drying and transporting the crops to produce the fuel. EPA estimates the pollution created by producing and burning a gallon of ethanol is up to six times as much as producing and burning a gallon of gasoline. However, aldehydes are not produced (Frank, August 1992, p.106).

IMPACT WEIGHTING

The weighting scheme assumes that all impacts will be in the area of health (85% of the decision) or environment (15%) and will be based on each pollutant's contribution to impacts in those areas. For example, CO_2 has an impact on the environment but little or no impact on health. For CO, the reverse is true. Note that we are not considering health impacts derived from environmental impacts as health impacts. We are using the more conventional understanding that, for example, CO_2 is not considered a respiratory hazard (health) but is a greenhouse gas (environment).

In general, the reasoning behind the weightings is as follows:

- **Carbon Monoxide (CO) —** A moderate health hazard for its role in surface-level ozone creation; its environmental effect is negligible.

- **Non-Methane Hydrocarbons (NMHC) —** Serious health hazard for its significant role in surface-level ozone creation; its environmental effect is negligible.

- **Methane (Met) —** Important greenhouse gas; negligible health threat.

- **Nitrogen Oxides (NO_x) —** Serious health hazard for their role in surface-level ozone creation; also a significant greenhouse gas.

- **Carbon Dioxide (CO_2) —** Statistically insignificant health impact but some greenhouse impact.

The choice of the five pollutants (CO, CO_2, NO_x, methane, and NMHC) was based partly on the availability of detailed technical literature and partly on SAIC's judgment about the pollutants likely to affect vehicle choice and public policy in the coming decades. Additional pollutants, notably aldehydes and particulates, could have been added. The ultimate selection of five pollutants was based on computational tractability. The specific inclusion of methane and non-methane hydrocarbons was based on the need to distinguish natural gas-fueled vehicles based on smog-related and non-smog-related emissions. The impact of the various pollutants per unit emitted is assumed not to change over time.

Table F-12. Pollutant Impact Weighting Factors (Health vs. Environment)

IMPACT	WEIGHT	CO	NMHC	MET	NO_x	CO_2
Health	0.85	0.02	0.44	0.00	0.39	0.00
Environment	0.15	0.00	0.00	0.09	0.06	0.0005

The database treats electric vehicles as zero-emissions vehicles (ZEVs) in accordance with California regulations and shows them with zero emissions. Powerplant emissions are not included in the database. Emissions for the gas turbine engines are generally guesses. Emissions levels for the fuel cells are approximately zero, except for NO_x. The emissions for converting coal or natural gas to methanol or hydrogen for use in the fuel cells are not included. Similarly, emissions from ethanol exclude the CO, CO_2, and nitrogen compounds emitted during growing, fertilizing, harvesting, drying, and transporting the crops. Emissions and leakage from tanks (e.g., CNG and hydrogen releases) are also not considered.

DECLINES IN EMISSIONS OVER TIME

The simple annual percentage rate at which the vehicle emissions decline is based on an extensive review of the literature for both the vehicles and the fuels. The decay rates are provided in the following table.

Table F-13. LDV & AFV Emissions Decay Rates

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2
Gasoline & Diesel	10.0%	10.0%	0.0%	5.0%	0.0%
Alcohol Fuels/Neat & Flex	5.0%	10.0%	0.0%	5.0%	0.0%
Electric Hybrids/ICE & Turbine	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	5.0%	10.0%	10.0%	5.0%	3.0%
LPG	5.0%	10.0%	0.0%	5.0%	3.0%
Turbine/Gasoline	10.0%	10.0%	0.0%	5.0%	0.0%
Turbine/CNG	5.0%	10.0%	10.0%	5.0%	3.0%
Fuel Cell/Methanol & Hydrogen	0.1%	0.1%	0.1%	0.1%	0.1%

In general, the following factors were considered.

- **Gasoline —** Development of upgraded on-board computers for more precise spark timing and fuel injection (so gasoline burns more completely and less HC's escape); widespread use of catalytic converters that will eliminate up to 99% of CO and NO_x pollution by electronically preheating before a car starts; consequent increase in CO2.

- **Electric —** Assigned zero emissions in isolation of power source, therefore decay function is also zero. Even if power source is included there will be dramatic reductions compared to gasoline emissions, depending on fuel burned (natural gas or coal) to generate power. Improvements in emission controls at the source are expected to keep electricity ahead of gasoline.

- **Electric Hybrid/Gas Turbine —** Gas turbine would emit insignificant amounts of pollutants, so they may not need a catalytic converter. Without including power source, the electric part would have zero emissions (see above paragraph.) Although not yet engineered as such, turbine technology has been fully developed.

- **Turbine/CNG —** Widely used in other applications, with well-known emissions.

For passenger vehicle applications this technology will emit insignificant amounts of pollutants and may not need catalytic converters.

SOURCES AND REFERENCES:

- **Gasoline —** Clean, highly efficient vehicles such as the M-Miller Cycle engine vehicle are being developed in Japan (Japan 21st, 1992).

- **Methanol Neat —** A dedicated vehicle has higher compression ratios, thus higher heat and NO_x than gasoline I.C.E.; high level of formaldehyde (Oil & Gas, Dec 1991, p.59); high level of carcinogen formaldehyde (Oil & Gas, Dec 1991, p.59).

- **CNG —** The cleanest running nonelectric production vehicle available today full-size Dodge van (Frank, August 1992, p.105). CO level is 1/2 to 1/10 lower, but NO_x is higher due to higher peak combustion temperature in the presence of excess oxygen (Oil & Gas, Dec 1991, p.59).

- **LPG —** Low CO and HC, higher NO (Oil & Gas, Dec 1991, p.60). In the 1992 Ford F-700 Medium Duty Truck, HC and NO_x are significantly lower than their conventional equivalent, while CO emissions are comparable (NREL, 1992, On line).

- **Fuel Cell/Hydrogen and Methanol —** Would meet California's no-emissions requirements for 1994 (McCosh, 1992, p.29); cleanest emissions of any fuel; emissions are water and a low quantity of NO_x (SAIC/report, 1991, p.22); temperature of the electrochemical reaction is low enough to keep NO_x from being a problem (Romano, 1989, p.75).

  Production process reverses gains in emissions; CO2 & NO_x are byproducts of hydrogen production (Ondrey, 1992, p.30).

  Japan in investing in hydrogen-burning vehicles that are far cleaner than any other AFV (Maruyama, 1991); environmentally friendly HR-X by Mazda, a prototype with a hydrogen-burning rotary engine developed already (Japan 21st, 1992).

- **Gasoline —** Upgraded on-board computers for more precise spark timing and fuel injection; future catalytic converters may eliminate 99% of pollution by electronically preheating before a car starts (Woodruff, 1991, p.56).

  Possibilities of catalytic converters: Ford's 1993 Escort/Mercury Tracer models pass California's 1994 TLEV standard; Corning's EHC prototype passes 1997 ULEV standard (Cogan, September 1992, ps.35); 96% HC and 76% NO_x reduction comparing 1992 to 1960's vehicles (Frank, August 1992, p.103); improvements in refueling connection (Oil & Gas, Dec 1991, p.38). By 2003 the CAA could require 25% of all US cars to cut HC by 40%, and NO_x by 50%. By 2006 100% of US cars must meet that standard (Woodruff, 1991, p.59).

- **Electric —** Dramatic reductions compared to gasoline emissions depending on fuel burned (natural gas or coal), emissions controls at the power plant and type of generating equipment (Frank, August 1992, p.105).

- **Electric Hybrid/Turbine —** No direct reference. See relevant entries ELECTRIC above and TURBINE below.

- **CNG —** Considerable improvement potential for emissions in three areas: fuel metering and mixing, lean/dilute combustion systems, catalytic converters (Weaver, 1991, ps.4-7).

- **Turbine/Gasoline —** Gas turbine would emit insignificant amounts of pollutants, may not need a catalytic converter (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen —** Hydrogen already is the cleanest fuel available; only emissions are water and small quantities of NO_x (SAIC/report, 1991, p.22).

FUEL OPERATING COST

This section documents fuel operating cost in the database. The output of the database is operating cost for eight fuels, for nine regions, through three penetration scenarios (base, high, and low), from 1990 to 2030. The results are expressed in constant 1990 $/MMBtu.

The general approach is to establish the current national average fuel operating cost for each fuel. Regional differences are obtained using a percentage deviation from the minimum regional price and are assumed to remain constant over time. The sustainability of any such regional price deviations absent government intervention (or unusually skewed tax policies) is questionable. This issue is raised in Section 2 of the report.

Projected operating costs are found using a compound annual percentage fuel price escalation rate for each individual fuel, for each scenario (base, high, low).

The inputs used to forecast fuel costs are:

- Fuel operating cost in 1990 $/MMBtu.
- Regional fuel price differences, as a percentage deviation from the minimum regional prices, by region, by fuel.
- Fuel price escalation, compound annual percentage, all fuels individually, by scenario.

The approach has the following advantages:

- Projected fuel prices should be relatively consistent vis a vis conventional gasoline and other fuel prices.
- Updating and revising figures based on future developments are facilitated.

CURRENT AVERAGE FUEL OPERATING COST

Operating cost is derived from the current national average retail price usually given in $/gallon or similar measure. To allow comparisons between fuels, retail price was converted into dollars per energy content ($/MMBtu). Retail prices by fuel are tabulated below.

Table F-14. Average Fuel Prices, $1990

FUEL TYPE	RETAIL PRICE ($/MMBtu)
Gasoline	$9.70
Diesel	$7.69
Ethanol	$14.55
Methanol	$19.23
CNG	$8.50
LPG	$7.83
Electricity	$23.53
Hydrogen	$30.00

REGIONAL DIFFERENCES, ASSUMPTIONS, AND CRITERIA

Regional fuel prices are calculated by adding a percentage price differential to the national average retail prices found in the preceding table. The price differentials for each region shown in Table F-15 are based on factors such as proximity or access to major ports, production fields, refineries, state/regional consumer price index, adequate infrastructure, local producer and government support. These factors, assumptions and caveats are discussed after the table. The subsequent notes raise questions about the sustainability of these differences in a national market.

Table F-15. Regional Fuel Price Differences

FUEL TYPE	PERCENTAGE DIFFERENCE BY REGION

	NE	MA	SA	ENC	ESC	WSC	WNC	MTN	PAC
Gasoline	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Diesel	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Ethanol	0.075	0.0375	0.037	0	0	0.01	0	0.0375	0.05
Methanol	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
CNG	0.05	0.025	0.0375	0.025	0.025	0	0.025	0	0.025
LPG	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Electricity	0.1	0.05	0.025	0.01	0.025	0.01	0	0	0.0375
Hydrogen	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01

Abbreviations:

NE New England
MA Mid Atlantic
SA South Atlantic
ENC East North Central
WSC West South Central
WNC West North Central
MTN Mountain
PAC Pacific

EXPLANATIONS

- **Gasoline —** In the U.S. national market gasoline prices are essentially the same.

- **Diesel —** In the U.S. national market diesel prices are essentially the same.

- **Ethanol —** Mainly produced from corn in Midwest states; the regions that are part of it, or closest to it, enjoy lower prices due to advantages such as access, convenient transportation, and local support (i.e., state subsidies, farmers interests).

- **Methanol —** Mostly imported, therefore regions enjoying proximity and easy access to major ports and processing infrastructure, i.e., Los Angeles and New Orleans, would have a price advantage. The Pacific region also benefits from California's acute interest in this fuel, i.e., special incentives from the state. Inflexible infrastructure and the high cost of living in NE and WNC explain higher prices in those regions.

- **Electricity —** Regions with access to relatively abundant and cheap power produced by hydroelectric and coal-fired power plants benefit, e.g., WNC, WSC, MTN, and ENC. More expensive power from regions without low-cost fossil fuels drives prices up in NE and MA.

- **CNG —** Proximity to the rich fields in WSC and MTN benefits those regions and ESC, WNC, ENC and PAC. Competing imports benefit areas near major ports, i.e., PAC, ESC. The high cost of living and inaccessibility to fields drive prices up in NE.

- **LPG —** Access to competitive imports and refineries benefits PAC, ESC and ENC. Local production and support would benefit ENC and PAC. Higher transportation costs, infrastructure inflexibility and higher cost of living puts NE at a disadvantage.

- **Hydrogen —** Access to abundant raw materials, i.e., especially low-cost electricity benefits such regions as PAC, ENC, SA, WSC. Infrastructure and local support also push prices down in PAC. WSC, and MTN.

IMPORTANT ASSUMPTIONS AND CAVEATS

- Regional fuel price differences may persist due to transportation costs from producing or importing regions. These differences, however, are likely to be no more than $.05/gallon equivalent and are generally less than differences in state excise taxes.

- Differences in state excise taxes within a region can easily exceed differences in transportation costs from region to region.

- Electricity is shown at an average price. Off-peak electricity will cost less and on-peak electricity will cost much more. If EV sales are induced with the promise of daytime refueling at the office, much higher charges than those shown on the table will apply.

PROJECTED FUEL OPERATING COSTS

Projected fuel operating costs are found using a fuel price escalation rate. This section describes the escalation rate in more detail, and provides a representative sample of the output.

FUEL PRICE ESCALATION RATE

The escalation rate is a compound annual percentage, applied to each fuel individually. The rates for each fuel and the assumptions behind them are shown below.

Table F-16. Fuel Price Escalation Rates

FUEL	RATE	EXPLANATION AND ASSUMPTIONS
Gasoline	2%	Rate consistent with projections of oil prices based on current and future demand, output, refining capacity, etc.
Diesel		
Ethanol	3%	Mostly from domestic production, ethanol is a net energy loser (which implies the need of subsidies to make it competitive.) Assuming the cost of subsidies is incorporated, and due to the cyclical nature of the corn crops, the escalation rate would be the highest for all ATFs.
Methanol	1%	Assuming it is produced mostly from cheap imports without significant supply disruptions.
Electricity	1%	Assuming most power is used during off-peak hours when power plants have excess capacity. Also assuming regions with excess capacity will compensate for areas where increasing capacity would be prohibitive.
CNG	1%	Mostly from cheap, large fields in the U.S.
LPG	1%	Mostly from domestic production.

Hydrogen	1%	Assuming the current trend in production costs reduction continues, and assuming that sufficient power for production process is obtained from a reliable source.

SOURCES OF ESTIMATES:

- **Gasoline —** Escalation rates for periods: 1990-95 = 1.3%, 1995-2000 = 3.18%, 2000-2005 = 1.63%, 2005-2010 = 1.24 (D.O.E., July 1991, p.25); escalation rates due to reformulation: from 1990 to 2010 a 13.53% increase every five years (SAIC & Oil & Gas, Dec 1991, p.61). Fuel prices will go up as oxygenate-hydrocarbon shift takes place by replacing aromatics with ethers (Unzelman, 1991).

- **Diesel —** SAIC.

- **Ethanol —** Current production is 1 billion gallons per year; 3 to 8 billion gallons possible by 2010 without exerting strong upward pressure on feedstock prices.

- **Methanol —** Increase of 19.31% every ten years (SAIC & Oil & Gas, Dec 1991, p.60).

- **Electricity —** SAIC.

- **CNG —** Increase of 29.18% every ten years (SAIC & Oil & Gas, Dec 1991, p.60).

- **LPG —** Increase of 27.94% every ten years (SAIC & Oil & Gas, Dec 1991, p.60).

- **Hydrogen —** Projected operating costs for five-year intervals: $0.69 per mile by year 2000, down to $0.18 by 2005, $0.15 by 2015, and $0.12 by 2020 (SAIC/report, 1990); the fuel is projected to be cost equivalent with $1/gallon of diesel in the near future (SAIC/Ballard, 1992, p.1-22); demand stimulated by the Clean Air Act (CAA) of 1994; already there is new related investment; new production processes could cut costs by 5-10% and increase capacity by 50% (i.e., high temperature steam electrolizer); 80% of production costs are electricity-related (Ondrey, 1992, pp.31-35).

FUTURE FUEL PRICES IN THE LITERATURE
(In Gasoline-Gallon-Equivalent Unless Specified)

- **Gasoline —** $11.00 per MMBtu (reformulated) By the year 2000 (SAIC /report, 1991, p.26). $1.25-1.39 by the year 2000 (C.E.C., 1989, p.11). $1.58 (D.O.E., July 1991, p.25). $0.20 per gallon rise for reformulated gasoline (Woodruff, 1991, p.56). $0.32 per gallon (1990$) for gasoline reformulation for $2.08 pump price in the year 2010; 26 cents for $1.70 by 2005 (Oil & Gas, Dec 1991, p.59).

- **Ethanol Flex —** $1-1.50 per gallon under expanded fuel ethanol program; produced from corn (EPA, April 1990, p.i).

- **Ethanol Neat —** $17.70 per MMBtu by year 2000 (SAIC /report, p.26).$2.33 by year 2000 (C.E.C., 1989, p.11).

- **Methanol Flex —** $1.01-1.14 established market with guarantees. $1.14-1.35 with few guarantees (O.T.A., 1990, p.76). $1.39 by year 2000 (C.E.C., 1989, p.11). $2.79 (Oil & Gas, Dec 1991, p.60).

- **Methanol Neat —** $0.55-0.83 wholesale per gallons of methanol, by years 2004-2007 (CRS,1989,p.16). $1.35-1.75 by 2007 (A.P.I., August 1989, p.10). $14.50 MMBtu by year 2000 (SAIC /report, 1991, p.26). $1.29-1.37 during a transition phase, with strong market guarantees,$1.61-1.81 with few guarantees. $0.89-1.09 for an established market, with strong guarantees. $1.02-1.27 with few guarantees (O.T.A.,1990, pp.75-6).

- **Electric —** $18.00 MMBtu by year 2000 (SAIC/report, 1991, p.26). $1.31 by year 2000 (C.E.C., 1989, p.11). $5.28 or 15 cents kw/hr if produced with nuclear power (Oil & Gas, Dec 1991, p.61).

- **CNG —** $9.60 MMBtu by year 2000 (SAIC/report, 1991, p.26).$0.84 by year 2000 (C.E.C., 1989, p.11). $2.16 (Oil & Gas, Dec 1991, p.60).

- **LPG —** $0.98 by year 2000 (C.E.C., 1989, p.11). $1.29 (Oil & Gas, Dec 1991, p.60).

- **Fuel Cell/Hydrogen —** $0.18 per mile (SAIC/report, 1990); below $2.00 if substantial improvements can be made in photovoltaic technology (O.T.A.,1990, p.129). $3.50 if nuclear power costs 15 cents kw/hr (Oil & Gas, Dec 1991, p.61). $0.10 per mile year 2030 (SAIC/report, 1990) More efficient solar energy technology (substantially above 30% today) is needed to produce hydrogen by electrolysis (Tyler, 1990, p.20); research into photochemical and photovoltaic conversion (Gross, 1992, p.74; & Hodgson, 1991, p.58); pre and post-reformers to increase capacity of existing hydrogen plants, boost yields, no major changes in existing basic technology (Ondrey, 1992, pp.31-35). Efficiency improvements in the production of hydrogen can be expect to reach 70 to 90% once improved electrolysis methods are developed (Tyler, 1990, p.20). Promising production methods may bring hydrogen closer to gasoline's production cost, e.g., photobiological and photochemical conversions (though the latter's theoretical maximum efficiency is 32%)(Hodgson, 1991, p.58); hydrogen is the most likely main energy source replacing oil in all applications in the 21st century (Templeman, 1991, pp.60-61).

FUEL AVAILABILITY

This section documents fuel availability in the database. The output is fuel availability as a percent of gasoline availability for eight fuels, for nine regions, from 1990 through 2030, through three penetration scenarios (base, high, low).

The general approach is to determine current and ultimate fuel availability as a percentage of gasoline availability (assumed to be 1). A number of current fuel availability factors were considered in creating a percentage index for each fuel. Projected availability is determined by changes in these factors over time, which are represented by an exponential rate of closure in the current availability gap between gasoline and each of seven alternative fuels. The rate of closure changes for each of three penetration scenarios (base, high, low).

The data reported in this section are uncertain and of questionable usefulness due to the uncertain specification of availability in the model. The values reported in this section must be read in the light of the subsequent extended comments on modeling problems related to fuel availability.

The inputs used to forecast fuel availability are:

- Current regional fuel availability factors, as a percentage of gasoline availability, for all fuels.
- Fuel availability growth factors, represented as an exponential rate of closure in the availability gap.

The approach has the following advantages:

- Projected alternative fuel availability index values should be relatively consistent vis a vis gasoline and other ATF availability indices.
- Updating and revising figures based on future developments are facilitated.

CURRENT FUEL AVAILABILITY

Current alternative fuel availability regional differences are expressed as a percentage of gasoline availability in the base year 1990 as shown in the following table. Important limitations on these values and their usage are subsequently discussed.

Table F-17. Base Year (1990) Fuel Availability, by Region

FUEL TYPE	NE	MA	SA	ENC	ESC	WNC	WSC	MTN	PAC

GASOLINE & DIESEL	1	1	1	1	1	1	1	1	1
ETHANOL	0.01	0.02	0.02	0.1	0.02	0.02	0.02	0.05	0.05
METHANOL	0.01	0.05	0.02	0.02	0.02	0.02	0.01	0.05	0.1
CNG	0.01	0.02	0.02	0.05	0.02	0.02	0.05	0.05	0.05
LPG	0.01	0.02	0.02	0.05	0.02	0.02	0.1	0.05	0.1
ELECTRICITY	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
HYDROGEN	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

FUTURE AVAILABILITY

Changes in infrastructure and other growth factors that are demanded by an economically significant ATF are discussed in this section, along with pertinent assumptions and caveats.

Future availability is determined by changes in the regional availability factors outlined in the previous section. Such changes affect the differences between gasoline and each ATF, so they are represented by an exponential rate of closure of the availability gap between gasoline and each ATF.

GASOLINE INFRASTRUCTURE AND OTHER GROWTH FACTORS

There are roughly a million gasoline stations in the United States at the present time. For any ATF to be accepted by the public a certain threshold of availability must be reached (aside from economic and other considerations). Attaining the threshold level would require government and private investments in infrastructure in the order of tens of billions of dollars in a very short time. It would also exclude the possibility of having more than one or two competitive different fuels at one time. The infrastructure required would vary considerably from fuel to fuel. The implications are explored for each fuel below.

- **Ethanol and methanol —** a large proportion of the existing equipment could be easily adapted as these two fuels have obvious physical similarities to gasoline, i.e., use same pumps and dispensing equipment. However in the case of methanol, its corrosive nature would demand upgrading the system's reservoirs and pipes. There are additional expenses associated with differences in water tolerance and fuel contamination, fire, and explosion hazards.

- **CNG and LPG —** there is a small infrastructure capable of handling vehicle fleets successfully. Both fuels are, and will continue to be, attractive for the vehicle fleet subset, because a central refueling site can service the entire fleet. However, for private passenger cars, adapting a single existing gasoline service station would require a minimum of $250,000 for a compressor. Such a price tag would rule out a wide distribution network for passenger vehicles unless there is some government subsidy.

- **Electricity —** the extensive existing electricity infrastructure should be capable of servicing a large number of vehicles in terms of megawatts of off-peak capacity. On-peak demand would cause massive cost and availability problems. Moreover, since long refueling time would make service station refueling impossible, costly adapters would have to find a place in every user's household.

- **Hydrogen —** although there is an almost limitless supply of raw materials (e.g., water), there is no existing infrastructure for the distribution of hydrogen. Hydrogen's low mass makes it expensive to store since it must be liquified or bound to other substances. For these reasons reaching the necessary threshold level would involve a much higher price tag than for other ATFs.

EXPONENTIAL RATE OF CLOSURE

The growth factors described above were used to determine the exponential rate of closure in the availability gap between gasoline and each ATF, for each penetration scenario. Assumptions and caveats in addition to the ones outlined above are provided after the table.

Table F-18. Availability Gap Closure Rates, By Scenario

FUEL TYPE	PENETRATION SCENARIO		
	BASE	HIGH	LOW
Diesel	99%	99%	99%
Ethanol	10%	20%	2%
Methanol	10%	20%	2%
CNG	10%	20%	2%
LPG	10%	20%	2%
Electricity	10%	40%	2%
Hydrogen	10%	10%	2%

ASSUMPTIONS AND CAVEATS

- Accelerated exponential rates in all penetration cases, especially in the high case, such that a common market would appear in the United States within ten to twenty years. The market arrival time span for each fuel was calculated based on each fuel individually without any other ATF challenger. Such a individual competition approach is inconsistent with the model specifications.

- Regional differences in availability are highly unlikely in any national market, though they can exist initially.

- Even though regional fuel price differences may persist due to transportation costs from producing or importing regions, availability differences cannot, and will not persist if a national market develops.

- It is not clear what constitutes availability for EV's, i.e., whether refueling time refers to recharging batteries as opposed to switching them. Therefore arbitrary assumptions have been made for this category.

SPECIFIC REFERENCES AND SOURCES

- **Gasoline —** Reformulated gasoline may require $20 to $40 billion in upgraded refineries (Woodruff, 1991, p.56).

- **Methanol —** Cannot be integrated into current distribution system without modifying the system: water tolerance and fuel contamination, materials compatibility in storage and distribution systems, fire and explosion hazards (A.P.I., September 1990, p.27).

- **CNG —** High pressure compressors cost $250,000 each (Woodruff, 1991, p.57).

- **LPG —** There are 10,000 propane refueling stations in the United States (Frank, 1992, p.106).

- **Hydrogen —** Supply of Hydrogen (Frank, August 1992, p.106).

VEHICLE RANGE

This section documents vehicle range in the database. The output of the database is vehicle range in miles for sixteen technologies for three vehicle sizes, through three penetration scenarios (high, low and base) from 1990 through 2030.

The general approach is to establish range (defined as average current miles between refueling) for a small vehicle, through an extensive literature search. The findings are used as base range figures to derive the other two vehicle sizes (e.g., large and medium) using a range credit or penalty. The credit/penalty is expressed as a percentage that lowers the base small vehicle range. Projected range is found by applying an annual simple percentage gain on the base current figures for each technology.

Thus, the inputs used to forecast vehicle range are:

- Miles between refueling for small cars in 1990, for all technologies.

- Range credit or penalty for mid-size and large cars in 1990, all fuels.

- Annual simple percentage gain in range, by vehicle type to 2030.

The results are displayed in miles for all vehicle-fuel types from 1990 to 2030.

CURRENT VEHICLE RANGE

This section describes current vehicle range. For each technology, the base small vehicle range in 1990 is based on the average number of miles between refueling found in the literature. These figures are shown in the following table, which also features the range credit or penalty for vehicle size. The credit is expressed as a percentage ranging from -10% to -15%, for mid and large size vehicles respectively. Sources for these figures are provided at the end of this section.

Table F-19. Current Small Vehicle Range and Size Range Credit

TECHNOLOGY	RANGE IN MILES (SMALL VEHICLE, 1990)	SIZE RANGE CREDIT	
		MID-SIZE	LARGE SIZE
Gasoline	350	-10.00%	-15.00%
Diesel	400	-10.00%	-15.00%
Ethanol Flex	260	-10.00%	-15.00%
Ethanol Neat	235	-10.00%	-15.00%
Methanol Flex	220	-10.00%	-15.00%
Methanol Neat	196	-10.00%	-15.00%
Electric	120	-10.00%	-15.00%
Electric Hyb/Large ICE	250	-10.00%	-15.00%
Electric Hyb/Small ICE	200	-10.00%	-15.00%
Electric Hybrid/Turbine	300	-10.00%	-15.00%
CNG	225	-10.00%	-15.00%
LPG	300	-10.00%	-15.00%
Turbine/CNG & Gasoline	100	-10.00%	-15.00%
Fuel Cell/Methanol & Hydrogen	100	-10.00%	-15.00%

SPECIFIC REFERENCES AND SOURCES: (Range in Miles)

- **Gasoline —** 424 (U.C.E.T.F., 1990, p.40).
- **Diesel —** 488 (U.C.E.T.F., 1990, p.40).
- **Ethanol Flex —** 331 (U.C.E.T.F., 1990, p.40).
- **Methanol Flex —** 350 for 1991 Ford Taurus 4D sedan; 400 for 1992 Ford Econoline van (NREL, 1992, on line); lower range than gasoline's by 40-43%, by

1995 38-41% (D.O.E., August 1990, p.13); 292 (U.C.E.T.F., 1990, p.40).

- **Methanol Neat —** 265 (U.C.E.T.F., 1990, p.40).

- **Electric —** 120 for 1992 GM Impact (G.M. Impact, 1992); 100 for Ford small van (NREL, 1992, on line); Pb-acid battery = 44, NiFe = 90, NaS = 207 (D.O.E.,August 1990, p.13);100 (U.C.E.T.F., 1990, p.40); 340 at 25 mph for Tokyo Electric Power prototype (Gross, 1992, p.74).

- **Electric Hybrid/Large I.C.E. —** 250 for 1993 Ford small Van (NREL, 1992, on line); 40 for electric engine extended range gasoline i.c.e. for the LA301 by International Automotive Design's (The Economist, September 28, 1991, pp.95,96).

- **Electric Hybrid/Small I.C.E. —** 300 for GM's HX3 gasoline prototype; 40 kilowatt generator to recharge its own batteries (Woodruff, 1991, p.59).

- **CNG —** 200 for 1992 GMC medium-duty truck (GM Natural Gas Powered, 1992); 200 for 1992 Chrysler Dodge B-series van/wagon NREL, 1992, on line); 1990-95 lower than gasoline by 61% (D.O.E.,August 1990, p.13); 106 (U.C.E.T.F., 1990, p.40).

- **LPG —** 34 (U.C.E.T.F., 1990, p.40).

- **Fuel Cell/Hydrogen —** 300-500 with electric engine and improved storage, i.e. liquid or absorption process (Rouse, 1991, p.15); 190 for BMW's liquid-hydrogen storage vehicle; 75 for Mercedes hydracide vehicle (Romano, 1989, pp.60, 61).

PROJECTED VEHICLE RANGE

Projected vehicle range for all technologies is found by applying an annual simple percentage gain to the current base for each technology. The annual gain is assumed to be 1% because most improvements in technology apply equally to all fuels, i.e., reduce air drag, advanced body materials. It is also assumed that there will be similar advances in areas that are not shared because the rationale for investment in R & D is the same regardless of fuel technology, i.e., fuel reformulation, engine enhancements. Market penetration does not affect the annual gain; therefore, the rate of 1% is valid for all penetration scenarios.

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Attachment 3: LDV Stock Module

Fuel Economy Gap Estimation

INTRODUCTION

This attachment presents long-term projections of the fuel efficiency degradation factor for automobiles and light-duty trucks. The projections are based on the analysis of important trends in driving patterns that affect fuel economy. These trends include the increase in urban share driving, urban congestion, and highway speeds. The projections are developed for the period 1990 through 2030. This appendix also outlines other efforts to project fuel economy degradation factors.[24]

BACKGROUND

A discrepancy exists between automotive fuel economy as measured by the Environmental Protection Agency (EPA) under controlled laboratory conditions and the actual fuel efficiency observed under real "on road" conditions. Public and private organizations such as the Department of Energy (DOE), the Environmental Protection Agency (EPA), Ford Motor Company, General Motors Corporation, and Mitsubitshi Motors Corporation have conducted independent research on fuel economy, in the past, confirming this discrepancy.[25] The fuel efficiency degradation factor (also known as "the gap") measures this discrepancy and is defined

[24] This appendix is taken from a report which was prepared by Decision Analysis Corporation of Virginia (DAC) for the Energy Demand Analysis Branch of the Energy Information Administration (EIA), under Task No. 92010, Subtask 1, Contract No. DE-AC01-92EI21946.

[25] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), p.3-9,March 1992.

as the difference between on-road fuel economy and EPA tested fuel economy.[26] When fuel economy is expressed in terms of miles per gallons (MPG), the degradation factor or gap is formulated as:

$$GAP = \frac{EPA\ Test\ MPG - On\text{-}Road\ MPG}{EPA\ Test\ MPG} \qquad (2)$$

On-road fuel efficiency depends on several determinants which can be classified into technological factors, driver behavior and habits, driving trends, and road and climate conditions. Furthermore, the magnitude of the gap between tested fuel efficiency and on-road fuel efficiency depends on the specific procedures and conditions used during the test and the closeness of the formulations used to represent real driving conditions.

EPA fuel economy estimates for city and highway driving are published every year for each new model available in the U.S.[27] These MPG estimates are obtained based on vehicle tests performed under controlled laboratory conditions and then adjusted downwards to reflect actual driving conditions. Separate tests are used to generate the city and highway MPG estimates.

The EPA city fuel economy estimates are based on a test that simulates a 7.5 mile, stop-and-go trip with an average speed of 20 mph. The trip lasts 23 minutes and has 18 stops. About 18 percent of the time is spent idling, such as waiting for traffic lights or in rush hour traffic. Two types of engine starts are used: a cold start and a hot start. The cold start is similar to starting the car in the morning after it has been parked all night. The hot start is similar to restarting a vehicle after it has been warmed up, driven and stopped for a short time.

The EPA highway fuel economy estimates represent a mixture of "non-city" driving. Segments corresponding to different kinds of rural roads and interstate highways are included. The test simulates a 10-mile trip and averages 48 mph. The test is run from hot start and has little idling time and no stops.

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[26] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

[27] DOE/EPA, Gas Mileage Guide: EPA Fuel Economy Estimates, DOE/CE-0019/10.

EPA adjusts these laboratory fuel economy estimates downwards to reflect actual driving on the road conditions. In the 1992 Gas Mileage Guide: EPA Fuel Economy Estimates the city estimates are lowered by 10 percent and the highway estimates by 22 percent from the laboratory test results. These adjustment factors represent the EPA estimates of the fuel efficiency gap for both city and highway driving.

Fuel economy can also be represented by a composite number that combines city and highway fuel economies. EPA computes composite fuel economies using the following formulation:

$$\textit{EPA Composite MPG} = \left[\frac{0.55}{MPG_c} + \frac{0.45}{MPG_h} \right]^{-1} \qquad (3)$$

where:

MPG_c = Miles per gallon for city driving
MPG_h = Miles per gallon for highway driving

EPA's composite formulation is developed based on 55% city driving and 45% highway driving. This formulation, combined with the EPA city and highway fuel efficiency gaps, leads to a base composite MPG gap for all new vehicles of 15 percent.

Previous attempts at estimating the base fuel efficiency gap have been made. In 1978, McNutt et al., measured the gap for model year 1974 through model year 1977 cars. The resulting estimates of the gap were between 6 and 9 percent.[28] In 1984, Hellman and Murrel estimated a composite MPG gap of 15 percent.[29] More recently in 1992, Oak Ridge National Laboratory (ORNL) reported composite gap estimates that apply to all automobiles and light trucks in

[28] SAE 780037

[29] SAE 840496

operation.[30] The ORNL base composite gap estimate for all automobiles in operation pre-1974 to 1989 was 15.2 percent. The ORNL gap estimate for light trucks in operation pre-1976 to 1989 was 28.3 percent. For this analysis, ORNL used EPA tested fuel economy data which was verified by the National Highway Safety Administration (NHTSA). These data were compared against on-road fuel economy data from (1) the Federal Highway Administration (FHWA) Highway Statistics 1989, (2) the Department of Energy, Energy Information Administration, 1988 Residential Transportation Energy Consumption Survey (RTECS), and (3) the Bureau of the Census, 1987 Census of Transportation, Truck Inventory and Use Survey (TIUS).

Very few attempts to forecast trends in the fuel economy gap are available. In 1989, Westbrook and Patterson analyzed trends in driving patterns and produced forecasts of the fuel economy gap for the year 2010.[31] Their results indicated a composite gap of 29.7 percent for automobiles for the year 2010. This combined fuel efficient gap corresponded to a city fuel efficiency gap of 23.5 percent and a highway fuel efficiency gap of 30.5 percent. Organizations such as Data Resources Incorporated (DRI) and Wharton Econometrics Forecasting Associates (WEFA) use values for the degradation factors that remain constant over their forecasting horizon. The Department of Energy (DOE) and the Energy Information Administration (EIA) in the 1990 National Energy Strategy (NES) projected the fuel efficiency gap to reach 30 percent by 2030 in the NES reference case.[32] The projected gap for the High Conservation and the Very High Conservation cases of NES were 25 and 20 percent respectively. Also, EIA in the Annual Energy Outlook 1992 (AEO) projected the fuel efficiency gap to increase from 20 percent in 1990 to 25 percent in 2010.

An ongoing effort by DOE's Office of Transportation Technologies in conjunction with the

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[30] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), p.3-9,March 1992.

Maples, John D., and Philip D. Patterson, "The Fuel Economy Gap for All Automobiles and Light Trucks in Operation," Draft, Washington, DC,1991.

[31] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

[32] EIA, Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy, SR/NES/90-02, Service Report, p. 89, Washington, D.C., December 1990.

University of Tennessee is focused on forecasting the fuel efficiency gap for automobiles and light duty trucks through 2010. This work considers three scenarios based on differing assumptions about urban shares, highway speed, and congestion trends.

This attachment presents independent projections of the fuel efficiency gap to the year 2030 for two vehicle types:

1) Automobiles, and
2) Light Duty Trucks

The projections are generated based on the analysis of three important trends in driving patterns that affect fuel efficiency. These factors are:

1) increasing urban share of vehicle miles traveled,
2) increasing average highway speed, and
3) increasing level of urban highway congestion.

Initially, forecasts for each of these factors were developed based on two different growth scenarios:

1) Logistic Growth, and
2) Linear Growth

These scenarios are fully described as follows, using urban share growth as an example:

Logistic Approach

Figure F-1 shows the historical urban share of automobile VMT driving from 1972 through 1990 and a logistic curve fitted to the historical period and extended through the year 2030. The logistic share values are developed based on a logistic functional form originally formulated by

Fisher and Pry [33] and defined by:

$$f_t^U = \frac{f_\infty^U}{1 + e^{-(\alpha - \beta t)}} \tag{4}$$

where:

f_t^U is the urban share in year t,

f_∞^U is the urban share asymptotic limit, α and β are parameters of the logistic curve defined by:

$$\alpha = \ln[f_0^U / (f_\infty^U - f_0^U)], \tag{5}$$

$$\beta = (1/h^U)\ln[(f_\infty^U + f_0^U) / f_0^U], \tag{6}$$

where:

f_0^U is the base year urban share, and

h^U is the halving factor for the logistic curve. The halving factor is the time required from the base year for the urban share to reach the midpoint between its base year value and its asymptotic limit.

The logistic curve in Figure F-1 represents the curve that best fits the historical data on urban share for the 1972-1990 period. This curve is generated by assuming two logistic parameters and by selecting a base share year. These two parameters are the asymptotic limit and the halving factor. The asymptotic limit represents an upper limit to the growth of the urban share. The halving factor is a measurement of the time needed for the share to reach this upper limit. The values for both parameters are specific to the best fit curve and they are determined using an iterative approach which minimizes the sum of the squares of the difference between the historical shares and the logistic estimated shares.

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[33] Fisher, J.G. and Pry, R.M., "A Simple Substitution Model of Technology Change." Technological Forecasting and Social Change, Vol.3, pp.75-88, 1971.

Linear Approach

If it is assumed that the urban share will continue growing linearly, the impact on the fuel efficiency gap differs. Figure F-2 shows the historical urban share of automobile VMT driving from 1972 through 1990 and both a logistic curve and a straight line, fitted to the historical period and extended through the year 2030. The linear share forecasts developed by simple regression are considerably larger than those resulting from the logistic functional form.

The conclusions of the report noted that the logistic approach seemed to yield a more realistic projection of the gap. This was based largely on intuition, as the logistic approach can account for constraints which the linear approach cannot. As a result, logistic data were used in forming the model and are presented herein.

A total of two sets of projections were generated for each of the vehicle types, factors, and scenarios. The first was based on the assumption that all urban driving is city driving and all rural driving is highway driving. Fuel economy gap projections generated in the past are based on such an assumption, as it makes the gap calculations considerably easier. However, the assumption oversimplifies reality since some of the urban driving is on interstate highways and other freeways located in urban areas, and some of the rural driving includes stop-and-go city type of driving. The second set of projections were generated taking into consideration the decomposition of urban and rural driving into city and highway driving according to road types. This adjusted city/highway driving share approach was deemed more realistic. This is due to the fact that such an approach more closely resembles actual driving behaviour and consequently avoids the restricting assumption that urban driving is equal to city driving and rural driving is equal to highway driving. As such, only these calculations are included in this appendix.

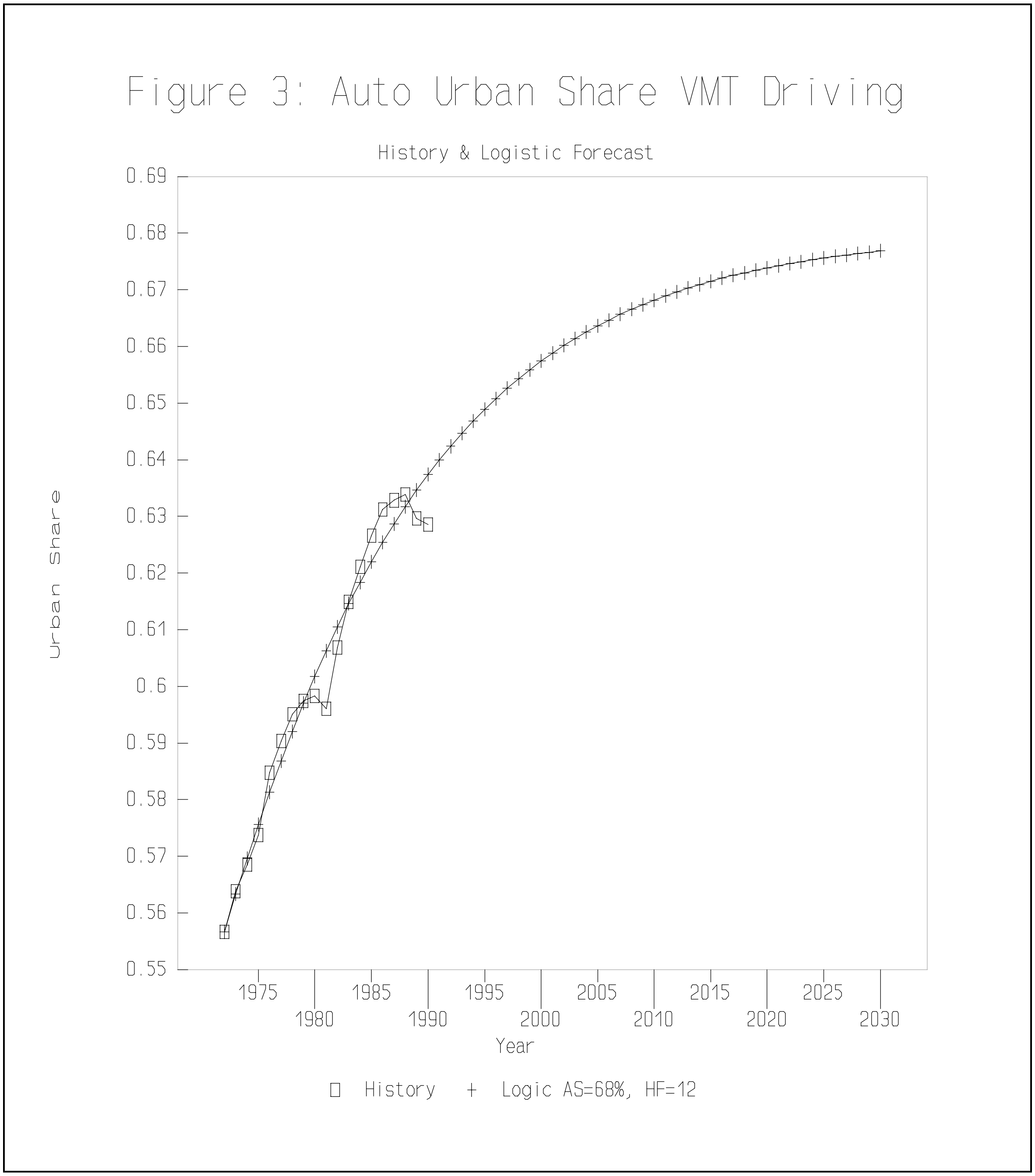
The decomposition is based on road types. Thus, VMT driving on roads identified as "interstate" and "other freeways and expressways" in urban areas are considered part of the highway driving share. Other road types located in urban areas are considered part of the city driving share. In addition, VMT driving on roads defined as "minor collectors" and "local" in rural areas are classified as city driving while the rest of the road types in rural area are considered highway driving. Although this road classification does not exactly replicate reality, it is a closer representation of the actual city/highway driving composition.

Approximately 63 percent of total 1990 VMT consisted of driving in urban areas and 37 percent in rural areas. 68 percent of the urban VMT is considered city driving and 32 percent highway driving. In rural areas, 17 percent is considered city driving and 83 percent highway driving. This composition represents overall city and highway driving shares for 1990 of:

City Share:	49.1 %
Highway Share:	50.9 %

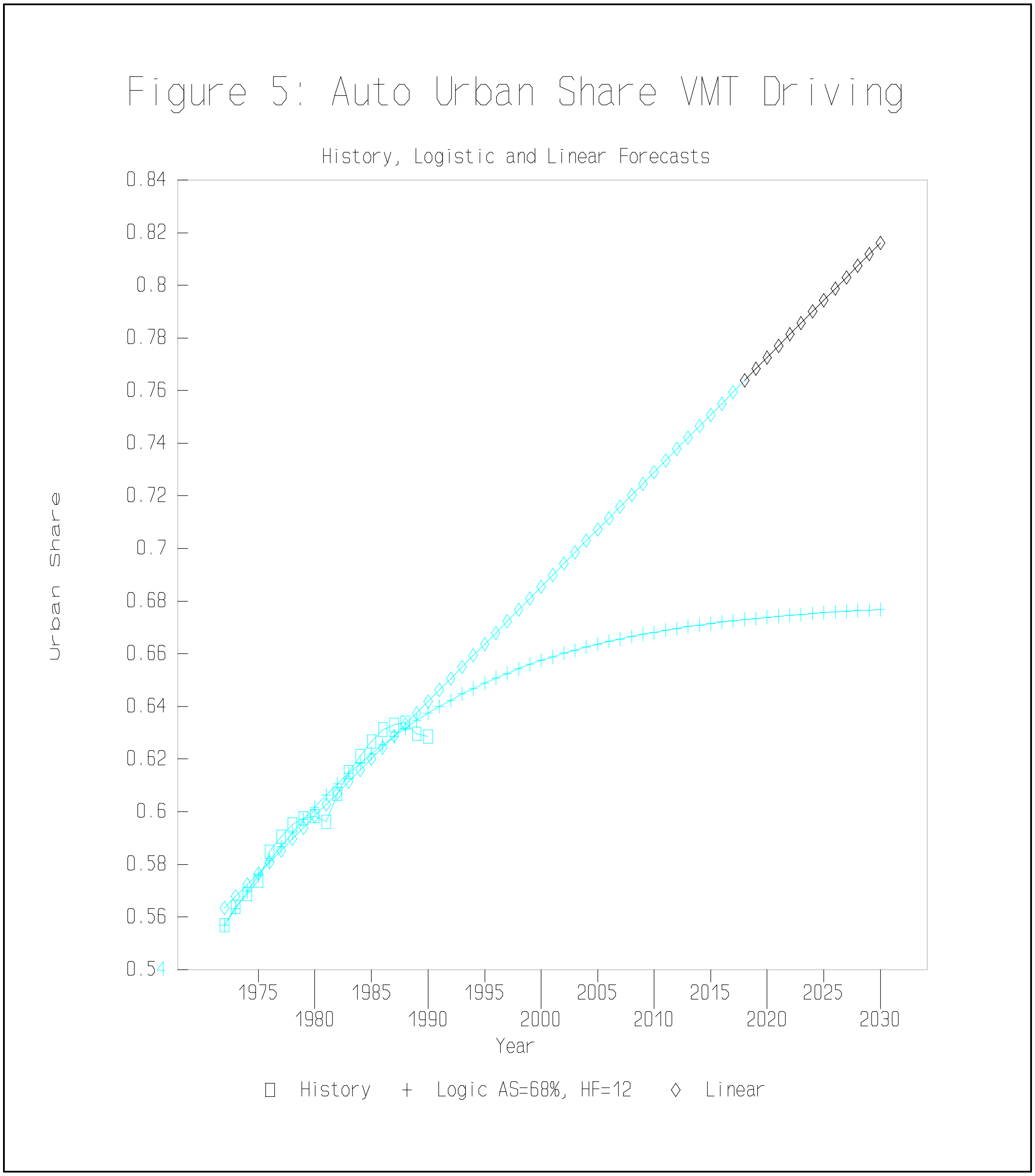
These adjusted city and highway shares are the bases for the calculations of the fuel efficiency gap projections in this chapter. The impact on fuel efficiency, from each of the three factors considered in this study, is affected by these adjusted shares. The impact from the increasing urban share trend is diminished since only part of the urban share (68% in 1990) is considered city share. The impact from increasing highway speeds is amplified since highway driving in both urban and rural areas is considered. Finally, the impact from increasing urban highway congestion is diminished since only part of the urban share is considered highway driving. The resulting fuel efficiency gap projections for automobiles and light duty trucks using the logistic approach based on these adjusted shares will be presented.

Figure F-1. Urban Share of Automobile VMT: Logistic Forecast



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Figure F-2. Urban Share of Automobile VMT: Logistic and Linear Forecasts



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

FUEL EFFICIENCY GAP PROJECTIONS

This section outlines the three trends which are assumed to affect the fuel efficiency gap estimates of the EPA. It then presents the projections of the fuel efficiency gap which have been utilized in the NEMS Transportation Sector Model.

Increasing Urban Share Driving

A review of the data from the last few decades on VMT for both automobiles and light duty trucks reflects a continuous increase in the share of urban driving.[34] For automobiles the urban share increased from 45.4 percent in 1953 to 62.9 in 1990. Figure F-3 shows the historical urban share of VMT for automobiles. This represents a 38.5 percent increase in 37 years, or an average annual rate of increase of 0.88 percent. For light duty trucks the urban share increased from 39.5 percent in 1966 to 55.4 in 1990. Figure F-4 shows the historical urban share of VMT for light duty trucks. This represents a 40.3 percent increase in 24 years, or an average annual rate of increase of 1.42 percent.

Westbrook and Patterson investigated the reasons for this increase in urban share by analyzing the data for the period from 1975 through 1985.[35] Their results indicated that the major reasons for this increase are the larger fraction of travel in urban roads and a larger fraction of roads being classified as urban. Population shifts to urban areas and driving shifts within metropolitan areas account for the larger fraction in urban driving which was estimated to be the cause for 58 percent of the increase in urban share. The other 42 percent increase was determined to be the consequence of the reclassification of roads from rural to urban. Any area reclassified by the U.S. Bureau of the Census from rural to urban results in the reclassification of all roads (regardless of the type) as urban.

Forecasts of the shares of urban and highway driving are necessary in order to forecast the

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[34] Data on VMT is published annually by the U.S. Department of Transportation, Federal Highway Administration, in Highway Statistics.

[35] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

change in the fuel efficiency gap due to changes in driving shares. It is very difficult to draw conclusions about the increasing trend in urban driving. Nevertheless, it can be expected that population shifts to urban areas will continue and that future land developments will force

Figure F-3. Urban Share of Automobile VMT: 1953-1990

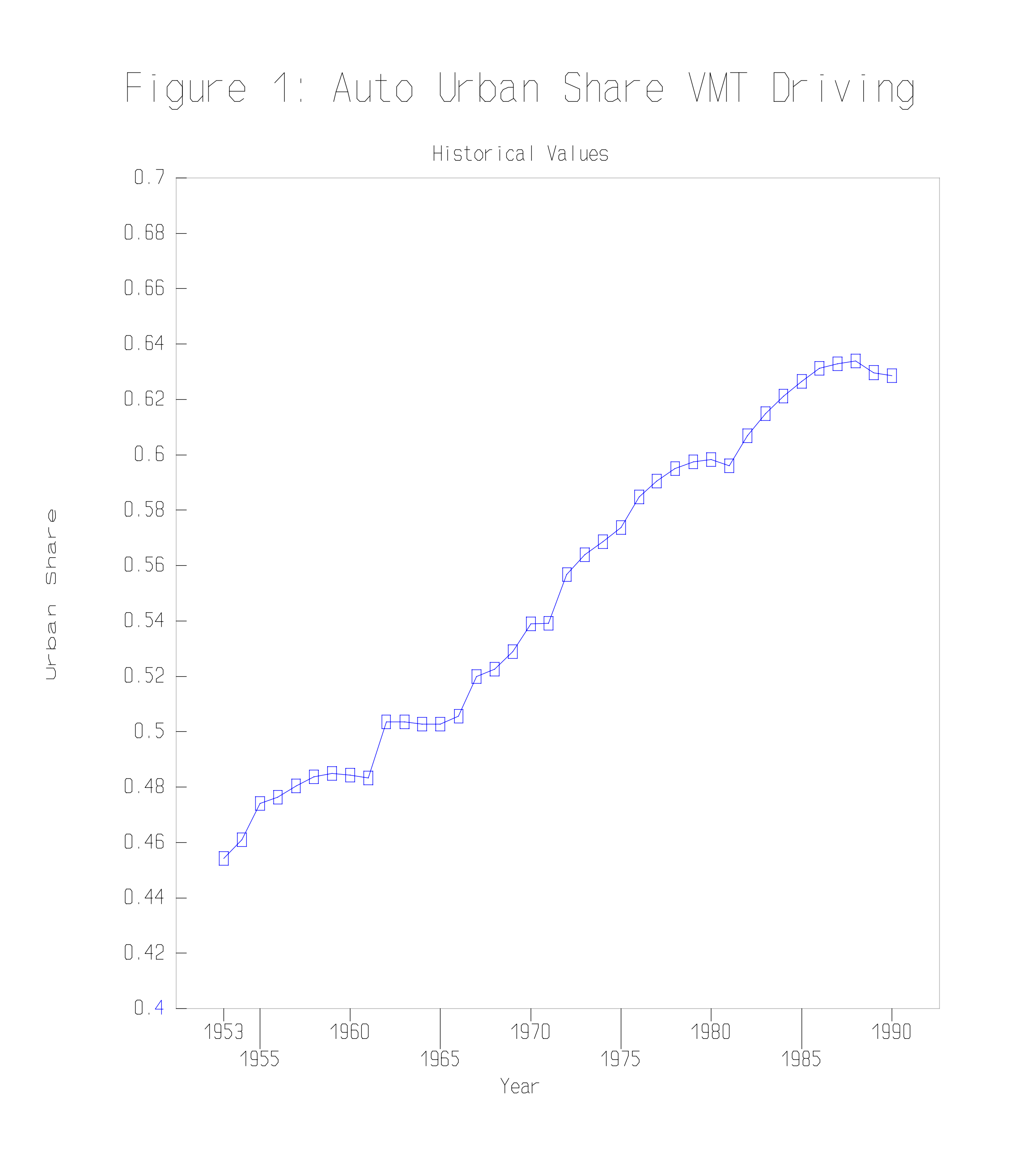
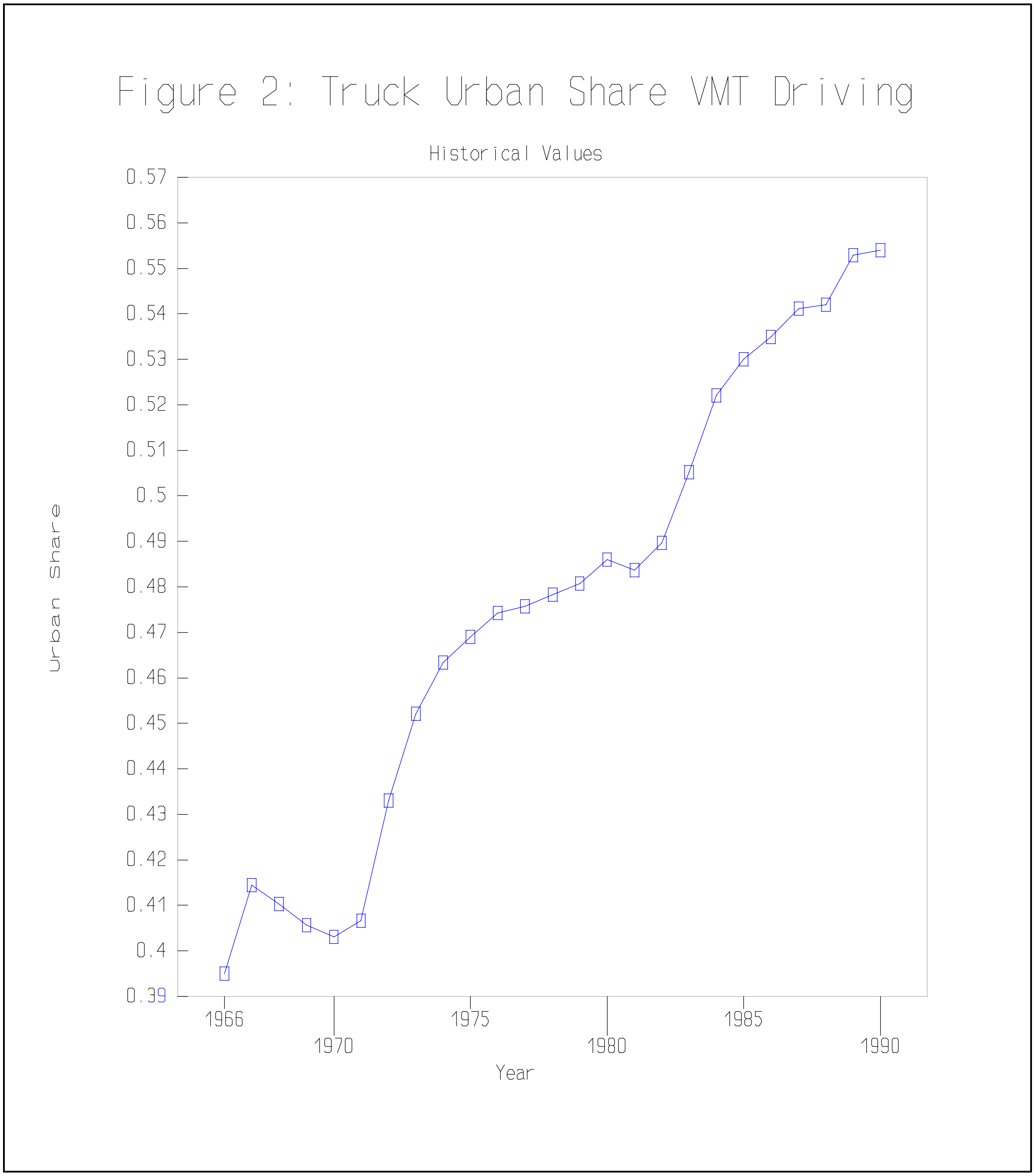


Figure 1: Auto Urban Share VMT Driving
Historical Values
Urban Share
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
1953
1955
1960
1965
1970
1975
1980
1985
1990
Year

Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Figure F-4. Urban Share of Light Truck VMT: 1966-1990



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

the reclassification of rural areas into urban areas. If we assume that this rate of increase in urban share will gradually diminish and level off, the logistic path applies (see Figure F-1). The calculations for logistic growth of increased urban share for automobiles and light trucks follow.

Automobiles:

Table F-20 summarizes the impact of the adjusted logistic city share growth on the composite fuel efficiency gap for automobiles. The adjusted logistic city share projection for the year 2010 becomes 51.1 percent as compared to the unadjusted logistic share of 66.8 percent; in the year 2030, the projection levels off at 51.5 percent as compared to an unadjusted 67.7 percent projected logistically. The adjusted logistic forecasts of city share increase are translated into a fuel efficiency gap of 16.05 percent by the year 2030. This represents an increase of only 0.85 percentage points over the base gap of 15.2 percent.

Light Duty Trucks:

The influence of the adjusted logistic urban share growth on the composite fuel efficiency gap for light duty trucks is presented in Table F-21. For the year 2010 the adjusted logistic city share projection becomes 48.8 percent as compared to an unadjusted logistic share of 62.3 percent. For the year 2030, the projection begins to level off at 50.3 percent as compared to an unadjusted 65.2 percent projected logistically. The adjusted logistic forecasts of urban share increase are translated into a fuel efficiency gap of 29.73 percent by the year 2030. This represents an increase of only 1.43 percentage points over the base gap of 28.3 percent.

Table F-20. Automobile Fuel Efficiency Gap Projections: Logistic Growth of City Driving Share (with Adjusted City Driving Share)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
City Share	49.3%	49.1%	50.1%	50.5%	50.8%	51.1%	51.2%	51.4%	51.5%	51.5%
Base Gap	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Gap Forecast	15.27	15.19	15.56	15.73	15.82	15.90	15.97	16.02	16.04	16.05
Change	0.07	-0.01	0.36	0.53	0.62	0.70	0.77	0.82	0.84	0.85

Sources: Base Gap from ORNL 1992, Urban Share Forecasts based on Fisher & Pry Logistic Function.

Table F-21. Light Truck Fuel Efficiency Gap Projections: Logistic Growth of City Driving Share (with Adjusted City Driving Share)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
City Share	44.6%	45.3%	46.3%	47.3%	48.1%	48.8%	49.3%	49.7%	50.0%	50.3%
Base Gap	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30
Gap Forecast	28.30	28.48	28.72	28.98	29.21	29.35	29.50	29.60	29.66	29.73
Change	0.00	0.18	0.42	0.68	0.91	1.05	1.20	1.30	1.36	1.43

Sources: Base Gap from ORNL 1992, Urban Share Forecasts based on Fisher & Pry Logistic Function.

Increasing Highway Speeds

The level of speed of a vehicle is one of the relevant factors that affects its fuel efficiency. Specifically, it has been determined that speeds over 45 mph decrease fuel efficiency for most vehicles. Furthermore, EPA estimates that traveling at 65 mph as compared to 55 mph lowers fuel economy over 15 percent.[36] ORNL's 1992 Transportation Energy Data Book presents the findings of a fuel economy study performed by the Federal Highway Administration in 1984.[37] This study concluded that, on average, vehicles experience fuel efficiency losses of about 17.8 percent when their speed is increased from 55 mph to 65 mph. This is equivalent to a reduction of 1.78 percent for each mile per hour increase over speed ranging from 55 mph to 65 mph.

Average highway speeds in the United States have shown an increasing trend for several years with few exceptions. Figure F-5 presents average highway speeds in mph for the last 45 years. The data in this figure indicate two different increasing trend periods. The first period from 1945 through 1973 corresponds to the largest rate of increase on highway speeds. During these years, highway speed increased at an annual rate of 1.13 percent. In 1973, average highway speed suddenly dropped from about 66 mph to about 55 mph. This sudden drop corresponds to the implementation of the nationwide 55 mph speed limit. After 1974, the increasing trend has continued at a more moderate rate. In the 1974-1990 period the annual rate of speed increase has been 0.15 percent. A closer look at the post-1973 period indicates that through the rest of the 1970s, the average speed remained fairly constant between 55 and 56 mph; and, through the 1980s, the annual rate of increase was 0.34 percent.

The increase in highway speed can also be illustrated by considering the percentage of rural and urban VMT driving over 55 mph on highways with posted speed limits of 55 mph. Figure F-6 presents these data for the 1981-1990 period. In only 9 years, the percent of rural VMT driving over the 55 mph speed limit rose from 46.4 percent to 58.7 percent for a total of 12.3 percentage points. The percentage increase in urban VMT driving was even more dramatic, from 37.6 percent to 53.8 percent for a total of 16.2 percentage points. The percentage exceeding the speed

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[36] DOE/EPA, 1992 Gas Milage: EPA Fuel Economy Estimates, DOE/CE-019/10, October 1991.

[37] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), Table 3.42, p.3-66,March 1992. 1984 data from U.S. Department of Transportation, Federal Highway Administration, Fuel Consumption and Emission Values for Traffic Models, Washington, D.C., May 1985.

limit is far from homogeneous. Significant differences exist across states, highway types, and location for rural or urban areas. For instance, in 1990 the percentage of vehicles exceeding the 55 mph limit in urban interstate highways in New York was 82.5 as compared to 68.2 in California and only 33.7 in South Dakota.

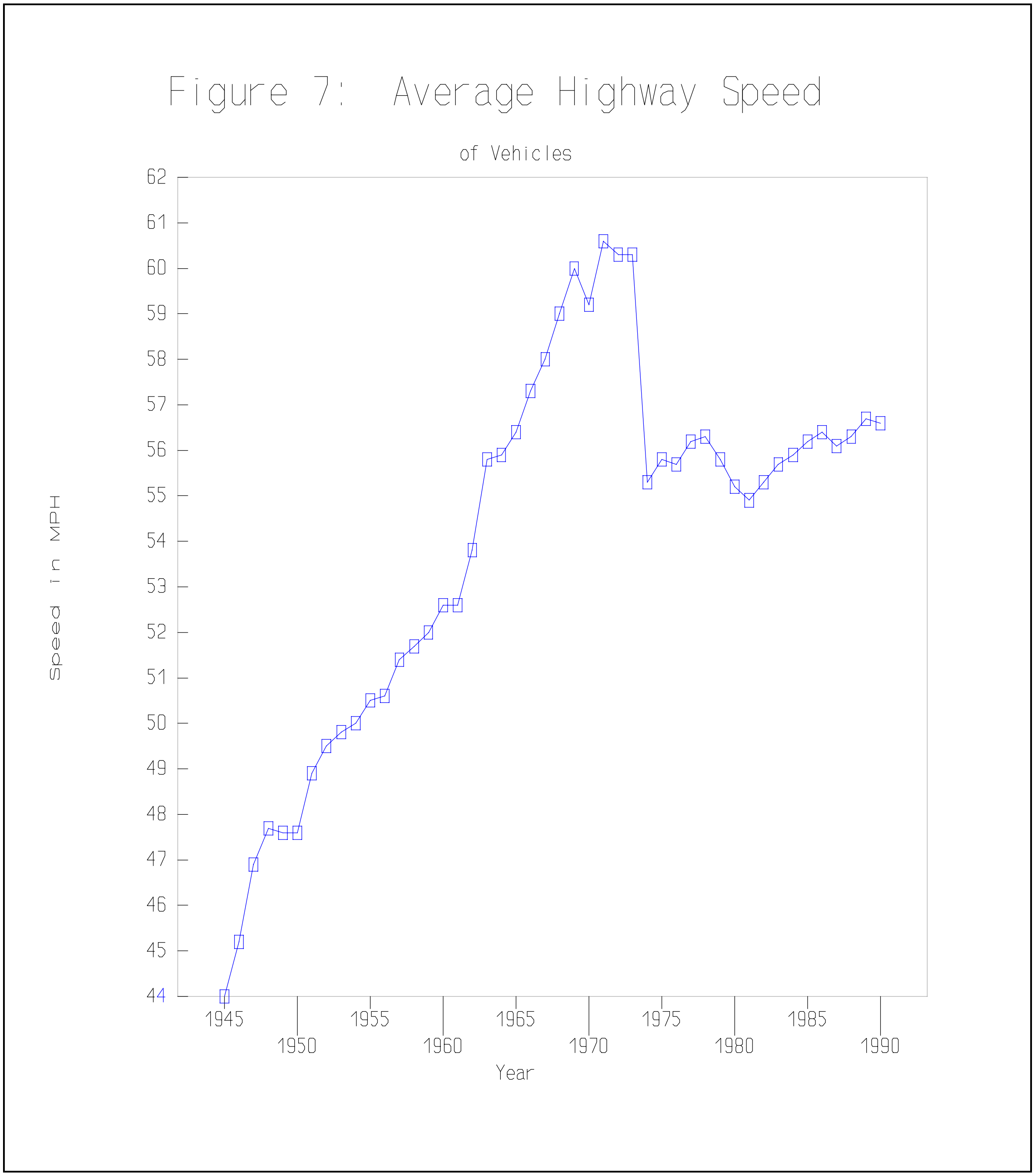
The estimation of the overall impact of speed trends in fuel economy is dependent on the specific data type selected to measure this trend and on the methodology used to forecast this trend. One could choose a disaggregated approach in which speed trend forecasts are developed by urban and rural driving, highway type, and vehicle type, for each state. Given the time limitations, the current study utilizes the nationwide average highway speed for all vehicles and highway types. Average speeds post-1980 are used as the basis to generate forecasts.

As Figure F-5 illustrates, average highway speed is influenced by regulatory policies such as the implementation of the nationwide speed limit in 1973-1974. Other factors affecting speed might include safety and environmental regulations, gasoline prices, oil shortages, income fluctuations, etc. Although a methodology to forecast speed trends which includes all relevant factors is desirable, a logistic approach based on historical trends has been applied.

Automobiles:

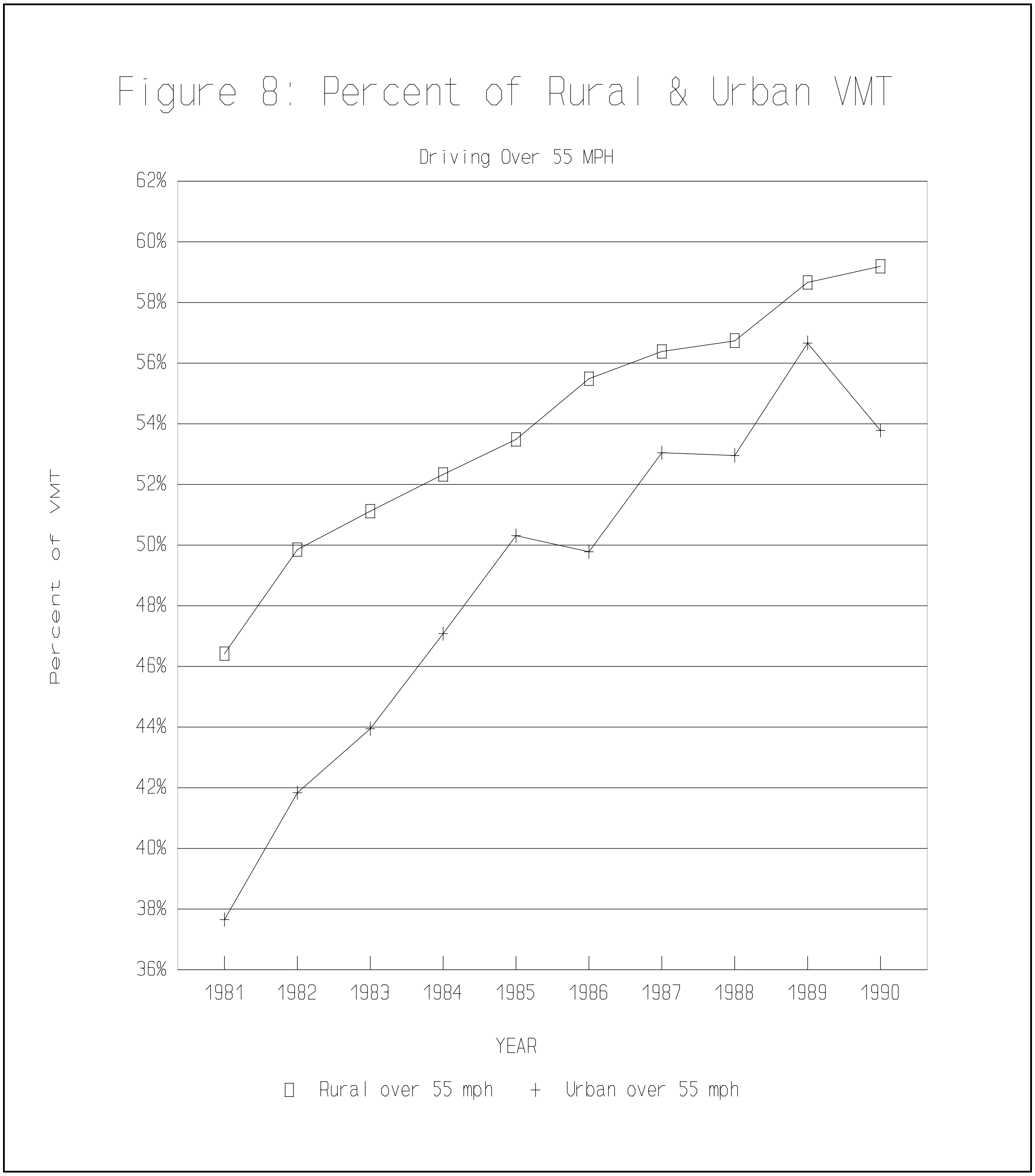
Table F-22 summarizes the impact of the adjusted highway share speeds on the composite fuel efficiency gap for automobiles using the logistic approach. Unlike the adjusted results for the urban driving share, the fuel efficiency gap forecasts indicate that in 2010 the gap has increased to 17.02 percent, which is greater than the unadjusted logistic forecast of 16.58 percent. By the year 2030, the adjusted forecast is 18.27 percent, which is above the unadjusted logistic forecast of 17.47. By the year 2030, the adjusted gap is 3.07 percent above the base gap of 15.2 percent.

Figure F-5. Average Vehicle Highway Speed: 1945-1990



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Figure F-6. Percent of Highway VMT over 55 MPH: 1981-1990



Note: Based on data for roads with posted speed limit of 55 mph.

Source: Historical values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Table F-22. Automobile Fuel Efficiency Gap Projections: Logistic Growth of Average Highway Speed (with Adjusted Highway Driving Shares)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
Highway Speed,mph	56.30	56.60	57.41	58.06	58.66	59.22	59.75	60.23	60.69	61.11
Base Gap	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Gap Forecast	15.19	15.39	15.89	16.31	16.67	17.02	17.38	17.70	18.00	18.27
Change	-0.01	0.19	0.69	1.11	1.47	1.82	2.18	2.50	2.80	3.07

Sources: Base Gap from ORNL 1992, Highway Speed Forecasts based on Fisher & Pry Logistic Function.

Table F-23. Light Truck Fuel Efficiency Gap Projection: Logistic Growth of Average Highway Speed (with Adjusted Highway Driving Share)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
Highway Speed,mph	56.30	56.60	57.41	58.06	58.66	59.22	59.75	60.23	60.69	61.11
Base Gap	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30
Gap Forecast	28.29	28.49	28.95	29.35	29.74	30.07	30.43	30.73	31.01	31.29
Change	-0.01	0.19	0.65	1.05	1.44	1.77	2.13	2.43	2.71	2.99

Sources: Base Gap from ORNL 1992, Highway Speed Forecasts based on Fisher & Pry Logistic Function.

Light Duty Trucks:
Table F-23 displays the fuel efficiency gap projections for light duty trucks assuming logistic growth for average highway speed and an adjusted driving share to reflect the city to highway driving proportion. The adjusted logistic projections imply that the fuel efficiency gap for light duty trucks will be 30.07 percent for an increase of 1.77 percentage points over the base gap in the year 2010. The gap forecast is larger than the unadjusted logistic projection of 29.74 percent. By 2030 the adjusted logistic forecast is 2.99 percent above the base gap of 28.30 percent, while the unadjusted logistic is 2.39 percent above the base gap. This implies a fuel efficiency gap of 31.29 percent in 2030.

Increasing Urban Highway Congestion

Congestion is a primary issue of the domestic transportation system. Urban congestion has increased in the last decades in most metropolitan areas as expansion and improvement of the transportation system lagged behind the rapid growth of travel demand.

The Federal Highway Administration (FHWA) classifies the two major causes of urban road congestion as recurring congestion and non-recurring congestion. Recurring congestion is that congestion which is the consequence of inadequate road capacity, reduction of through-put lanes, narrowing of lane widths, physical barriers, inadequate traffic light synchronization, and other similar causes. FHWA estimates that recurrent congestion accounts for 40 percent of all urban road congestion. Non-recurring congestion is that congestion resulting from disabled vehicles and accidents. FHWA estimates that disablement account for 55 percent of overall urban congestion, with the remaining 5 percent due to accidents.

One of the most important road types within urban areas in which congestion takes place is urban freeways. In 1990, 32 percent of the total vehicle miles of travel in urban areas corresponded to freeways, while freeways comprised only 5.7 percent of the urban roadway mileage.[38] The increase in urban congestion can be further analyzed by considering the increase in urban VMT as compared to the increase in urban lane miles. Data corresponding to the period 1975-1987 indicate that urban VMT demand growth rate is over 4 times the rate of new urban lane capacity

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[38] U.S. DOT, FHA, Highway Statistics 1990.

growth. This corresponds to an increase in the average urban through-put (urban VMT per mile) of 38.9 percent.

Differing methodologies have been developed recently to measure the extent and duration of freeway congestion in urban areas.[39] [40] Hanks and Lomax of the Texas Transportation Institute (TTI) have developed congestion indices for 39 urban areas. Table F-24 lists VMT, VMT per lane-mile, congestion indices, and rankings for each of the urban areas analyzed by TTI. Table F-25 lists, in addition to the congestion indices, estimates of the congestion cost per capita for each of these urban areas. Few attempts to forecast urban congestion and its effect on fuel economy are available. [41]

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[39] Cottrell, P., "Measurement of the Extent and Duration of Freeway Congestion in Urbanized Areas,"ITE 61st Annual Meeting, Milwaukee, Wisconsin, Sept. 1991.

[40] Hanks, J., and Lomax, T., Roadway Congestion in Major Urban Areas: 1982 to 1987, Texas Transportation Institute, Research Report 1131-2, College Station, Texas, Oct. 1989.

[41] Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," ITE Journal, Dec. 1989, pp. 21-23. Feng, An, "Automobile Fuel Economy and Traffic Congestion," Dissertation for PhD in Applied Physics, University of Michigan, 1992. Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

Table F-24. Congestion Index Value for Selected Cities

Urban Area	Freeway/Expressway Streets DVMT[1]	Freeway/Expressway Streets DVMT[2]	Principal Arterial DVMT[1]	Principal Arterial DVMT[2]	Congestion[3] Index	Rank
Western & Southern Cities	4,580	295	16,475	2610	1.23	4
Phoenix AZ	96,890	4,880	73,810	11,780	1.47	1
Los Angeles CA	8,055	660	6,135	1,000	1.00	17
Sacramento CA	23,155	1,640	8,180	1,560	1.08	12
San Diego CA	39,580	2,305	12,670	2,005	1.31	2
Denver CO	9,550	830	10,600	1,930	0.95	22
Miami FL	7,420	555	13,000	2,000	1.14	7
Tampa FL	3,300	280	3,880	610	1.02	16
Atlanta GA	23,940	1,600	9,350	1,500	1.16	6
Indianapolis IN	7,640	710	4,100	835	0.85	32
Louisville KY	5,380	515	2,975	520	0.86	30
Kansas City MO	11,920	1,410	4,350	910	0.69	39
St. Louis MO	16,290	1,430	11,215	1,745	0.96	20
Albuquerque NM	2,025	200	3,550	650	0.91	26
Oklahoma City OK	6,330	700	3,465	655	0.76	36
Portland OR	6,700	540	3,200	525	1.00	17
Memphis TN	3,730	375	3,930	760	0.84	34
Nashville TN	5,000	430	4,915	905	0.95	22
Salt Lake City UT	3,810	410	1,865	340	0.78	35
Seattle-Everett WA	16,600	1,140	8,950	1,475	1.14	7
Northeast & Midwest Cities						
Washington DC	22,910	1,555	18,400	2,240	1.25	3
Chicago IL	30,945	2,260	24,965	3,870	1.11	9
Baltimore MD	13,735	1,200	9,020	1,680	0.92	25
Boston MA	20,205	1,490	13,700	2,675	1.04	14
Detroit MI	21,800	1,610	21,545	3,450	1.10	11
Minn-St. Paul MN	15,620	1,230	5,200	1,160	0.97	19
New York NY	73,615	5,385	46,490	6,930	1.11	9
Cincinnati OH	9,560	845	3,315	790	0.87	29
Cleveland OH	11,185	960	4,840	1,100	0.89	27
Philadelphia PA	15,125	1,370	22,550	3,150	1.06	13
Pittsburgh PA	7,190	925	9,905	1,510	0.85	32
Milwaukee WI	6,820	570	4,640	930	0.94	24
Major Texas Cities						
Austin TX	5,150	420	2,150	415	0.96	20
Corpus Christi TX	1,500	180	1,490	320	0.72	37
Dallas TX	22,100	1,640	8,200	1,690	1.03	15
El Paso TX	3,200	345	3,000	805	0.72	37
Fort Worth TX	11,000	990	4,250	840	0.88	28
Houston TX	25,800	1,640	10,500	1,970	1.19	5
San Antonio TX	8,800	810	4,800	1,050	0.86	30
West/South Avg	15,095	1,045	9,750	1,715	1.01	
North/Midwest Avg	20,725	1,615	15,380	2,455	1.01	
Outside TX Avg	17,205	1,260	11,860	1,995	1.01	
Texas Avg	11,080	860	4,910	1,015	0.91	
Congested TX Avg	14,570	1,100	5,980	1,195	0.98	
Total Avg	16,105	1,190	10,610	1,820	0.99	
Maximum Value	96,890	5,385	73,810	11,780	1.47	
Minimum Value	1,500	180	1,490	320	0.69	

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio.

[1]Daily vehicle-miles of travel

[2]Daily vehicle-miles of travel per lane-mile

[3]See Equation s-1

Table F-25. 1987 Urban Area Rankings by Congestion Index and Cost per Capita

Urban Area	Congestion Index		Congestion Cost per Capita	
	Value	Rank	Value (Dollars)	Rank
Western & Southern Cities				
Phoenix AZ	1.23	4	510	10
Los Angeles CA	1.47	1	730	2
Sacramento CA	1.00	17	360	19
San Diego CA	1.08	12	280	25
San Fran-Oakland CA	1.31	2	670	3
Denver CO	0.95	22	420	14
Miami FL	1.14	7	670	4
Tampa FL	1.02	16	340	22
Atlanta GA	1.16	6	650	5
Indianapolis IN	0.85	32	100	38
Louisville KY	0.86	29	180	31
Kansas City MO	0.69	39	130	35
St. Louis MO	0.96	20	380	17
Albuquerque NM	0.91	26	250	27
Oklahoma City OK	0.76	36	170	34
Portland OR	1.00	18	300	24
Memphis TN	0.84	34	210	29
Nashville TN	0.95	23	380	18
Salt Lake City UT	0.78	35	120	36
Seattle-Everett WA	1.14	8	580	6
Northeast & Midwest Cities				
Washington DC	1.25	3	740	1
Chicago IL	1.11	9	340	21
Baltimore MD	0.92	25	340	23
Boston MA	1.04	14	400	16
Detroit MI	1.10	11	480	11
Minn-St. Paul MN	0.97	19	240	28
New York NY	1.11	9	430	12
Cincinnati OH	0.87	29	180	32
Cleveland OH	0.89	27	170	33
Philadelphia PA	1.06	13	520	9
Pittsburgh PA	0.85	32	410	15
Milwaukee WI	0.94	24	190	30
Major Texas Cities				
Austin TX	0.96	21	420	13
Corpus Christi TX	0.72	37	80	39
Dallas TX	1.03	15	530	8
El Paso TX	0.72	37	110	37
Fort Worth TX	0.88	27	360	20
Houston TX	1.19	5	550	7
San Antonio TX	0.86	30	260	26

Source: Hanks, J., and Lomax, T., Roadway Congestion in Major Urban Areas: 1982 to 1987, TTI, Research Report 1131-2, College Station, TX, Oct. 1989.

Lindley's projections of consumption statistics for the year 2005 take into account factors including time delays, wasted fuel, and user cost. The urban freeway congestion statistic projections developed by Lindley are presented in Table F-26.

The projections generated in this study utilize the wasted fuel values developed by Lindley as the basis to measure the impact of urban congestion on the fuel efficiency gap. The study further assumes that the amount of wasted fuel due to congestion will increase following a logistic trend.

The amount of wasted fuel is divided between automobiles and light duty trucks assuming that the light duty trucks VMT driving share will increase from 23.4 percent in 1989 to 33 percent in 2010, and will remain constant at 33 percent through 2030.

Automobiles:
The wasted fuel forecast due to traffic delays for the year 2010 is 9,164 mil.gal. and for the year 2030 it is 11,426 mil.gal. as summarized in Table F-27. This implies that the fuel efficiency gap will be 18.66 percent in 2010 and 23.08 percent in 2030. These are lower projections as compared to the unadjusted figures of 21.53 percent and 26.32 percent corresponding to the same years.

Light Duty Trucks:
Table F-28 presents the fuel efficiency gap projections for light duty trucks based on adjusted city/highway shares and assuming logistic growth of wasted fuel due to congestion. The wasted fuel forecast for light duty trucks for the year 2010 is 4,513 mil.gal. and for the year 2030 it is 5,628 mil.gal. This implies that the fuel efficiency gap will be 32.77 percent in 2010 and 33.43 percent in 2030 as compared to the unadjusted figures of 32.91 percent and 34.09 percent.

Overall Degradation Factor Forecast

Figures F-7 and F-8 summarize the projections of the fuel efficiency gap using assumptions of logistic growth and adjusted city/highway shares for automobiles and light duty trucks, respectively. The overall results are listed in Table F-29.

As illustrated in Table F-29, the logistic approach generates lower forecasts for the overall fuel efficiency gap for both automobiles and light duty trucks as compared to the ones generated using the linear approach. The overall fuel efficiency gap for automobiles is expected to increase from a base of 15.2 to 27.00 by the year 2030 assuming a logistic trend. The fuel efficiency gap will increase further to 34.07 if a linear trend is assumed instead. The overall fuel efficiency gap for light duty trucks is expected to increase from a base of 28.3 to 37.85 or 42.91 by the year 2030 assuming logistic and linear growth respectively.

Table F-26. Urban Freeway Congestion Statistics

	1984	1987	(1984 data) 2005	(1987 data) 2005
Freeway Miles	15335	16097	15335	16097
Vehicle-Miles of Travel (billions)	277	337	411.0	493
Recurring delay (million vehicle-hours)	485	728	2049	3030
Delay due to incidents (million vehicle-hours)	767	1287	4858	7978
Total delay (million vehicle-hours)	1252	2015	6907	11008
Total wasted fuel (million gallons)	1378	2206	7317	11638
Total user costs (billion dollars)	9	16	51	88

Source: Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," ITE Journal, December 1989, pages 21-23.

Table F-27. Automobile Fuel Efficiency Gap Projections: Logistic Increasing Congestion Trend (with Adjusted City/Highway Driving Share)

	1990	1995	2000	2005	2010	2015	2020	2025	2030

Wasted Fuel (Million Gallons)	2252	3865	5788	7764	9164	10284	10924	11259	11426
Base Gap	15	15	15	15	15	15	15	15	15
Gap Forecast	15.69	16.37	17.34	18.20	18.66	22.08	22.50	22.79	23.08
Change	0.49	1.17	2.14	3.00	3.46	6.88	7.30	7.59	7.88

Figure F-7. Fuel Efficiency Gap for Automobiles (with Adjusted Driving Share)

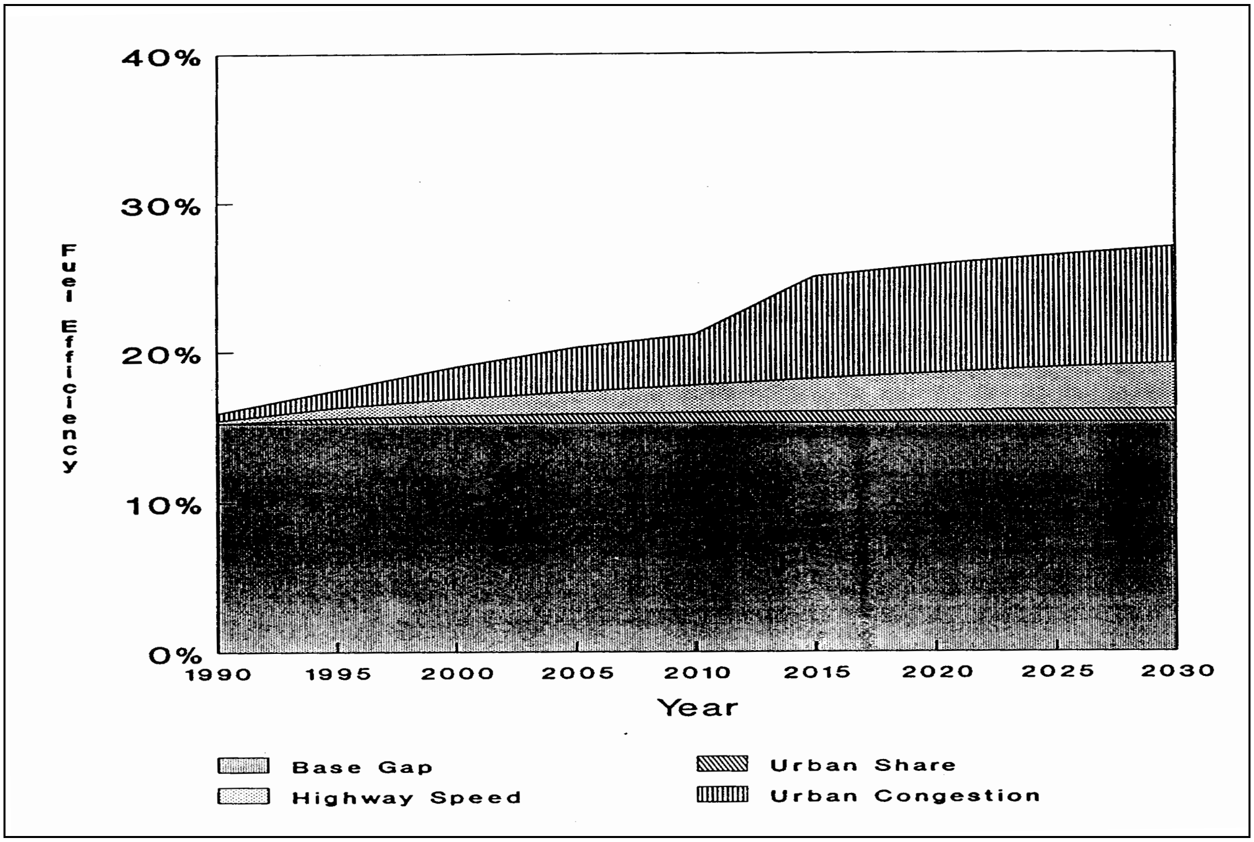


Figure F-8. Fuel Efficiency Gap for Light Duty Trucks (Logistic Forecast)

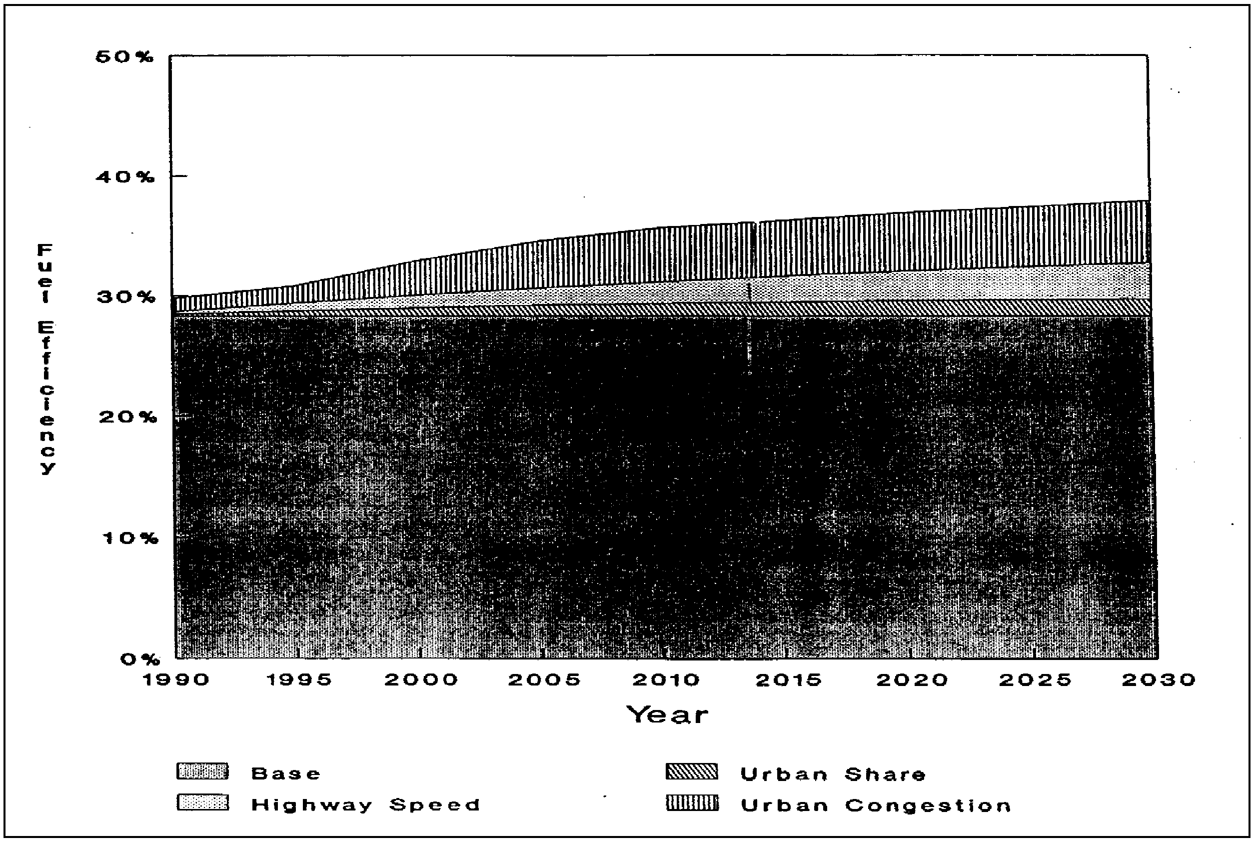


Table F-28. Light Truck Fuel Efficiency Gap Projections: Logistic Increasing Congestion Trend (with Adjusted City/Highway Driving Share)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Wasted Fuel (Million Gallons)	611	1203	2240	3375	4513	5065	5380	5545	5628
Base Gap	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
Gap Forecast	29.41	29.76	31.17	32.17	32.77	32.89	33.14	33.28	33.43
Change	1.11	1.46	2.87	3.87	4.47	4.59	4.84	4.98	5.13

Table F-29. Total Fuel Efficiency Gap Projections for Automobiles and Light Duty Trucks with Adjusted City/Highway Driving Share

	1990	1995	2000	2005	2010	2015	2020	2025	2030
AUTOMOBILES									
Base Gap	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Gap Forecast	15.87	17.42	18.98	20.29	21.18	25.03	25.82	26.43	27.00
Change	0.67	2.22	3.78	5.09	5.98	9.83	10.62	11.23	11.80
L. D. TRUCKS									
Base Gap	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30
Gap Forecast	29.78	30.83	32.90	34.52	35.59	36.22	36.87	37.35	37.85
Change	1.48	2.53	4.60	6.22	7.29	7.92	8.57	9.05	9.55

Attachment 4: Vehicle-Miles Traveled Model

Development of the VMT Forecasting Model

INTRODUCTION

The following is a description of a new VMT forecasting model which has been developed to replace the approach previously used. This approach addresses two demographic issues which have been shown to influence driving rates:

1. Historically, the proportion of Female VMT to Male VMT has grown steadily. This factor has been an important explanatory variable explaining aggregate VMT growth in the past.

2. The proportion of the population 60 or over (a reasonable proxy for retirement) has remained extremely steady over the period of estimation (1970-1991). This share was approximately 20 percent in 1970 and it was still 20 percent in 1990.

The first item is relatively easy to deal with. Traditional econometric techniques provide an estimate of how total VMT has varied as the proportion of Female to Male VMT has increased. This proportion, however, is not likely to continue to grow as it has in the past. Specifically, it is assumed in the analysis that follows that the Female to Male VMT ratio asymptotically approaches 0.8. This proportion is consistent with several recent Department of Transportation Nationwide Personal Transportation Surveys (NPTS).

The affect of the "aging of the population" on VMT cannot be assessed by analyzing historical data. There has been no 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.

Rather than ignore the forecast shift in demographic trends, the methodology described in the following pages explicitly adjusts the forecast based on survey information. In 2015, the total VMT forecast is 3.6 percent lower once the aging of the population is accounted for.

METHODOLOGY

- VMT per capita is considered to be a function of economic and demographic variables.[42] The variables which are considered are as follows:

CPM87, the fuel cost of driving a mile, expressed in 1987 dollars.
YPC87, disposable personal income per capita, expressed in 1987 dollars.
PrFem, the ratio of per capita female driving to per capita male driving.
P>60, the proportion of the population greater than or equal to 60 years of age.

- The following correlation table suggests that multicollinearity between P>60 and YPC87 would result in biased estimators. P>60 is not included in the regression, but there is strong reason to expect the aging of the population to influence driving habits early in the next century. The proposed adjustment factor based on aging will be described below.

Table F-30. VMT Variable Correlation Coefficients

	VMTPC	YPC87	CPM87	PrFem	P>60
VMTPC	1.000	0.961	-0.589	0.783	0.925

[42] VMT per capita should be understood to 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.

YPC87	0.961	1.000	-0.410	0.643	0.947
CPM87	-0.589	-0.410	1.000	-0.803	-0.467
PrFem	0.783	0.643	-0.803	1.000	0.748
P>60	0.925	0.947	-0.467	0.748	1.000

- The following linear model is tested, using data from 1969-1990:

$$VMTPC = \alpha + \beta_1 CPM87 + \beta_2 YPC87 + \beta_3 PrFem \qquad (7)$$

The regression provides the following output:

Table F-31. VMT Linear Regression Output

	Constant	CPM87	YPC87	PrFem	D-W	Adj. R-Sq
Parameter	-0.148	-4.878	5.9e-04	4.470	0.925	0.968
T-Stat		-1.574	15.348	2.638		

- The D-W statistic for this model suggests the possibility of serial correlation. A generalized difference equation of the following form is tested, using the Cochrane-Orcutt iterative procedure:

$$VMTPC_T - \rho\, VMTPC_{T-1} = \alpha(1-\rho) + \sum_{N=1}^{3} \beta_N (X_{N,T} - \rho\, X_{N,T-1}) \qquad (2)$$

where $X_{N=1,..,3}$ represent the input variables. This results in the following parameters, which are used to produce an unadjusted forecast of VMTPC:

Table F-32. VMT Generalized Difference Equation Output

	ρ	Constant	CPM87	YPC87	PrFem	Adj. R-Sq
Parameter	0.72	0.28	-7.50	3.6e-04	8.36	0.841
T-Stat			-2.32	2.46	2.99	

- The unadjusted forecast is subsequently modified by a demographic adjustment factor (DAF). This is an index which is based on projections of the proportion of the population over 60 years of age (P>60) and the expected ratio of per capita driving by those over 60 to those under 60 (PVMT60). Historical data and projections until 2030 are provided in the graph below. The DAF, also graphed, is calculated as follows:

$$DAF_T = 1 - \left[P{>}60_T \cdot (1 - PVMT60_T) \right] \qquad (9)$$

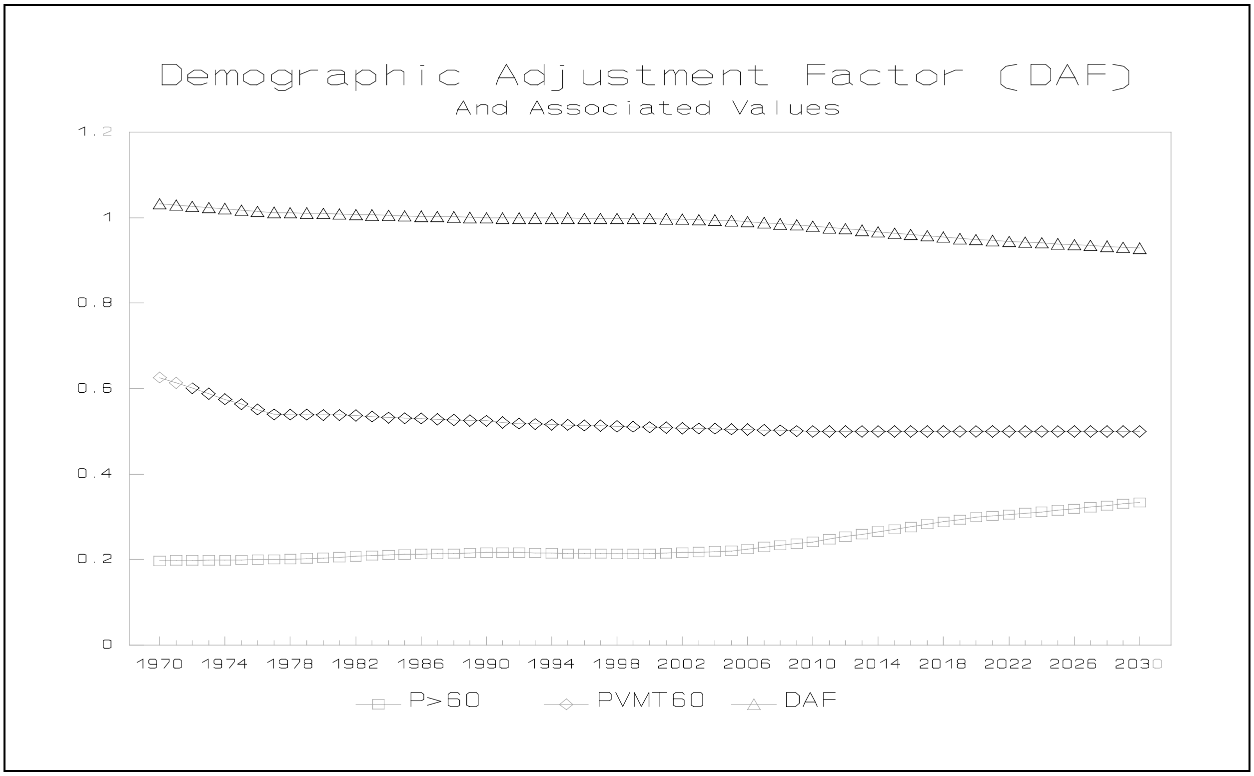
The DAF is subsequently indexed to 1.0 in 1990.

Figure F-9. VMT Demographic Adjustment Factor: 1970-2030

- The Adjusted VMTPC forecast is the product of the DAF and the unadjusted VMTPC. Figure F-10 presents forecasts of VMTPC made with the original linear equation, the generalized difference equation, and the demographically-adjusted model. Figure F-11 depicts the total VMT forecasts associated with the linear equation and the adjusted difference equation.

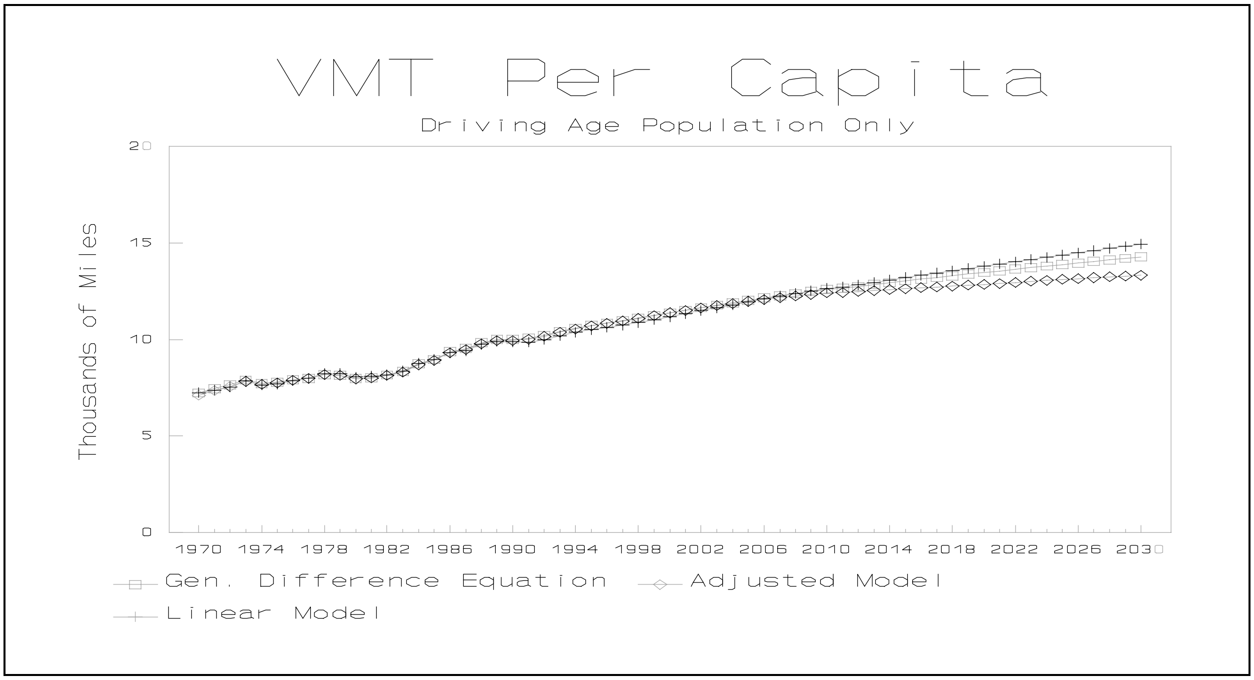
- The average annual growth rates of VMT per capita and total VMT are as follows:

Table F-33. Average Annual VMT Growth Rates



Interval	Adjusted VMT per Capita	Total VMT	
		Linear Model	Adjusted Model
1990 - 2000	1.3%	2.2%	2.2%
2000 - 2010	0.8%	2.0%	1.6%
2010 - 2020	0.3%	1.4%	0.9%
2020 - 2030	0.4%	1.1%	0.7%
1990 - 2030	0.7%	1.7%	1.3%

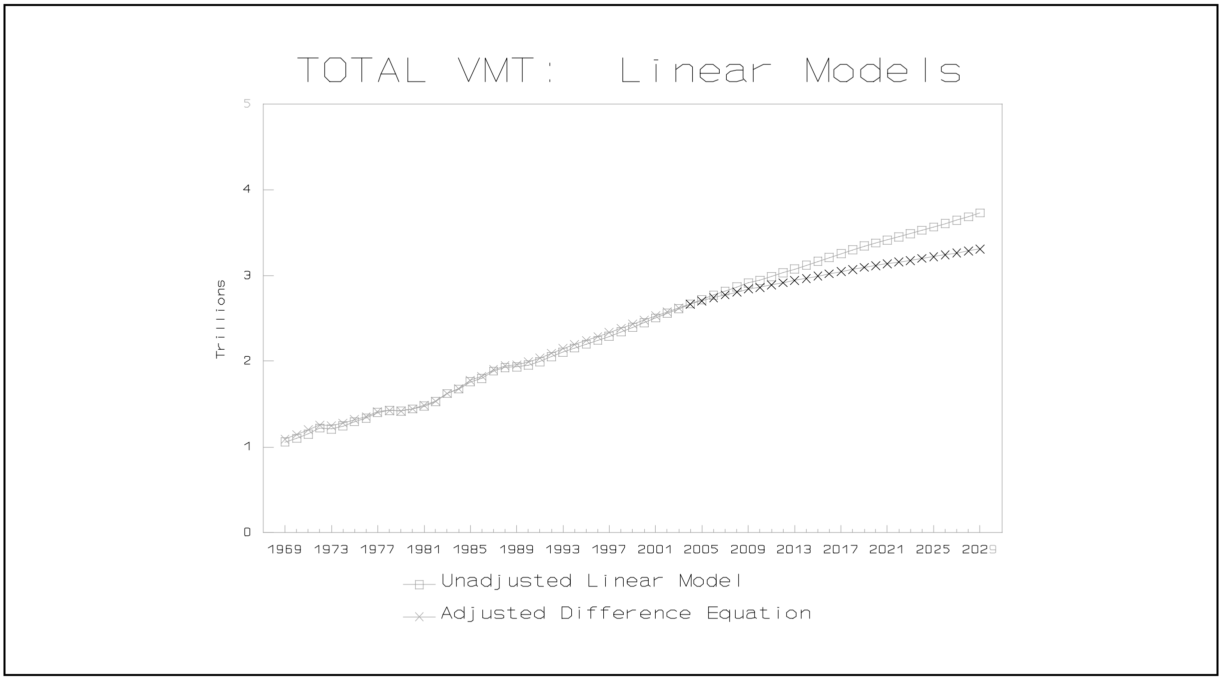
Figure F-10. VMT Per Capita: 1970-2030

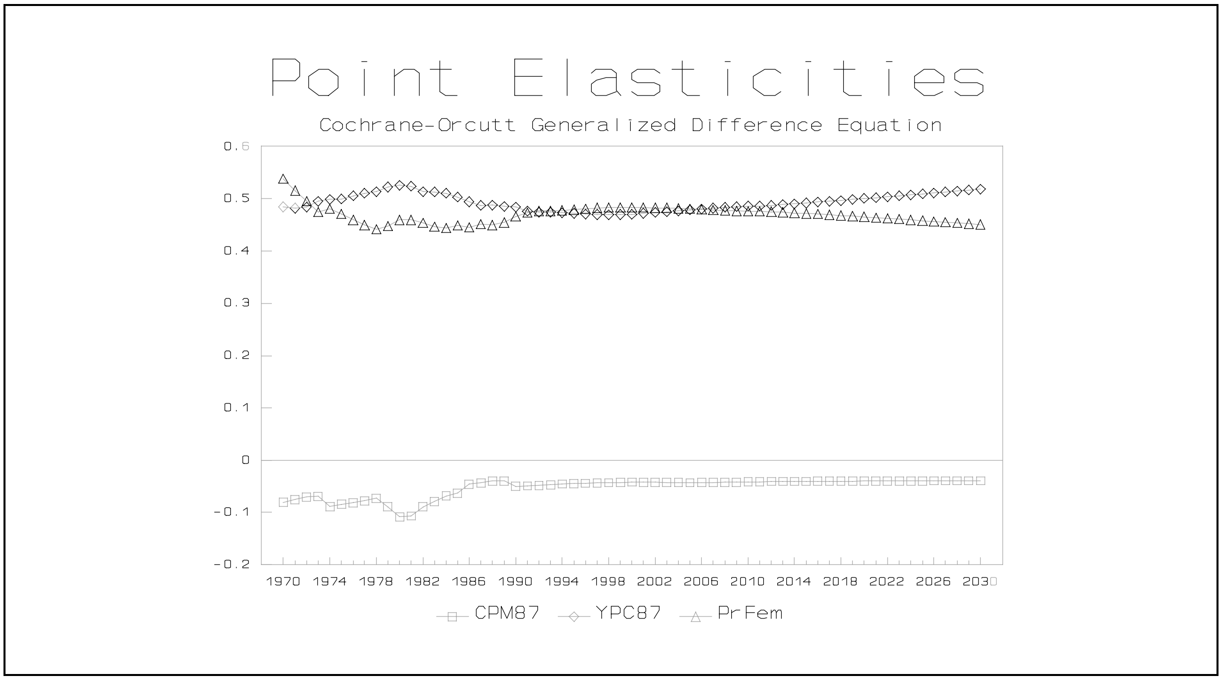


■ Point elasticities associated with the difference equation are presented in Figure F-12.

Figure F-11. Linear VMT Projections

Figure F-12. VMT Point Elasticities: 1970-2030





Attachment 5: Air Travel Module

It is expected that the "personal travel" segment of commercial passenger traffic will be more sensitive to air fares than the "business travel" segment. It is also likely that the volume of discretionary travel will be more influenced by public perceptions of airline safety, convenience, and quality of service. One way of quantifying this effect is in a stratified measure of the "propensity to fly" which, in its most rudimentary form, associates with each age group and gender a static value obtained from a survey of travelers.[43] The propensity to fly is considered to be the product of the percentage of a given population segment to have flown in the previous year, and the average number of flights taken by the travelers. This translates into the number of trips per capita associated with that population cohort. These values are subsequently used to modulate forecasts produced by the conventional model as follows:

$$ARPM_T = DI_T \cdot RPM_{D,P,T} \tag{10}$$

where:

$ARPM_T$ = Adjusted personal-travel revenue passenger miles in year t.
DI_T = Demographic index in year t.
$RPM_{D,P,T}$ = Unadjusted forecast of domestic personal RPM in year t.

and:

$$DI_T = \left[\frac{\sum_I POP_{I,T} \cdot PROFLY_{I,T}}{\sum_I POP_{I,T}}\right] \div \left[\frac{\sum_I POP_{I,0} \cdot PROFLY_{I,0}}{\sum_I POP_{I,0}}\right] \tag{11}$$

where:

$POP_{I,T}$ = The population of the I^{th} cohort in year T.
$POP_{I,0}$ = The population of the I^{th} cohort in the base year.
$PROFLY_{I,T}$ = The propensity to fly for the I^{th} cohort.

The following describes the assumptions and data manipulations undertaken to develop age- and gender-specific demographic adjustments to forecasts of personal travel. The use of these factors

[43] This adjustment algorithm has been adapted from that provided in Appendix A of *Forecasting Civil Aviation Activity: Methods and Approaches,* Transportation Research Circular Number 372, Transportation Research Board, June 1991.

is predicated on the static nature of the public's propensity to fly ($PROFLY_{I,T} = PROFLY_{I,0}$), absent sufficient time series data to reflect and predict changing trends.

- The ATA travel survey provides the percentage of each age group which has flown in the previous year (π_A), as well as the fraction of men and women of all age groups who have flown (π_M, π_W). The first step is to derive an estimate of the percentage of each age group and sex which has flown.

- Given that N_M and N_W represent the total number of men and women, respectively, the percent of the flying population that are of each gender can be represented as follows:

$$P_M = \frac{\pi_M N_M}{\pi_M N_M + \pi_W N_W} \quad ; \quad P_W = 1 - P_M \tag{12}$$

Using the 1990 Census numbers, $P_M = 0.53$ and $P_W = 0.47$. In other words, 53 percent of people who took at least one air trip in the previous year were male.

- It is assumed that this gender ratio is constant across age groups and time. This ratio is used to estimate the percentage of the population by gender and age group which has flown in the previous year. The equation for males is as follows:

$$\pi_{M,A} = \frac{P_M \pi_A N_A}{N_{M,A}} \tag{13}$$

In order to determine the number of trips per capita for male and female cohorts, further assumptions are necessary.

- According to the ATA survey, male travelers flew more than female travelers; the ratio of male to female trips per capita is 1.72, i.e.:

$$\frac{T_M}{N_M} = 1.72 \frac{T_W}{N_W} \tag{14}$$

where T_M and T_W represent the total number of trips by male and female travellers, respectively.

■ In each age group, the number of average trips per capita is reported. It is assumed that the male/female travel ratio holds across age groups, which enables the subsequent division of each figure into two gender-specific figures.

For each age group, the number of trips per capita (TPC) is expressed as:

$$\frac{T_{M,A} + T_{W,A}}{N_{M,A} + N_{W,A}} = TPC_A \tag{15}$$

From above:

$$T_{M,A} = 1.72\left(\frac{T_{W,A}\, N_{M,A}}{N_{W,A}}\right) \tag{16}$$

Substituting, and rearranging:

$$T_{W,A}\left(1 + 1.72\left(\frac{N_{M,A}}{N_{W,A}}\right)\right) = TPC_A\,(N_{M,A} + N_{W,A}) \tag{17}$$

which leads to the trips per capita for women, by age group:

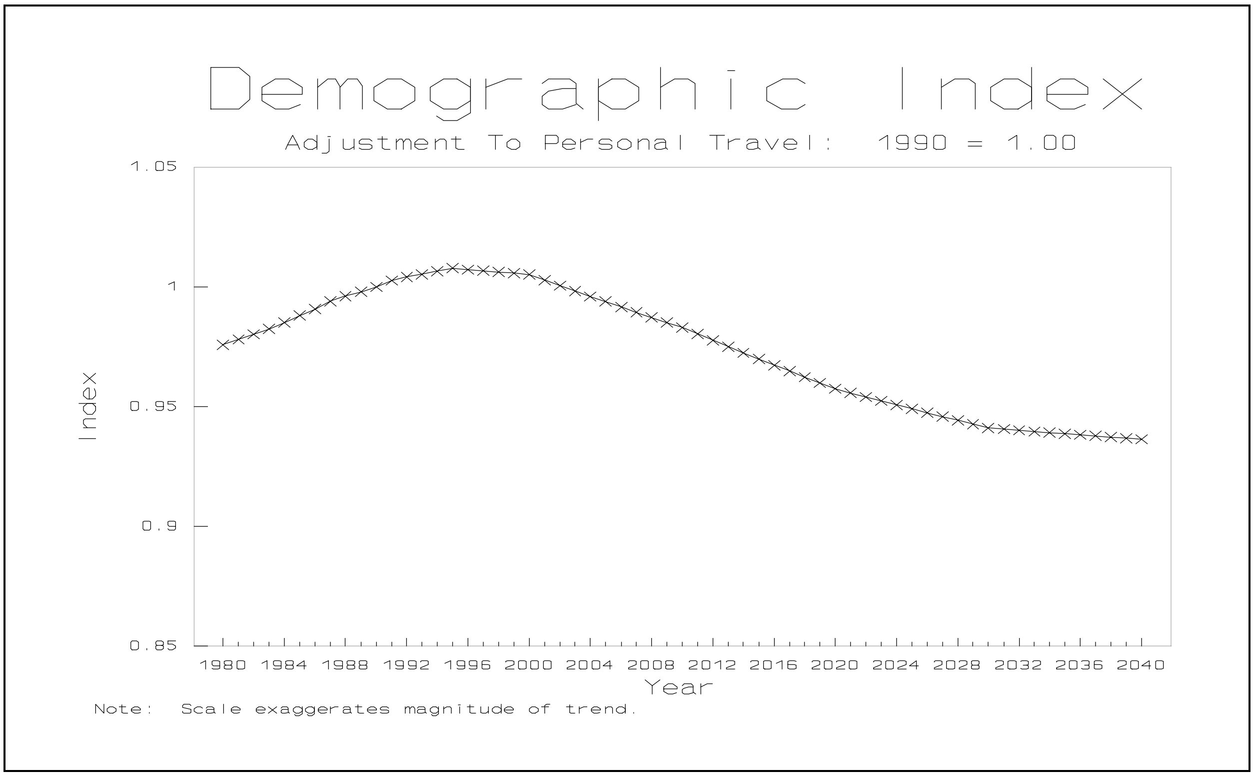
$$\frac{T_{W,A}}{N_{W,A}} = TPC_A\left[\frac{N_{M,A} + N_{W,A}}{N_{W,A} + 1.72\, N_{M,A}}\right] \tag{18}$$

The resulting figures are tabulated, and a graph of the demographic index through the year 2040 is provided on the following page.

Table F-34. ATA 1990 Air Travel Survey Data

Age Group	1990 Population ('000)		Percentage Flown		Average Trips per Capita		Propensity to Fly ($PROFLY_{I,T}$)	
	Male	Female	Male	Female	Male	Female	Male	Female
18-24	13,215	12,925	0.31	0.29	3.29	1.91	1.03	0.55
25-34	22,078	21,848	0.37	0.33	4.88	2.83	1.80	0.94
35-44	18,193	19,112	0.38	0.32	5.18	3.03	1.97	0.97
45-54	12,406	13,081	0.39	0.33	4.82	2.81	1.89	0.93
55-64	10,103	11,260	0.33	0.26	4.17	2.45	1.36	0.63
65+	12,853	18,706	0.31	0.19	4.28	2.52	1.34	0.48

Figure F-13. Demographic Adjustment Index for Personal Air Travel: 1980-2040



Sources:

Population Data: U.S. Department of Commerce, Bureau of the Census, *Projections of the Population*

of the United States by Age, Sex, and Race: 1988 to 2080, Population Estimates and Projections, Series P-25, No. 1018.

Percentage Flown & Trips per Capita: ATA, *Air Travel Survey, 1990.*

Attachment 6: Vehicle Emissions Module

Derivation of Emission Factors

INTRODUCTION

This report provides EPA emission factors to be used in the transportation vehicle emission solution algorithm, which is outlined in the *Transportation Sector Component Design Report* (TSCDR) section on emissions. This algorithm is as follows:

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T}$$

where *EMISS* is total emissions of pollutant IP by mode IM, in region IR, and time T, *EFACT* is an emission factor based on technology, fuel and vintage weights, and *U* is a measure of annual vehicle activity (vehicle-miles-traveled or fuel consumption in gallons).

The TSCDR specifies modal emission factors for SO_x, NO_x, carbon, CO, CO_2 and VOCs, and calls for emissions to be calculated for the following six transportation modes:

Highway	Non-Highway
Light-Duty Vehicles	Rail
Freight Trucks	Air
Buses	Water

A number of these transportation modes have subcomponent modes that are to be handled in a separate TERF "Miscellaneous End-Use Component" module. These subcomponent modes include military aircraft, recreational boating, passenger rail, and buses. This report also provides the emission factors for these miscellaneous transportation energy end-use categories, as well as for alternative fuel vehicles (AFVs).

Pollutant emission factors are not reported for certain transportation vehicles. Reasons for the exclusion of these emission factors include one or more of the following:

- the lack of adequate EPA emissions testing results for the production of reliable fleet-average emission rates,

- the quantities of a pollutant generated a vehicle type are not significant,

- the pollutant is not regulated by the EPA (for example, only aircraft HC and smoke emissions are currently regulated).

Such instances of nonreported emission factors are documented in the relevant transportation mode sections of this report.

HIGHWAY MOBILE SOURCE EMISSION FACTORS

Highway Source Emission Factor Information Sources

Emission factors and the accompanying calculation procedures used for virtually all federal and state mobile source emission inventory studies come from the following EPA source documents:

- *Compilation of Air Pollutant Emission Factors - Volume II: Mobile Sources* (AP-42, Fourth Edition, September 1985)

- *Supplement A to AP-42 Volume II*, January 1991.

- *User's Guide to MOBILE4.1*, EPA-AA-TEB-91-01 (EPA Office of Mobile Sources, Emission Control Technology Division, July 1991).

- *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachments A through J (This EPA memorandum supersedes the mobile source emission inventory preparation instructions contained in *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, which is currently being revised)

- *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, EPA-450/4-81-26d (revised), (July 1992).

The document, *Compilation of Air Pollutant Emission Factors - Volume II*, reports all data and emission factor calculation algorithms for both highway and off-highway emission sources. Supplement A to AP-42 presents updated emissions factor information for highway sources based on the results of additional vehicle test data obtained subsequent to the publication of the original AP-42 Air Pollutant Emission Factor compilation document, as well as methodological modifications reflecting calculation refinements and new emission regulations. Both EPA data source documents categorize highway mobile sources into eight types: light-duty gasoline vehicles (LDGVs), light-duty gasoline-powered trucks with a gross vehicle weight rating of less than or equal to 6,000 lbs (LDGT1s), light-duty gasoline-powered trucks with a gross vehicle weight rating greater than 6,000 lbs (LDGT2s), heavy-duty gasoline-powered vehicles (HDGVs), light-duty diesel-powered vehicles (LDDVs), light-duty diesel-powered trucks (LDDTs), heavy-duty diesel-powered vehicles (HDDVs), and motorcycles. The EPA document, *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, provides the most up-to-date instructions for all state and local agencies involved in the preparation of mobile source inventories. The EPA makes frequent mention of the fact that a number of emission rate studies are ongoing. Therefore, frequent monitoring of the status of EPA analytical studies is suggested in order to ensure that TERF emission factors reflect the latest available emission testing and methodological information.

Highway mobile source emission factor calculation routines, outlined in the above EPA documents, are incorporated into EPA's MOBILE model, which estimates hydrocarbon, carbon monoxide, and oxides of nitrogen emission factors for gasoline and diesel-powered vehicles. The most recent version of the mobile emissions model, MOBILE4.1, was released in 1991 for the express purpose of preparing all 1990 base year emission inventories mandated by the CAAA for all areas exclusive of California, and to prepare CAAA-mandated carbon monoxide emissions inventory projections. However, MOBILE4.1 does not incorporate the effects of other CAAA provisions, such as the Tier I exhaust emissions standards for light-duty vehicles and light-duty trucks. Revisions to the MOBILE4.1 model to reflect CAAA provisions for NMHC and NO_x and additional test data are being discussed and planned for incorporation into the new MOBILE5 model. The EPA is currently seeking recommendations through a series of public workshops, and expects to release MOBILE5 in the fall of 1992. Appendix E.EM.B provides an excerpt from an EPA letter handout (dated March 5, 1992) that outlines potential MOBILE5 revisions.

Highway source emission factors for California are calculated through the use of the California Air Resources Board's own emission factor model, EMFAC. The most recent version of this model is EMFAC7EP, which incorporates the most recent California vehicle and fuel standards. All EMFAC model versions are variants of EPA's MOBILE model, and have been customized to serve the emission calculation needs of the CARB. EPA's Office of Mobile Sources is currently examining CARB in-use test data for vehicles certified to meet California's 0.7 gpm NO_x emission standard. Emission rate equations for reflecting the effects of California's low-emitting vehicle (LEV) program and inspection/maintenance credits are also being considered for inclusion in MOBILE model updates.

The California Air Resources Board uses a separate computer model to assimilate emission test data and calculate basic emission rates. This model, CALIFAC, uses the CARB's In-Use Surveillance Program and the Inspection/Maintenance Project databases (along with EPA data) to derive the basic emission factors. The basic emission factors serve as the inputs to EMFAC, which subsequently applies emission correction factors to produce final emission factors. This report lists the California highway emission factors along with the EPA national emission factors.

The EPA Procedure for Calculating Mobile Source Emissions Factors

Methodology Overview

Federal and state agency-developed emission factors for each vehicle type are derived from a four-step process[44]:

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[44] All emission rate equations and data referenced in this section come from EPA's AP-42 document and accompanying supplements, or the MOBILE4.1 model documentation, unless otherwise noted.

First, "basic exhaust emission factors", or BEFs, are estimated according to rigid federal testing procedures[45].

Second, the BEFs are adjusted with a series of multiplicative and additive correction factors that account for testing condition variances in ambient temperature and operating mode, as well as expected emission cont^Xxl device tampering rates.

Third, the BEFs are further adjusted with a composite correction factor that reflects actual vehicle characteristics and driver operating practices (For the hydrocarbon BEF, separate emission factors for evaporative and running losses are added. In addition, the hydrocarbon and carbon monoxide BEFs are adjusted for fuel volatility.). A number of these correction factors are not included in the emission factor calculations for diesel-powered vehicles and trucks due primarily to a lack of reliable data.

Fourth, consolidated BEFs are derived by weighting the adjusted BEFs according to the fraction of total miles driven for each model year, and then summing over the 25 historical model years that constitute the in-use vehicle fleet for each calendar year.[46] The equations for the consolidated emission factors are as follows:

$$EFHC = \Sigma\ TF * [(ADJBEF * SALHCF * RVPCF) + REFUEL + RNGLOS + CCEVRT]$$

$$EFCO = \Sigma\ TF * (ADJBEF * SALHCF * RVPCF)$$

$$EFNO_x = \Sigma\ TF * (ADJBEF * SALHCF)$$

where:

ADJBEF = Adjusted basic exhaust emission factor in grams per mile,
SALHCF = Composite speed, air conditioning, extra load, and trailer towing correction factor,
RVPCF = Fuel volatility correction factor,
REFUEL = Refueling hydrocarbon emission factor (g/mile),
RNGLOS = Running loss hydrocarbon emission factor (g/mile),

[45] Exhaust and evaporative emissions testing procedures for light-duty gasoline and diesel-powered vehicles are stipulated in the Code of Federal Regulations, 40 CFR Part 86, Subpart B, July 1, 1989. Testing procedures for heavy-duty gasoline and diesel-powered vehicles are stipulated in 40 CFR Part 86, Subpart N, July 1, 1989.

[46] The number of model years for the in-use fleet was expanded from 20 to 25 with the release of MOBILE4.1 (see User's Guide to MOBILE4.1, Sec. 1.1.4.).

CCERVT = Crankcase and evaporative hydrocarbon emission factor (g/mile),
TF = Fraction of total miles driven

(Summation occurs over 25 model years *i*, from n-24 to n, where *n* is the calendar year)

Methodology Details

Federal Test Procedures. The federal test procedures calculate basic exhaust and evaporative emissions for each vehicle model under specified ambient temperature and humidity levels, average speed and idle time, vehicle-miles-traveled (VMT), percent of VMT in cold-start, hot-start, and stabilized operations, trip length, and fuel volatility.[47] The gathering of exhaust emissions data is accomplished with three test segments. For Segment No. 1 (cold-start test), emissions for the first 505 seconds after engine start-up are collected. For Segment No. 2 (stabilized test), emissions are collected for the next 870 seconds. Finally, for Segment No. 3 (hot-start test), the engine is turned off for a ten-minute duration, and is restarted and run for an additional 505 seconds with emissions being collected. The EPA conducts the test cycles at both low and high altitude locations.

Basic Emission Rates. The basic emission rate is calculated by a two-step formula based on the assumption that emission rates increase linearly with respect to accumulated vehicle mileage. First, a zero-mile emission level is obtained from the in-use vehicle testing results for a specific model year and pollutant. Added to this basic emission rate is an adjustment that reflects the culmulative mileage for the model year vehicle and a per-10,000 mile emission deterioration rate. The two step formula accounts for vehicles with cumulative mileage of less than 50,000, and vehicles with mileage in excess of 50,000. The following example shows the equations and calculations used to obtain basic carbon monoxide emission rates for light-duty vehicles with a 1990 model year.

[47] The measure of volatility is *Reid Vapor Pressure*. Vapor pressure measures the level of surface pressure in pounds per square inch (psi) required to keep a liquid from vaporizing. Vehicles are tested at a certified RVP of 9.0 psi.

Example 1: Calculating Carbon Monoxide Base Emission Rates

BER Two-Step Formula

BER = ZML + (DR1 * M), for M ≤ 50,000 Miles
= ZML + (DR1 * 5) + (DR2 * (M - 5), for M ≤ 50,000 Miles

where
ZML = Zero-mile emission level in gpm
DR1 = Emission deterioration rate for vehicles with less than or equal to 50,000 miles, in gpm per 10,000 miles
DR2 = Emission deterioration rate for vehicles with more than 50,000 miles, in gpm per 10,000 miles
M = Model year cumulative mileage divided by 10,000 miles

Assumptions:

(1) CO emissions are for light-duty gasoline-powered vehicles with a 1990 model year
(2) Tests conducted at low altitude
(3) Calculate emission levels at cumulative mileage intervals of 50,000 and 100,000 miles.

50,000 Mile Emission Level:

BER = 2.813 + (0.769 * 5) = 6.658 grams per mile CO

100,000 Mile Emission Level:

BER = 2.813 + (0.769 * 5) + (0.961 * (10 - 5)) = 11.463 grams per mile CO

Data Source: U.S. Environmental Protection Agency Office of Mobile Sources, *Supplement A, Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources* (AP-42), January 1991.

Basic Emission Factor Adjustments. The basic emission factors are adjusted with a series of general and pollutant-specific correction factors to account for ambient and vehicle operation characteristics that differ from the standardized federal testing conditions. The adjusted BER equations are as follows:

$$ADJBEF_{HC} = \{[(BER * OMTCF) - OFFMTH] * PCLEFT\} + OMTTAM$$
$$ADJBEF_{CO} = (BER * OMTCF * PCLEFT) + OFFCO + OMTTAM$$
$$ADJBEF_{NOx} = (BER * OMTCF) + OMTTAM$$

The equation terms are described below:

Temperature/Operating-Mode Correction Factor (OMTCF) — This multiplicative correction factor accounts for the observation that vehicles produce a smaller quantity of emissions as they move from cold-start to stabilized and hot-start operating modes. The OMTCF is expressed as a sum of VMT-weighted linear functions of the fleet cumulative mileage for each model year, adjusted for (1) the emissions contribution attributable to each operating mode (represented as intercept and slope coefficients of the linear functions), and (2) a previously estimated temperature correction factor for each model year, pollutant, test segment, and ambient temperature (not applicable to diesel-powered vehicles and trucks). As with the basic emission rate formula, OMTCFs are calculated with a two-stage formula to reflect emissions deterioration for vehicles with cumulative mileage greater than 50,000 miles:

$$OMTCF = (TERM1 + TERM2 + TERM3) / DENOM$$

	Cumulative Mileage ≤ 50,000	Cumulative Mileage > 50,000
TERM1 =	$W * TCF_1 * [B_1 + (D_{11} * M)]$	$W * TCF_1 * [B_1 + (D_{11} * 5)] + [D_{12} * (M - 5)]$
TERM2 =	$(1-W-X) * TCF_2 * [B_2 + (D_{21} * M)]$	$(1-W-X) * TCF_2 * [B_2 + (D_{21} * 5)] + [D_{22} * (M - 5)]$
TERM3 =	$X * TCF_3 * [B_3 + (D_{31} * M)]$	$W * TCF_3 * [B_3 + (D_{31} * 5)] + [D_{32} * (M - 5)]$
DENOM =	$B_0 + (D_{01} * M)$	$B_0 + (D_{01} * 5) + [D_{02} * (M - 5)]$

where:

W =	fraction of vehicle-miles-traveled in the cold start mode
X =	fraction of vehicle-miles-traveled in the hot start mode
TCF_i =	high or low temperature correction factor (depending on ambient testing temperature) for pollutant, model year, and test segment "i"
B_i =	normalized intercept coefficient for pollutant, model year, and test segment "i"
D_{ij} =	normalized slope coefficient for pollutant, model year, test segment "i" and culmulative mileage level "j" (1 if $M \leq 5$; 2 if $M > 5$)
M =	cumulative mileage divided by 10,000 miles for each model year

The low temperature correction factor is applied when the ambient temperature is lower than the reference test temperature of 75°F. For all pollutants, test segments, and model years, *except* segment 1 (cold start) CO emissions for model years from 1980 and later, a simple exponential model is used.[48] In the case of cold start carbon monoxide OMTCFs for model years 1980 and later, two additional calculation steps are necessary. First, TCF_1 is removed from the TERM1 equation in order to eliminate the temperature correction related to the cold start mode. Second, an alternative additive version of the low temperature correction factor is calculated, the "CO offset" (**OFFCO**), which adjusts the cold start emissions for higher CO produced during the cold start mode. The CO offset is multiplied by the percent of VMT in the cold start mode (the "W" term) and adjusted for fuel volatility if the temperature is greater than 40°F. The CO offset term is then added to the basic CO exhaust emission rate factor.

The high temperature correction factor equation for pre-1980 model years, applied when the ambient temperature is higher than 75°F, is similar to that of the low temperature correction factor. For post-1979 model years, an alternative correction factor is used that incorporates a fuel volatility correction component. The combined high temperature/fuel volatility correction factor model is:

$$TRCF = e^{\{[A * (RVP - 9.0)] + [B * (T - 75.0)] + [C * (RVP - 9.0)] * (T - 75.0)\}}$$

where RVP is the fuel volatility level in psi RVP, T is the ambient temperature, and A, B, and C are estimated coefficients.

Tampering Offset (TAMPOFF) — A tampering and misfueling offset (in grams per mile) is added to the basic emission rate to reflect the assumption that a certain fraction of flHxt vehicles have had emission control components disabled or fueling components damaged. Such tampering and misfueling occurrences increase exhaust and evaporative emissions. Tampering/misfueling types tracked by the EPA include air pump disablement, catalyst removal, EGR system disablement, filler neck damage, fuel tank

[48] The equation is: TCF_{low} = EXP [TC_{ibp} * (T - 75.0)], where TC_{ibp} is a coefficient for model year *i*, pollutant *p*, and test segment *b*, at the ambient reference temperature of 75 degrees Fahrenheit; and T is the ambient temperature.

misfueled, combined filler neck damage and fuel tank misfueled, PCV system disablement, canister disconnection, and combined canister and fuel cap removal.

The EPA has conducted nationwide tampering/misfueling surveys since 1978, and data for surveys completed in 1984, 1985, and 1986 have been incorporated into the Tampering Offset calculation methodology.[49] The TAMPOFF is applied to only four vehicle types due to the lack of comprehensive data: light-duty gas-powered vehicles, light-duty gas-powered trucks (both weight categories I and II), and heavy-duty gas-powered vehicles. The TAMPOFFs for each tampering type are calculated with the following equation for calendar year $_n$:

$$TAMPOFF = TAMP_{ipm} * PEQUIP_{im} * RATE_{im}$$

where:

$TAMP_{ipm}$ = incremental increase in emissions from tampered vehicles for model year *i*, pollutant *p*, and tampering type *m*,

$PEQUIP_{im}$ = percent of the model-year *i* vehicles that are equipped with item *m* that can be tampered,

$RATE_{im}$ = percent of model-year *i* vehicles with equipment *m* that has been tampered with.

The term, TAMP, is derived from linear regression equations with cumulative mileage in 10,000-mile increments serving as the regressor or explanatory variable (the regression intercept is interpreted as the zero-mileage emission rate). The regressions yield deterioration rates up to 50,000 cumulative mileage, with mileage in the 50,000 to 130,000 range handled with an additional adjustment factor representing each tampering-type/vehicle-type combination.

The tampering-type emissions offsets are combined to form an overall composite offset with each tampering-type offset adjusted with the applicable temperature correction factor (TCF), and weighted according to the percent of accumulated vehicle-miles-traveled in

[49] Source: *Compilation of Air Pollutant Emission Factors, Volume 2 — Mobile Sources, Supplement A*, Appendix E, p. E-1. Additional survey results gathered after the publication of this document are also included in the offset estimation equations.

cold start, stabilized, and hot start modes. The tampering offset is not applicable to diesel-powered vehicles and trucks.

Inspection and Maintenance (I/M) Program Exhaust Emission Benefit (PCLEFT) — This optional emissions rate adjustment factor accounts for the hydrocarbon and CO emissions reduction benefits attributable to inspection/maintenance programs. The emission rate I/M credits are estimated using a separate EPA model, TECH IV+, which is currently being updated into a TECH 5 version that will include a NO_x benefit submodel and other revisions reflecting new I/M program data.[50] I/M program parameters for the TECH model include program start year, stringency level, first/last model years of vehicle subject to program requirements, waiver rates, compliance rates, program type, inspection frequency, vehicle type, test type, and availability of alternative I/M credits for certain technology groups. The I/M program emissions benefit is not applicable to diesel-powered vehicles and all truck types.

Methane Offset (OFFMTH) — This grams-per-mile offset is used to adjust the hydrocarbon basic emission rate when nonmethane HC emissions are estimated. Model-year offsets are calculated for each of the three test segments.

The BEFs are further adjusted by a *composite speed, air conditioning, extra load, and trailer towing correction factor* (**SALHCF**), with the following form:

$$SALHCF_{HC,CO} = SCF * ACCF * XLCF * TWCF$$

and

$$SALHCF_{NOx} = SCF * ACCF * XLCF * TWCF * HCF$$

Each of the equation terms are described below.

Speed Correction Factor (SCF) — Federal test procedures call for the collection of

[50] The only NO_x reduction benefit currently modeled is from a reduction in tampering rates resulting from I/M programs. EPA analysis of transient I/M test (IM240) data indicates that additional emissions reductions result from NO_x cutpoint I/M programs. (See Appendix E.EM.C, List of Potential Revisions for MOBILE5, Item No. 3-5.)

basic exhaust emissions at an average speed of 19.6 miles per hour. To account for higher and lower average speeds exhibited by in-use vehicles, correction factors for three speed ranges were calculated using linear regression.[51] The ranges are low speeds (2.5 to 19.6 mph), moderate speeds (19.6 to 48 mph), and high speeds (48 to 65 mph). The speed correction factors are delineated by model year group, technology, pollutant, and emission level (i.e., normal vs high emitters), but are weighted and combined into one basic speed correction factor applied to base emission rates.

Air Conditioning Correction Factor (ACCF) — The air conditioning correction accounts for the impact of air conditioner operations on pollutant emission types at various ambient temperatures for each model year (This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles). The correction factor is expressed as a linear relationship to temperature, adjusted with a multiplicative factor that reflects the fraction of AC units in use. The air conditioning correction factor equation has the following form:

$$ACCF = V * U * [A + (B * (T - 75) - 1)] + 1$$

where:

V	=	fraction of vehicles equipped with AC,
U	=	faction of AC units in use = (DI - 70)/10, where DI is the temperature discomfort index,
DI	=	((DB + WB)*0.4) + 15,
DB	=	dry bulb temperature,
WB	=	wet bulb temperature,
A	=	intercept coefficient,
B	=	slope coefficient,
T	=	ambient temperature.

Extra Load Correction Factor (XLCF) — This correction factor incorporates the impacts on emissions of an increase of 500 pounds to the test standard vehicle weight, which includes a driver and one passenger. (This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks,

[51] The speed correction factors are normalized to the speed associated with a weighted sum of the cold start and hot start mode VMT fractions. The SCFs were derived from multiplicative linear regression equations.

and heavy-duty diesel-powered vehicles). The extra load correction factor equation is:

$$XLCF = [(XLC - 1.0) * U] + 1.0$$

where XLC is a factor coefficient for each model year and pollutant,[52] and U is the fraction of vehicle-miles-traveled with the extra load.

Trailer Towing Correction Factor (TWCF) — The trailer towing correction factor, which accounts for the effect on emissions of an extra trailer weight of 1,000 pounds, is calculated with an equation that is identical in structure to that used for calculating the extra load correction factor:

$$TTCF = [(TTC - 1.0) * U] + 1.0$$

where TTC is a factor coefficient for each model year and pollutant,[53] and U is the fraction of vehicle-miles-traveled with the extra trailer load.

This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles.

NO_x Humidity Correction Factor (HCF) — NO_x emission factors are normalized to 75 grains of water per pound of dry air. To achieve this normalization given various humidity levels, a multiplicative correction factor is applied to the composite NO_x SALHCF. The following HCF equation is applicable for all model years:

$$HCF = 1.0 - 0.0038 * (H - 75.0)$$

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[52] For example, XLC varies from 1.0786 to 1.0455 for low altitude light-duty gas-powered vehicles, depending on the model year. The XLC range for CO is 1.3058 to 1.1347, and the range for NO_x is 1.0719 to 0.9535.

[53] For example, TTC varies from 1.7288 to 1.2614 for low altitude light-duty gas-powered vehicles, depending on the model year. The TTC range for CO is 1.8940 to 3.9722, and the range for NO_x is 1.1184 to 1.3875.

where H = humidity level in grains of water/lb. dry air. This humidity correction factor is not applicable to heavy-duty diesel-powered trucks.

Data obtained from monitoring emissions at different Reid Vapor Pressure levels shows that hydrocarbon and CO emissions increase as volatility increases. For exhaust emissions at fuel volatility levels different from the test certification RVP of 9.0 psi, and when the ambient temperature is greater than 40°F, a *fuel volatility correction factor* (**RVPCF**) is applied to the basic hydrocarbon and CO emission factors.

There are three fuel volatility correction factor equations, with the selection based on vehicle model year and ambient temperature. For model years 1971 through 1979 (and at all temperatures), the RVPCFs for hydrocarbons and CO are based on a simple linear extrapolation model[54]:

$$RVPCF_{HC} = (0.56222 + 0.012512 * RVP) / 0.67483$$
$$RVPCF_{CO} = (7.1656 + 0.33413 * RVP) / 10.17277$$

For post-1979 model years and at a temperature greater than 75°F, the RVPCF is incorporated with the high temperature correction factor discussed in the Temperature/Operating-Mode Correction Factor (OMTCF) section.

For post-1979 model years and at a temperature in the 40°F to 75°F range, a two-step correction procedure is used. First, a RVP correction factor evaluated at 75°F is obtained using the combined high temperature/fuel volatility model. The resulting RVPCF is then used as an input to the following equation:

$$RVPCF = = 1.0 + \{[(RVPCF_{75°F} - 1.0) * [(T - 40.0) / 35.0)]\}$$

where T is the ambient temperature in the range of 40°F to 75°F.

The post-1979 model year fuel volatility correction factors are also disaggregated based on test

[54] The denominator value represents the numerator evaluated at the certification Reid Vapor Pressure of 9 psi.

segment and fuel delivery system (carbureted, throttle-body fuel injection, and multi-point fuel injection).

Evaporative Emissions Factors. In addition to the basic exhaust emission factors for hydrocarbons, evaporative emissions from carburetion and fuel tank systems must be included in the consolidated hydrocarbon emission factors. The EPA models five types of HC evaporative emissions: *crankcase*, *hot soak* (evaporative emissions occurring after a trip), *diurnal* (release of fuel vapors due to an expansion of the air-fuel mixture in a partially filled fuel tank when the ambient temperature increases), *running loss* (emission generated during vehicle operation), and *refueling* (displacement of fuel vapor from the tank during refueling, and spillage). Evaporative emission factors are not applicable to diesel-powered vehicles and trucks.

Crankcase, hot soak, and diurnal emissions (CCERVT) are calculated with one equation:

$$CCERVT = [(HS + TAMPHS) * TPD_j] + [(DI + TAMPDI) / MPD_j] + (CC + TAMPCC)$$

where:

HS = Hot soak emission rates in grams per trip, corrected for temperature and RVP fuel volatility,
TAMPHS = Excess hot soak emission rates due to tampering, corrected for RVP fuel volatility,
TPD_j = Trips per day for age *j* vehicles,
DI = Diurnal emission rates in grams, corrected for temperature and fuel volatility,
TAMPDI = Excess diurnal emission rates due to tampering, corrected for temperature and RVP fuel volatility,
MPD_j = Miles-per-day values for age *j* vehicles,
CC = Crankcase emissions in grams per mile,
TAMPCC = Excess crankcase emissions due to tampering.

Running loss emissions (RNGLOS) are calculated in a similar manner: loss emission rates in grams per mile are corrected for temperature and RVP fuel volatility (RULOSS), and then are added to the excess running loss emissions ascribed to tampering (TAMPRL).

Refueling loss emissions (REFUEL) are calculated by adding together the displacement fueling losses corrected for RVP fuel volatility (DISP) and an average spillage rate (SPILL), both measured in grams per gallon. This figure is divided by the road fuel economy rate (ROADFE), measured in gallons per mile.

All evaporative emission factor components are modeled as a function of the ambient temperature and fuel volatility. Running losses are modeled with two additional variables — average speed and trip duration. Refueling losses are modeled with one additional variable, defined as the temperature difference between the dispensed fuel and the residual tank fuel. EPA has also recently incorporated into its modeling the results of inspection/maintenance program testing for fuel/evaporative control system leaks and the capability of the carbon canister to properly purge vapors. The impact of "pressure and purge" problems on hot soak, diurnal, and running loss emission rates are reflected in MOBILE4.1.[55]

Calculation of Travel Weighting Fractions. After emission factor corrections have been applied to the basic exhaust emission factors, and hydrocarbon evaporative and exhaust emission factor components have been added together, travel weighting fractions (TFs) are applied for deriving the final consolidated emission factors.

The TFs represent model-year proportions of total vehicle-miles-traveled for each vehicle type. They are calculated with the use of an annual mileage accumulation rate distribution, a registration distribution[56], and a diesel sales distribution (applicable to all vehicle types *except* heavy-duty gas-powered vehicles and heavy-duty gas-powered trucks).

Example 2 shows the calculation of a consolidated hydrocarbon emission factor for model-year 1988 light-duty gasoline-powered vehicles.

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[55] User's Guide to MOBILE4.1, Sec. 1.1.6, p. 1-12.

[56] The EPA collects July 1 registration data, which is adjusted to reflect registration activity as of January 1. Vehicle sales are assumed to be uniform throughout the year.

Example 2: Calculating a Consolidated Hydrocarbon Emission Factor for Light-Duty Gasoline Powered Vehicles

Assumptions:

(1) HC emissions are for light-duty gasoline-powered vehicles with a 1988 evaluation calendar year, 20-model-year vehicle window, with testing conducted at low altitude.
(2) Daily minimum and maximum ambient temperatures are 60°F and 80°F, respectively.
(3) All conditions match the basic federal test conditions (i.e., air conditioning, extra load, trailer towing, humidity levels, and other basic exhaust emission correction factors have no affect on the calculations, and are therefore set to 1.0).
(4) No inspection/maintenance or anti-tampering programs are assumed.
(5) Certification fuel volatility of 9.0 psi is assumed.
(6) Total HC emissions are calculated at an average speed of 30 miles per hour.
(7) Percentages of vehicle-miles-traveled in the cold start, stabilized, and hot start operating modes are 40%, 30%, and 30%, respectively.
(8) Basic HC emission factors are adjusted for the effects of tampering.
(9) Methane is included in HC calculations.

Consolidated Emission Factor Equation

$$CONBEFHC_n = \sum TF_i * [(BEF * SALHCF) + REFUEL + RNGLOS + CCEVERT]$$

where:

$CONBEFHC_n$= Consolidated Hydrocarbon Emission Factor for calendar year *n*,
TF_i= Travel Weighting Fraction for Model Year *i*,
BEF= Adjusted Hydrocarbon Exhaust Emission Factor,
SALHCF= Speed Correction Factor,
REFUEL= Refueling HC Emission Factor,
RNGLOS= Running Loss HC Emission Factor,
CCEVERT= Crankcase and Evaporative HC Emission Factor.

Data Table

Model Year (i)	TF	BEF (gpm)	SALHCF (gpm)	REFUEL (gpm)	RNGLOS (gpm)	CCEVERT (gpm)	$CONBEFHC_n$: TF*(BEF*SALHCF)+ REFUEL+RNGLOS+ CCEVERT
1988*	0.0307	0.415	0.730	0.243	0.254	0.147	0.029
1987	0.1209	0.472	0.730	0.244	0.254	0.155	0.121
1986	0.1102	0.577	0.730	0.248	0.264	0.177	0.122
1985	0.0985	0.688	0.730	0.255	0.275	0.215	0.123
1984	0.0879	0.808	0.730	0.262	0.285	0.258	0.123
1983	0.0783	0.938	0.730	0.266	0.294	0.300	0.121
1982	0.0679	1.257	0.730	0.263	0.303	0.345	0.124
1981	0.0598	1.480	0.730	0.272	0.311	0.390	0.123
1980	0.0537	2.507	0.730	0.291	0.551	0.576	0.174
1979	0.0481	4.941	0.730	0.335	0.559	0.620	0.246
1978	0.0427	5.253	0.730	0.339	0.566	0.665	0.231
1977	0.0381	5.505	0.730	0.370	0.650	1.515	0.250
1976	0.0328	5.807	0.717	0.387	0.656	1.593	0.223
1975	0.0280	6.043	0.717	0.427	0.662	1.674	0.199
1974	0.0237	5.844	0.706	0.473	0.668	1.759	0.167
1973	0.0197	5.945	0.706	0.473	0.673	1.846	0.142
1972	0.0167	5.906	0.795	0.465	0.679	1.937	0.130
1971	0.0134	9.089	0.798	0.469	0.683	2.726	0.149
1970	0.0104	9.296	0.811	0.451	0.715	3.556	0.128
1969	0.0185	8.856	0.781	0.454	0.684	3.660	0.217

$$\sum_{I=n-19}^{n} = \mathbf{3.142}$$

Data Source: U.S. Environmental Protection Agency Office of Mobile Sources, *Supplement A, Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources* (AP-42), January 1991, Appendix G.

DAC Highway Mobile Source Emissions Factor Methodology

Carbon Monoxide, Volatile Organic Compound, and Nitrogen Oxide Emission Factors: Conventional Vehicles

DAC calculated VOC, CO, and NO_x emission factors for highway sources using a two-step methodology. First, MOBILE4.1 model runs were conducted to obtain baseline emission factor forecasts. Second, off-line adjustments to the baseline emission factor forecasts were made to reflect the new CAAA regulations that have not been incorporated into the MOBILE4.1 solution algorithms. Table F-35 provides the adjusted MOBILE4.1 emission factors for conventional vehicle types.[57] The vehicle types consist of LDGVs, LDGTs (combined Class 1 and 2), HDGVs, LDDVs, LDDTs, and HDDVs. Table F-36 provides the EPA definitions for each of the vehicle-type categories.

Emission factors for heavy-duty diesel-powered vehicles (HDDVs) should be used for diesel-powered buses. This is recommended by the EPA, which cites the similarities between the two vehicles types as well as the lack of comprehensive emission testing for buses (note that the EPA bus emission factors are reported in grams per mile as opposed to the TERF lbs./1,000 gal. specification). Efforts at improving the EPA bus emission data base are ongoing because of concern that the HDDV emission factors do not accurately reflect in-use characteristics of buses in urban areas.

A complication results in trying to combine the EPA vehicle-type emission factors into the freight truck category designated in the TSCDR. As shown in Table F-36, the EPA vehicle-type categories for heavy-duty vehicles and trucks do not correspond to the weight categories used by either the TIUS or the FHWA Highway statistics report. The EPA uses a weight cut-off of 8,500 pounds GVW for its heavy-duty classifications. Trucks with an average weight greater than 10,000 pounds are classified as medium, light-heavy, or heavy-heavy by the TIUS. There is no weighting method that proves satisfactory for normalizing the EPA emission factors to the FHWA weight categories. Therefore, we recommend that the EPA emission factors for gasoline and diesel heavy-duty vehicles (HDGVs and HDDVs) be used as the TERF freight truck emission

[57] Five-year interval forecasts were interpolated to produce year-to-year emission factors.

factors.

Table F-35. Adjusted MOBILE4.1 Emission Factors

YEAR	LDGV			LDGT			HDGV		
	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx
1990	2.09	20.63	1.43	4.20	29.16	1.93	10.84	101.36	5.82
1991	2.33	18.67	1.16	3.84	26.16	1.81	9.90	90.91	5.61
1992	2.59	16.89	0.94	3.51	23.47	1.70	9.05	81.53	5.41
1993	2.89	15.28	0.76	3.21	21.06	1.59	8.27	73.12	5.21
1994	3.22	13.83	0.62	2.93	18.89	1.49	7.55	65.58	5.02
1995	3.59	12.51	0.50	2.68	16.95	1.40	6.90	58.82	4.84
1996	2.98	11.88	0.50	2.54	15.72	1.35	6.45	52.74	4.73
1997	2.47	11.29	0.50	2.41	14.58	1.29	6.04	47.28	4.63
1998	2.05	10.72	0.50	2.28	13.53	1.24	5.65	42.39	4.53
1999	1.70	10.18	0.50	2.16	12.55	1.20	5.28	38.01	4.43
2000	1.41	9.67	0.50	2.05	11.64	1.15	4.94	34.08	4.33
2001	1.34	9.27	0.50	1.96	11.01	1.13	4.66	31.50	4.29
2002	1.27	8.88	0.50	1.87	10.41	1.10	4.40	29.11	4.26
2003	1.21	8.51	0.50	1.79	9.85	1.08	4.15	26.90	4.22
2004	1.15	8.15	0.50	1.71	9.31	1.06	3.92	24.86	4.19
2005	1.09	7.81	0.50	1.63	8.81	1.04	3.70	22.98	4.15
2006	1.09	7.78	0.50	1.62	8.75	1.04	3.66	22.33	4.13
2007	1.09	7.76	0.50	1.62	8.69	1.03	3.61	21.71	4.11
2008	1.08	7.73	0.50	1.61	8.63	1.03	3.57	21.10	4.10
2009	1.08	7.71	0.50	1.61	8.58	1.02	3.53	20.51	4.08
2010	1.08	7.68	0.50	1.60	8.52	1.02	3.49	19.93	4.06
2011	1.08	7.67	0.50	1.60	8.52	1.02	3.49	19.87	4.05
2012	1.08	7.67	0.50	1.60	8.52	1.02	3.49	19.81	4.04
2013	1.08	7.66	0.50	1.60	8.52	1.01	3.48	19.76	4.04
2014	1.08	7.66	0.50	1.60	8.52	1.01	3.48	19.70	4.03
2015	1.08	7.65	0.50	1.60	8.52	1.01	3.48	19.64	4.02
2016	1.08	7.65	0.50	1.60	8.52	1.01	3.48	19.64	4.02
2017	1.08	7.65	0.50	1.60	8.51	1.01	3.48	19.64	4.02
2018	1.08	7.65	0.50	1.60	8.51	1.01	3.48	19.63	4.02
2019	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2020	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2025	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2030	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02

Adjustment notation:

(1) LDGV's: Adjust VOC downward by 0.14 gpm for 1995 through 2030 to reflect decrease in exhause emission standard from 0.39 gpm to 0.25 gpm.

(2) LDGV'S: Assume NO_x emissions of 0.50 gpm beginning in 1995 and forward to reflect new/in-use standard fo 0.40 gpm and 0.6 gpm 100,000-mile certification standard.

(3) LDGV's: CO emission factors include new cold temperature standards.

(4) LDDV's: MOBILE4.1 emission factors are below standards; therefore no adjustments to LDDV emission factors are necessary.

(5) HDDV's: MOBILE4.1 incorporates 1994 HC and CO standards. NO_x standard was lowered, but MOBILE4.1 produces forcast emission factors at about the same level as the standards.

Table F-35. (Continued)

YEAR	LDDV			LDDT			HDDV		
	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx
1990	0.71	1.67	1.63	0.96	1.90	1.87	2.84	13.03	19.45
1991	0.72	1.68	1.63	0.97	1.91	1.86	2.73	12.75	17.72
1992	0.73	1.70	1.64	0.98	1.91	1.85	2.62	12.49	16.14
1993	0.74	1.71	1.64	1.00	1.92	1.85	2.52	12.22	14.70
1994	0.75	1.73	1.65	1.01	1.92	1.84	2.42	11.96	13.39
1995	0.76	1.74	1.65	1.02	1.93	1.83	2.32	11.71	12.20
1996	0.74	1.71	1.59	0.98	1.89	1.76	2.28	11.61	11.56
1997	0.71	1.68	1.53	0.94	1.85	1.69	2.25	11.51	10.94
1998	0.69	1.65	1.48	0.91	1.81	1.62	2.22	11.41	10.37
1999	0.67	1.63	1.42	0.87	1.78	1.56	2.18	11.31	9.82
2000	0.65	1.60	1.37	0.84	1.74	1.50	2.15	11.21	9.30
2001	0.62	1.57	1.32	0.80	1.70	1.44	2.14	11.18	9.11
2002	0.59	1.53	1.27	0.76	1.66	1.39	2.13	11.16	8.92
2003	0.57	1.50	1.22	0.73	1.62	1.33	2.13	11.13	8.73
2004	0.54	1.47	1.17	0.69	1.59	1.28	2.12	11.11	8.55
2005	0.52	1.44	1.13	0.66	1.55	1.23	2.11	11.08	8.37
2006	0.52	1.44	1.12	0.66	1.55	1.22	2.11	11.07	8.32
2007	0.51	1.43	1.11	0.66	1.55	1.21	2.11	11.07	8.27
2008	0.51	1.43	1.09	0.65	1.54	1.21	2.10	11.06	8.21
2009	0.50	1.42	1.08	0.65	1.54	1.20	2.10	11.06	8.16
2010	0.50	1.42	1.07	0.65	1.54	1.19	2.10	11.05	8.11
2011	0.50	1.42	1.07	0.65	1.54	1.19	2.10	11.05	8.10
2012	0.51	1.43	1.08	0.65	1.54	1.19	2.10	11.05	8.09
2013	0.51	1.43	1.08	0.66	1.54	1.19	2.10	11.04	8.07
2014	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.06
2015	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.05
2016	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.05
2017	0.52	1.44	1.09	0.67	1.55	1.20	2.10	11.04	8.05
2018	0.52	1.44	1.09	0.67	1.55	1.20	2.10	11.04	8.05
2019	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2020	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2025	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2030	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05

Adjustment notation:

(1) LDGV's: Adjust VOC downward by 0.14 gpm for 1995 through 2030 to reflect decrease in exhause emission standard from 0.39 gpm to 0.25 gpm.

(2) LDGV'S: Assume NO_x emissions of 0.50 gpm beginning in 1995 and forward to reflect new/in-use standard fo 0.40 gpm and 0.6 gpm 100,000-mile certification standard.

(3) LDGV's: CO emission factors include new cold temperature standards.

(4) LDDV's: MOBILE4.1 emission factors are below standards; therefore no adjustments to LDDV emission factors are necessary.

(5) HDDV's: MOBILE4.1 incorporates 1994 HC and CO standards. NO_x standard was lowered, but MOBILE4.1 produces forcast emission factors at about the same level as the standards.

Table F-36. EPA Highway Vehicle Classification Categories and Definitions

Vehicle-Type Classification Category	EPA Category Definition
Light-duty gasoline-powered vehicles (LDGVs)	Gas-fueled vehicle primarily designed for passenger transportation with a design capacity of 12 persons or less.
Light-duty gasoline-powered trucks, Class 1 (LDGT1s)	Diesel-fueled vehicle primarily designed for passenger transportation with a design capacity of 12 persons or less.
Light-duty gasoline-powered trucks, Class 2 (LDGT2s)	Gas-fueled vehicle with a Gross Vehicle Weight (GVW) between 6,001 and 8,500 pounds.
Heavy-duty gasoline-powered vehicles (HDGVs)	Gas-fueled vehicle designed to carry property, with a Gross Vehicle Weight (GVW) over 8,500 pounds, or; any vehicle designated for passenger transportation having a design capacity of more than 12 persons.
Light-duty diesel-powered vehicles (LDDVs)	Any diesel-fueled vehicle designated primarily for passenger transportation and having a design capacity of 12 persons or less.
Light-duty diesel-powered trucks (LDDTs)	Any diesel-fueled vehicle designed primarily for property transportation, and rated at 8,500 lbs. GVW or less.
Heavy-duty diesel-powered vehicles (HDDVs)	Any diesel-fueled vehicle designed primarily for property transportation, and rated at more than 8,500 lbs. GVW.

Source: U.S. Environmental Protection Agency, *Supplement A to AP-42 Volume II*, January 1991.

DAC obtained the MOBILE4.1 model from the EPA, and used the model to calculate national CO, NO_x, and VOC emission factors to the year 2020 (the last MOBILE4.1 forecast year) using a scenario-based input data set. EPA staff make the assumption that emission factors remain relatively stable after 2010.[58] Therefore, emission factors for 2020 are used for the subsequent forecast years. As already noted, the MOBILE4.1 emission factors do not reflect many new CAAA standards that should affect emission rates after 1993. Post hoc adjustments need to be made to account for new vehicle standards, in-use standards, and other CAAA emission control requirements if the forecasted emission factors exceed the standards in any year. It is important to note that any emission factor adjustments are based on gross assumptions, with the resulting emission factors considered to be interim in nature.

The MOBILE4.1 input data set consists of a series of user-specified control flags, data inputs common to all emission scenarios, and data inputs specific to an individual scenario. In addition to regulating program execution and input/output stream formatting, the control flags determine

[58] Personal communication with Lois Platte, EPA Motor Vehicle Emission Laboratory, Ann Arbor, Michigan, June 26, 1992.

model actions such as the use of emission control device tampering rates, average vehicle speed selection, mileage accumulation rate selection, VMT mix selection, I/M program impact, ambient temperature selection, and many other factors. Control flags specifying EPA default values and national averages were included to the maximum extent.

The greatest difficulty in developing the MOBILE4.1 data set was accounting for the impact of inspection/maintenance programs. MOBILE4.1 was not designed with the capability for estimating national average I/M program impacts. The I/M program data set record must be specified according to local I/M program attributes. Such program attributes are highly customized to met locale-specific implementation needs, and therefore cannot be formulated into a national average I/M program. Further complications result from the fact that I/M programs are not required nor implemented in many areas of the country, and new EPA regulations have resulted in greater complexity for existing and planned programs.

To account for the effects of I/M and anti-tampering programs on emission factors, a model-run interpolation method was used. Inspection and maintenance programs are required for 162 ozone areas based on CAAA regulations. A data set was created that included parameters and data for an "enhanced" I/M model program (required for serious, severe, and extreme ozone nonattainment areas) as outlined in the EPA's Notice of Proposed Rulemaking.[59] An enhanced I/M program includes annual centralized testing for light-duty vehicles and trucks, and include such tests as the transient IM240 exhaust emission test, the transient purge test, the pressure test, the two-speed exhaust test, and the idle exhaust test. The EPA estimates that such an I/M program could reduce vehicle VOC emissions by 28 percent, CO emissions by 30 percent, and NO_x emissions by 9 percent.[60]

A MOBILE4.1 emission factor based on national imposition of enhanced I/M programs is assumed to represent an upper bound for vehicle emissions. To account for areas that have no I/M and anti-tampering programs, a MOBILE4.1 data set was created that excluded operating I/M and anti-tampering programs. Separate sets of emission factors were generated from MOBILE4.1 model runs employing each data set. Composite emission factors were derived by taking the

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59 EPA Notice of Proposed Rulemaking, "Vehicle Inspection and Maintenance Requirements for State Implementation Plans," 40 CFR Part 51, July 9, 1992.

60 Ibid., section II.

arithmetic average of the two emission factor sets. Ideally, the composite emission factor set should be calculated as a weighted average, using vehicle mileage data for each type of ozone nonattainment area and I/M program type. Such a procedure is complex and time-consuming (and perhaps not doable because of the flexibility afforded to the states for choosing I/M program elements), and could not be attempted given the resources available for this subtask. The simple arithmetic average approach, while producing somewhat arbitrary results, is superior to assuming a universally-applied I/M program for all areas of the country. Such an assumption yields overly-optimistic emission factor reductions.

Sulfur Dioxide and Carbon Dioxide Emission Factors: Conventional Vehicles

The EPA does not regularly monitor and report carbon dioxide and sulfur dioxide emissions for highway mobile sources. The relatively small amounts of SO_2 emitted by trucks and cars are quickly converted to sulfuric acid, and therefore do not represent a significant air pollution hazard. Although the EPA produced SO_2 measurement procedures in the early 1980's, the Agency has not published SO_2 emission factors.[61]

The SO_2 and CO_2 emission factors to be used in TERF come from the Argonne National Laboratory's Transportation Energy and Emissions model (TEEMS). Table F-37 provides the emission factors produced for the DOE Office of Environmental Analysis as part of data input to the NESEAM model.[62] These emission factors include the effects of CAAA emission standards, and are forecasted to the year 2030.

The TEEMS/NEASAM emission factors were reported in pounds of emissions per million Btu. To convert the emission factors to a grams-per-mile equivalent, the following formula was used:

$$EF_{gpm} = EF_{ppBtu} \times 57.9549 / MPG_c$$

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[61] Personal communication with Penny Carey, EPA Motor Vehicle Emissions Laboratory, Ann Arbor, Michigan, August 4, 1992.

[62] See, *Decision Analysis Corporation, Mobile Source Air Emissions Regulations and Inventories, Draft Report*, (Prepared for the EIA Energy Demand Analysis Branch under Contract No. DE-AC01-92EI21946, July 15, 1992).

where:

EF_{gpm} = Emission factor in grams per mile,
EF_{ppBtu} = TEEMS emission factor in pounds per million Btu,
MPG = TEEMS forecasted fuel economy for category c vehicles in gallons per mile,

The TEEMS model does not report CO_2 emission factors for heavy-duty diesel trucks and heavy-duty gasoline vehicles.

Table F-37. LDV Sulfur Dioxide and Carbon Dioxide Emission Factors (Grams/Mile)

YEAR	SO2					CO2		
	HDDT	HDGV	LDDT	LDGT	LDGV	LDDT	LDGT	LDGV
1990	1.3892	0.3890	0.5156	0.0968	0.0846	178.2613	178.2613	98.0075
1991	1.0592	0.3913	0.3898	0.0957	0.0827	176.1273	176.1273	96.8204
1992	0.8075	0.3937	0.2947	0.0947	0.0809	174.0188	174.0188	95.6477
1993	0.6157	0.3961	0.2228	0.0937	0.0791	171.9355	171.9355	94.4891
1994	0.4694	0.3985	0.1685	0.0927	0.0773	169.8771	169.8771	93.3446
1995	0.3579	0.4009	0.1274	0.0917	0.0756	167.8435	167.8435	92.2140
1996	0.3586	0.3987	0.1263	0.0913	0.0747	167.1971	167.1971	91.5909
1997	0.3593	0.3966	0.1253	0.0910	0.0738	166.5531	166.5531	90.9719
1998	0.3600	0.3945	0.1243	0.0906	0.0729	165.9117	165.9117	90.3572
1999	0.3607	0.3924	0.1233	0.0902	0.0721	165.2728	165.2728	89.7466
2000	0.3615	0.3904	0.1222	0.0898	0.0712	164.6363	164.6363	89.1402
2001	0.3540	0.3895	0.1206	0.0887	0.0705	162.6740	162.6740	87.8486
2002	0.3467	0.3886	0.1190	0.0875	0.0698	160.7351	160.7351	86.5757
2003	0.3396	0.3877	0.1174	0.0863	0.0691	158.8193	158.8193	85.3213
2004	0.3326	0.3869	0.1158	0.0852	0.0684	156.9264	156.9264	84.0850
2005	0.3258	0.3860	0.1143	0.0841	0.0678	155.0560	155.0560	82.8667
2006	0.3191	0.3851	0.1127	0.0830	0.0671	153.2080	153.2080	81.6660
2007	0.3125	0.3843	0.1112	0.0819	0.0664	151.3819	151.3819	80.4827
2008	0.3061	0.3834	0.1097	0.0808	0.0658	149.5776	149.5776	79.3166
2009	0.2998	0.3825	0.1082	0.0797	0.0651	147.7948	147.7948	78.1673
2010	0.2936	0.3817	0.1068	0.0787	0.0645	146.0333	146.0333	77.0347
2020	0.31806	0.413476	0.10608	0.076857	0.063419	146.0333	146.0333	77.03472

2030	0.31806	0.413476	0.10608	0.076857	0.063419	146.0333	146.0333	77.03472

Source: Argonne National Laboratory Transportation Energy and Emissions Modeling System (TEEMS), Model run ANL-90N.

Total Carbon Emission Factors: Conventional Vehicles

The calculation of total carbon emission factors for gasoline and diesel fuels is straightforward. The following formulae are used to produce carbon emission factors in grams per mile:

$$CarbonEF_{gas} = 0.866 * (2791.0/MPG)$$
$$CarbonEF_{diesel} = 0.858 * (3192.0/MPG)$$

The constant values of 0.886 and 0.858 are the carbon mass fractions of gasoline and diesel, respectively.[63] The constant values of 2791 and 3192 are the densities for gasoline and diesel fuel, and were obtained from EIA's *1989 International Energy Annual* (February 1991).[64] To obtain the carbon emission factors, the endogenously calculated TERF miles-per-gallon estimates (MPG) will need to be passed to the emissions module. As currently configured, MPG forecasts will be determined using the Argonne National Laboratory TEEMS methodology, which uses lagged MPG and other economic variables.

Using Argonne's ANL-90N TEEMS run as an example, automobile and diesel freight truck carbon emission factors for 1990, 1995, 2005 and 2010 are shown below (MPG figures are in parentheses).

Year	Emission Factor, g/mile (MPG)	
	Automobiles	Light Trucks
1990	120.8 (20.0)	464.2 (5.9)
1995	119.5 (20.7)	449.0 (6.1)
2000	116.1 (21.3)	427.9 (6.4)
2005	107.5 (23.0)	421.3 (6.5)
2010	89.3 (27.7)	415.0 (6.6)

[63] This value is reported by the EPA. See, Frank Black, 3rd U.S. - Dutch International Symposium, "Atmospheric Ozone Research and Its Policy Implications" (May 9-13, 1988, Nijmegen, the Netherlands), or the DeLuchi/Argonne greenhouse gas study.

[64] Appendix F, Volume, Weight, and Monetary Conversions, p. 149.

Emission Factors: Alternative Fuel Vehicles

The calculation of emission factors for alternative fuel vehicles (AFVs) is subjective in nature, and depends on emissions data from test vehicles and the likely capability of AFVs to meet new CAAA clean-fuel vehicle emission standards. Emission factors for NMHC, CO, NO_x, and CO_2 were provided to Argonne National Laboratory in a greenhouse gas emission study conducted jointly by the Institute of Transportation Studies at the University of California-Davis, and the Center for Energy and Environmental Studies at Princeton University.[65] Table F-38 lists these AFV emission factors for light-duty vehicles (LDV's) and heavy-duty vehicles, such as freight trucks and buses (HDV's), powered by the following fuels: methanol (100%), compressed natural gas, hydrogen, ethanol (100%), and liquid petroleum gas (LPG). Electric vehicles are considered to emit no pollutants other than a small quantity of chlorofluorocarbons (CFCs).

Table F-38. Lifetime Average Emission Factors for Alternative Fuel Vehicles (Grams per Mile)

	Methanol*		**Natural Gas**		**Hydrogen**		**Ethanol***		**LPG**	
	LDV	**HDV**	**LDV**	**HDV**	**LDV**	**HDV**	**LDV**	**HDV**	**LDV**	**HDV**
NMHC	0.56	4.86	0.22	0.60	0.04	0.04	0.38	4.42	0.22	1.80
CO	7.21	13.00	3.60	7.00	0.70	0.10	7.21	13.00	5.50	9.00
NO_x	0.45	8.05	0.45	8.05	0.45	8.05	0.45	8.05	0.45	8.05
CO_2	214.64	1495.41	195.51	1463.94	0.00	0.00	0.00	0.00	226.72	1695.56

*Emission factors are for M100 (100% methanol) and 100% ethanol fuels.

[65] Mark A. DeLuchi, University of California Institute of Transportation Studies, *Emissions of Greenhouse Gases From the Use of Transportation Fuels and Electricity* (for the Argonne National Laboratory Center for Transportation Research, June 26, 1991).

OFF-HIGHWAY SOURCES EMISSIONS FACTORS

Off-Highway Mobile Source Emission Factor Information Sources

The following documents were used to compile off-highway emission factors or supply background information on emission factor calculation methods:

- *Compilation of Air Pollutant Emission Factors - Volume II: Mobile Sources* (AP-42, Fourth Edition, September 1985)

- *Nonroad Engine and Vehicle Emission Study—Report*, EPA 460/3-91-02 (November 1991)

- *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachments A through J (This EPA memorandum supersedes the mobile source emission inventory preparation instructions contained in *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, which is currently being revised)

- *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, EPA-450/4-81-026d (revised), (July 1992).

The document, *Compilation of Air Pollutant Emission Factors - Volume II,* reports all data and emission factor calculation algorithms for both highway and off-highway emission sources. Section II outlines the emission calculation methodologies for off-highway mobile sources, including aircraft, railroad locomotives, inboard-powered vessels, outboard-powered vessels, small general utility engines, agricultural equipment, heavy duty construction equipment, and snowmobiles. The EPA is planning to issue an updated version of the AP-42 document, although no estimate has been given as to the release date. The EPA's *Nonroad Engine and Vehicle Emission Study*, which was mandated as part of CAAA Section 213(a), provides new or updated emission inventory data and emission factors for ten nonroad equipment categories including commercial marine vessels, which is one of the transport modes to be modeled in TERF.[66] The Nonroad Emission study targeted 24 nonattainment areas as well as national totals. The document, *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, provides state and local agencies with detailed guidance on the preparation of highway and off-highway mobile source emission inventories. The off-highway emission factors contained in this section were derived either directly from the inventory preparation procedure report, or were calculated using data tables contained therein.

Railroad Locomotive Emission Factors

Table F-39 lists the railroad locomotive emission factors to be incorporated into the TERF model. Emission factors for CO, NO_x, SO_2 and HC are included.[67] Note that the EPA does not measure separately the volatile component of total hydrocarbons. Also, no distinction is made between freight and passenger locomotives because both travel modes use the same locomotive technology types. These emission factors are reported in the July 1992 edition of *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*. They are considered default values for fleet-average line haul locomotives.[68] Line haul locomotives represent the largest segment of the locomotive population, and include all locomotives used for freight and passenger service. As of mid-1991, 9,708 line haul locomotives were in service.[69] Yard locomotives are used for moving railcars within a rail switchyard, and are considered a negligible source of emissions. As of mid-1991, 4,589 yard locomotives were in service.[70]

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[66] The other nine equipment categories are lawn and garden equipment, airport service equipment, recreational vehicles, recreational marine equipment, light commercial equipment, industrial equipment, construction equipment, agricultural equipment, and logging equipment.

[67] Source: EPA Office of Mobile Sources, *Locomotive Emission Factors for Inventory Guidance Document* (June 1991).

[68] The EPA also outlines a methodology for calculating more detailed locomotive emissions for areas that are expected to deviate significantly from the national average. The methodology is called the *roster tailoring method*, and uses emissions data from individual locomotive makes and models.

[69] *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachment J, Emissions from Railroads (EPA Office of Mobile Sources, February 15, 1992), Appendix 6-5, p. 6-23.

[70] Ibid, p. 6-23.

The emission factors represent an average of emission factors for five diesel engine configuration types: 2-stroke supercharged switch locomotive, 4-stroke switch locomotive, 2-stoke super-charged road service locomotive, 2-stroke turbocharged road service locomotive, and 4-stroke road service locomotive. The emission factors are based on duty cycle testing and average fuel consumption rates. A duty cycle consists of the operating time in eight throttle notch settings plus idle and dynamic braking. The fuel consumption rate of a locomotive is determined by the throttle notch position — the higher the notch, the higher the fuel consumption, and vice versa. Therefore, fuel consumption is proportional to the amount of time the locomotive spends in each throttle notch position.[71] The locomotive emission factors apply to all three Interstate Commerce Commission (ICC) railroad classes: Class I — annual revenues greater than $93.5 million; Class II — annual revenues greater than $18.7 million but less than $93.5 million; Class III — annual revenues less than $18.7 million.

Table F-39. TRAN Locomotive Emission Factors

Pollutant	Emission Factor (lbs./1,000 gal of fuel)
HC	21.10
CO	6.26
NO_x	493.10
SO_2*	36.00
PM	11.60

*Based on fuel sulfur content of 0.25 percent by weight.

Look-Ahead Issues Concerning Locomotive Emission Factors

In terms of specifying future-year locomotive emission factors given CAAA requirements, the emission factors in Table F-39 are to be used for all forecast years. Section 213 of the Amended

[71] Ibid, p. 6-13.

Act requires the EPA to promulgate emission standards for new locomotives by November 1995. These new standards are to be designed to obtain the greatest degree of emission reduction achievable, with due consideration given to compliance cost, energy consumption, safety and noise.[72] New emission factors would be based on testing of the applicable locomotive emission reduction technologies that would be manufactured to comply with new standards. Given the large uncertainty over the prospective emission standards and technologies, as well as the low stock turnover of locomotive engines, there is no justification for assigning alternative emission factors to the forecast interval.

Aircraft Emission Factors

Overview of the EPA Aircraft Emissions Inventory Methodology

The EPA bases its aircraft emission factors on five operating modes that together consist of the landing and takeoff (LTO) cycle. The first operating mode is the approach, in which the aircraft makes its airport approach after the descent from cruising altitude. The second operating mode is taxi/idle-in, where the aircraft lands and taxis to the gate. The third mode is taxi/idle-out, in which the aircraft taxis back out to the runway for subsequent takeoff.[73] The fourth mode is takeoff, in which the aircraft attains liftoff speed and becomes airborne. The fifth mode is termed the climbout, and represents the aircraft's accent to cruising altitude. Most aircraft go through a similar sequence during an LTO cycle.

During each operation mode the aircraft engines operate at a fairly standard power setting for a given aircraft category. The power setting results in a certain rate of fuel flow (expressed in pounds per minute) for the operating mode. Total emissions from the aircraft engine are thus determined by the amount of time that an aircraft engine spends in each operation mode (termed the "Time-in Mode"), the fuel consumption rate, and the engine-specific emission factors for each operating mode, expressed in pounds of emissions per 1,000 pounds of fuel consumed.

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[72] CAAA, sec. 213 (a)(5), 104 STAT 2501.

[73] Both Taxi/idle operating modes are highly variable, and depend on such factors as airport size and layout, the amount of ground congestion, airport-specific operational procedures, time of day, and seasonal travel activity.

The EPA aircraft emission factors and inventory preparation procedures are site-specific; they are highly dependent on local airport and aircraft population data. Generally, the emissions inventory is prepared using the following steps: (1) identify airports to be included in the inventory area, (2) determine the mixing height[74] to be applied to the LTO cycle (a standard default value of 3,000 feet is assumed), (3) define the aircraft fleet population for each aircraft category across all airports, (4) determine the number of LTOs for each aircraft category, (5) select emission factors for each aircraft category, (6) estimate a time-in-mode for each aircraft category at each airport, and (7) calculate an inventory based on the airport activity, time-in-mode, and emission factors.

EPA Aircraft Categorization

The EPA categorizes aircraft by the type of use: commercial, general aviation, and military. Commercial aircraft include those used for scheduled service transporting passengers, freight, or both. Air taxis also fly scheduled service carrying passengers and/or freight, but usually are smaller aircraft and operate on a more limited basis than the commercial carriers. Business aircraft support business travel, usually on an unscheduled basis, and general aviation includes most other non-military aircraft used for recreational flying, personal transportation, and various other activities.

The EPA combines business aircraft with general aviation aircraft because of their similar size, use frequency, and operating profiles. Similarly, air taxis are treated much like the general aviation category because they are typically the same types of aircraft. Military aircraft cover a wide range of sizes, uses, and operating missions. While they often are similar to civil aircraft, they are handled separately because they typically operate exclusively out of military air bases and frequently have distinctive flight profiles. Helicopters, or rotary wing aircraft, can be found in each of the categories. Their operation is distinct because they do not always operate from an airport but may land and takeoff from a heliport at a hospital, police station, or similarly

[74] The height of the mixing zone — that portion of the atmosphere where aircraft emissions affect ground level pollutant concentrations — influences the time-in-mode for approach and climbout operation modes, and is particularly significant when calculating NO_x emissions.

dispersed location. Military rotorcraft are included in the military category and non-military rotorcraft are included in the general aviation category since information on size and number are usually found in common sources. However, they are combined into a single group for calculating emissions since their flight profiles are similar.

Commercial aircraft typically are the largest source of aircraft emissions. Although they make up less than half of all aircraft in operation around a metropolitan area, their emissions usually represent a large fraction of the total because of their size and operating frequency. This would not hold true for a city with a disproportionate amount of military activity, or a city with no major civil airports.

Aircraft Emissions Characteristics

The EPA views HC, CO, NO_x, SO_2, and PM_{10} as the significant aircraft pollutants. However, only HC emissions and smoke production are currently regulated.[75] For a single LTO cycle, aircraft emissions vary considerably depending on the category of aircraft and the aircraft's flight profile. Emission rates for HC and CO are high during the taxi/idle phases when aircraft engines are at low power and operate at suboptimum efficiency. The emission rates fall as the aircraft moves into the higher power operating modes of the LTO cycle. Conversely, NO_x emissions are low when engine power and combustion temperature are low, but increase as the power level is increased and combustion temperature rises. Therefore the takeoff and climbout modes have the highest NO_x emission rates.

Sulfur dioxide emission rates are highest during the takeoff and climbout operation modes when fuel consumption rates are high. Sulfur emissions typically are not measured when aircraft engines are tested. Therefore, the EPA uses a default emission factor of 0.54 pounds SO_2 per 1,000 pounds of fuel for all engine types. (EPA assumes that all sulfur in the fuel combines with oxygen during combustion to form SO_2. Nationally, the sulfur content of fuel remains fairly

[75] EPA established standards for aircraft HC emissions in 1984, which included the establishment of standard procedures for engine certification and emissions testing. The standard applies to jet engines with an engine thrust of over 6,000 pounds. The EPA reports that many older in-service engines exceed the standards. New engine designs produced since the standards went into effect have HC emissions lower than the standards, but the design changes made to reduce the HC emissions resulted in small increases in NO_x emissions.

constant from year to year at about 0.05% by weight for commercial jet fuel, 0.025% by weight for military fuel, and 0.006% by weight for aviation gasoline. These national sulfur content figures are used by the EPA for estimating the SO_2 default emission factors.

Particulate emission characteristics are similar to that of HC and CO in that emission rates are higher at low power rates than at high power rates because of greater combustion efficiency at a higher engine power. However, particulate emissions are highest during takeoff and climbout due to the greater fuel flow rate. The EPA does not report emission factors for particulates except for a small number of engine models, citing the difficulty in estimating PM emissions.[76] Direct measurement of particulate emissions from aircraft engines typically are not available from manufacturers, although emission of visible smoke is reported as part of the engine certification procedure.[77] The inventory preparation procedure document reports emission factors for only one civil aircraft engine model. This engine model is used in a number of European-built aircraft, and is not representative of the total aircraft fleet.

DAC Methodology for Calculating Aircraft Emission Factors

As mentioned above, the EPA aircraft emission factors are reported for individual engine models (currently 88 civil aircraft engines and 54 military engines) by LTO operation mode. Consequently, the emission factors apply to activity levels measured in full LTO cycles, not fuel consumption as specified in the TSCDR. DAC developed a methodology for converting the EPA operating-mode emission factors into a fleet average emission factor based on total gallons of fuel consumed. The data used to construct the fuel-based emission factors are presented in Appendix E.EM.C.

The first step of the conversion methodology involves the derivation of fleet-average time-in-

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[76] *Procedures for Emission Inventory Preparation, Vol IV,* page 149.

[77] Ibid., p. 149.

mode figures. The EPA reports default TIM values in minutes for each civil and military aircraft category. Since commercial aircraft accounted for 93.6 percent of civil aircraft energy consumption in 1989, the TIM values for jumbo, long, and medium range jet commercial carriers were used as proxies for the entire civil aircraft population.[78] These TIM figures are as follows: Takeoff — 0.7 minutes, Climbout — 2.2 minutes, Approach — 4.0 minutes, Taxi/Idle — 26.0 minutes. Military aircraft TIM's are highly variable. Therefore, the arithmetic averages of TIMs for combat, trainer, and transport aircraft were used as proxies for the fleet TIMs. Helicopter TIMs were excluded from the calculations due to LTO incompatibility with the other aircraft categories.

The second step of the conversion methodology is to determine the fuel use for each operating mode using the EPA's fuel flow data, and to construct fuel consumption shares. The LTO time-in-mode amounts (in minutes) were multiplied by the fuel flow amounts (in pounds per minute) to obtain fuel consumption in pounds for each operating mode. The modal fuel consumption figures were then divided by total LTO fuel consumption to derive the fuel consumption shares (see Appendix E.EM.C, pages E.EM.C-3 and E.EM.C-6).

The third step is to calculate average emission factors by pollutant type for the population of engine models reported by the EPA. Separate samples of 46 civil and 15 military aircraft engine models were created from the EPA's list.[79] The selection was based on reported engine market shares for each aircraft model, with aircraft models chosen based on a proportional representation of the commercial, general and military aircraft categories. The sample engine-model emission factors were aggregated by calculating the arithmetic average of reported pollutant emission factors.[80] (see Appendix E.EM.C, pages E.EM.C-1, E.EM.C-2, E.EM.C-4, and E.EM.C-5). Since the SO_2 emission factor is the same for each operation mode, this methodology is not applicable for SO_2 emission rate estimation.

The fourth step is to calculate the weighted fleet-average emission factors for HC, CO, and NO_x

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[78] Aircraft Btu energy consumption figures come from Oak Ridge National Laboratory, *Transportation Energy Data Book, Edition 12*, ORNL-6710 (Oak Ridge, Tennessee, March 1992).

[79] *Procedures for Emission Inventory Preparation*, Table 5-4, "Commercial Aircraft types and Engine Models," and Table 5-6, "Military Aircraft types and Engine Models."

[80] Ibid., Table 5-4, "Modal Emission Rates."

by multiplying the aggregated engine sample emission factors by the fuel consumption shares calculated in step 2. Two further calculations are necessary to produce emission factors that correspond to TSCDR specifications. First, the emission factors must be converted into gallons-of-fuel equivalents. A conversion factor of 6.2 pounds per gallon was used. Second, the total HC emission factors must be adjusted to produce volatile organic compound (VOC) emission factors. The following EPA adjustment factors, applicable to turbine engines, were used:

$$VOC_{COMMERCIAL} = THC_{COMMERCIAL} \times 1.0947$$
$$VOC_{MILITARY} = THC_{MILITARY} \times 1.1046$$

Table F-40 presents the TERF aircraft emissions factors for HC, VOC, CO, NO_x, and SO_2.[81]

Table F-40. TERF Aircraft Emission Factors

Pollutant	Emission Factors (lbs./1000 gal. of fuel)	
	Commercial Aircraft	Military Aircraft
HC	37.82	75.54
VOC	41.40	83.44
CO	101.97	330.17
NO_x	79.04	58.15
SO_2	3.35	3.35

Look-Ahead Issues Concerning Aircraft Emission Factors

[81] Source: Appendix E.EM.C, page E.EM.C-3;

Notes: Commercial and military VOC emission factors calculated by multiplying Appendix E.EM.C HC values by 1.0947 and 1.1046, respectively.

SO_2 emission factors calculated by dividing the EPA standard value of 0.54 pounds per 1,000 gallons by 6.2.

Among the factors expected to influence aircraft emission rates in a forecasting context are the following:

- new aircraft engine designs,
- airport noise regulations,
- an increase in airport congestion problems

Aircraft with cleaner and more energy-efficient engine designs are expected to continue to slowly penetrate the world aircraft fleet population. Since there is a significant engineering and development leadtime for producing new aircraft engines, most of the commercial aircraft to be added to the fleet in the next five to seven years will be powered by engines currently monitored by the EPA.[82] Given the 12-year average service life for commercial aircraft engines, the newer generation of aircraft engines are not expected to make a significant impact on national emission levels until 2010. However, a possible catalyst for an increased rate of new aircraft engine market penetration is the recent enactment of national airport noise regulations, which require the phase-out of loud aircraft by 2000. Airlines are expected to upgrade their fleets with quieter and cleaner engines once the industry formulates compliance plans. The extent of the emission rate impact of such fleet upgrading is unknown at this time.

Acting as a counterweight on the downward pressure on emission rates caused by stock turnover and new regulations is the growth in air travel combined with limited excess capacity at many airports. Air travel has experienced strong growth over the past several years, and this growth is expected to continue for the foreseeable future. The primary capacity squeeze will be felt at small feeder airports and regional hubs. Increased congestion at capacity-constrained airports will increase taxi/idle times, resulting in increased emissions per LTO.

Given these offsetting impacts on aircraft emissions, the emission factors listed in Table F-40 should be satisfactory for estimating future aircraft emission levels.

Waterborne Vessel Emission Factors

[82] Ibid., p. 208.

Commercial Vessels

Table F-41 provides the EPA emission factors for domestic commercial motorships. These emission factors are reported in the AP-42 document. The emission factors are based on Army Corps of Engineers waterway classification categories, which are defined as follows:

- **River** — All waterborne traffic between ports or landings wherein the entire movement takes place on inland waterways.
- **Great Lakes —** All waterborne traffic between United States ports on the Great Lakes.
- **Coastal —** All domestic traffic receiving a carriage over the ocean or between the Great Lakes ports and seacoast ports when having a carriage over the ocean.

To derived an average emission factor for all three waterway category vessels, a weighted-average methodology was applied whereby shipment tonnage and average length-of-haul data from the Army Corps of Engineers were used to construct emission factor weights.[83] Table F-41 provides more details on the weighting methodology.

The EPA *Nonroad Engine and Vehicle Emission Study Report* provides emission factors for two additional vessel categories: ocean-going steamships and harbor/fishing vessels.[84] These emission factors are based on engine sizes and operating mode (hoteling, cruise, and full power), and are not compatible with the emission factors provided in Table F-41. Because of the small emissions contribution of these vessels to the overall waterborne vessel total, they are not included in the composite waterborne vessel emission factors. For reference purposes, Appendix E.EM.D provides the ocean-going and harbor/fishing vessel emission factor tables from the Nonroad Engine and Vehicle report.

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[83] U.S. Army Corps of Engineers, *Waterborne Commerce of the United States, Calendar Year 1989* (Waterborne Statistics Center, New Orleans, LA, 1991), Part 5: National Summaries, pp. 32, 93.

[84] These emission factors were compiled and provided to the EPA in a Booz Allen & Hamilton report, *Commercial Marine Vessel Contributions to Emission Inventories* (Los Angeles, CA, October 7, 1991).

Table F-41. Commercial Vessel Emission Factors[85] (Pounds per 1,000 gallons of fuel)

Pollutant	Waterway Class			Weighted Average*
	River	Great Lakes	Coastal	
HC	50	59	50	51
CO	100	110	110	107
NO_x	280	260	270	273
SO_2	27	27	27	27

* Average emission factors calculated by multiplying pollutant emission factors for each waterway class by shipment mileage weights and then summing the weighted emission factor values. The shipment weights are as follows: River — 0.34, Great Lakes — 0.07, Coastal — 0.59. Shipment mileage weights were derived by multiplying tons shipped by the average length-of-haul per ton shipped for each waterway class.

Recreational Vessels

Table F-42 provides HC, CO, and NO_x emission factors for recreational marine vessels. These emission factors come from the EPA *Nonroad Engine and Vehicle Emission Study Report*. The EPA classifies and reports emission factors for the following vehicle/engine types:

- vessels with inboard engines (4-stroke)
- vessels with outboard engines (2-stroke)
- vessels with sterndrive engines (4-stroke)
- sailboats with auxiliary outboard engines (diesel)
- sailboats with auxiliary inboard engines (diesel)

[85] U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors, Volume II: Mobile Sources*, AP-42, PB-87-205266 (EPA Office of Mobile Sources, September 1985), Part II, Off-Highway Mobile Sources, Table II-3.1.

U.S. Army Corps of Engineers, *Waterborne Commerce of the United States, Calendar Year 1989* (Waterborne Statistics Center, New Orleans, LA, 1991), Part 5: National Summaries, pp. 32, 93.

When the AP-42 document was compiled, emission testing data was not available for recreational marine vessels. The EPA used coast guard diesel engine and automotive engine emission data to compute in-board emission factors based on the duty-cycle for engines classified as large out-boards. Out-board emission factors were derived from data supplied to the EPA by the Southwest Research Institute.

For the Nonroad Engine and Vehicle report, outboard engine emission factors were derived from test data supplied to EPA by the National Marine Manufacturers Association, which tested 25 two-stroke and three four-stroke outboard engines. For four-stroke outboards, emission factors recommended by the Southwest Research Institute were used for particulate matter emissions.[86] Since no data were available for 2-stroke outboard engine particulate matter emissions, EPA used emission factors from the CARB Technical Support Document for utility and lawn/garden equipment as approximations. For inboard/sterndrive gasoline engines, the EPA derived emission factors on the basis of test data on three 4-stroke gasoline marine inboard/sterndrive engines supplied by NMMA. The particulate emission factor used was 1.64 pounds per 1,000 gallons of fuel. The EPA used NMMA test data for a small diesel sailboat inboard and three large diesel inboard engines as the basis for calculating emission factors for inboard diesel engines.

As with the commercial marine vessels, vessel/engine-type emission factors must be weighted according to an activity or population level indicator and summed to obtain an average emission factor for the total recreational marine vessel population. Engine population data for each vessel/engine-type class was used to construct the weights. Boat population figures were gathered from local boat registration data bases, and were subsequently adjusted to obtain engine population estimates. Energy and Environmental Analysis developed the engine number derivation methodology for the EPA.

Table F-42. Recreational Marine Vessel Emission Factors[87] (Pounds per 1,000 gallons of fuel)

[86] U.S. Environmental Protection Agency, *Designation of Areas for Air Quality Planning Purposes*, 40 CFR Part 81, Final Rule, Washington, D.C., Office of Air and Radiation, November 6, 1991.

[87] U.S. Environmental Protection Agency, *Nonroad Engine and Vehicle Emission Study — Report*, EPA 460/3-91-02 (EPA Office of Mobile Sources, November 1991), Table 2-03, Appendix I, Table I-11.

Pollutant	Vessel/Engine Type				Weighted Average*
	Outboard/ 2-Stroke	Outboard/ 4-Stroke	Sterndrive/ 4-Stroke	Sailboard/ Diesel Aux.	
HC	1610	190	160	50	1233
CO	2990	3130	2680	80	2884
NO_x	20	150	100	380	44

* Weights for each vessel/engine-type category were constructed from the following engine population figures: Outboard/2-Stroke — 8,204,304, Outboard/4-Stroke — 41,228, Sterndrive/4-Stroke — 2,713,420, Sailboat/Diesel-Aux. — 114,502.

Table F-43. Ocean-Going Commercial Vessel Emission Factors

OPERATING PLANT Operating Mode/Rated Output	POLLUTANT				
	NO_x	HC	CO	SO_x	PM
STEAM PROPULSION					
Full Power	63.6	1.72	7.27	159x(%S)	56.5
Maneuver/Cruise	55.8	0.682	3.45	159x(%S)	20
Hotelling					
- Burning residual bunker fuel	36.4	3.2	*	159x(%S)	10
- Burning distillate oil	22.2	3	4	142x(%S)	15
MOTOR PROPULSION					
All underway operating modes	550	24	61	157x(%S)	33
AUXILLARY DIESEL GENERATORS					
- 20 KW (50% Load)	477	144	53.4	27	17
- 40 KW (50% Load)	226	285	67.6	27	17
- 200 KW (50% Load)	140	17.8	62.3	27	17
- 500 KW (50% Load)	293	81.9	48.1	27	17

Notes:
1) Emissions factors showing an asterisk (*) are considered negligible for these operating modes.
2) Average sulfur concentrations used are 0.8 percent for marine diesel, and 2.0 percent for bunker fuel oil.

Sources:
1) U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, 1985.
2) U.S. Department of Transportation, Port Vessel Emissions Model, 1986.
3) California Air Resources Board, Report to the California Legislature on Air pollutant Emissions from Marine Vessels.

Table F-44. Harbor and Fishing Vessel Emission Factors

OPERATING PLANT Operating Mode/Rated Output	POLLUTANT				
	NO_x	HC	CO	SO_x	PM
DIESEL ENGINES	Pounds per Thousand Gallons of Fuel Consumed				
< 500 Horsepower					
Full	275.1	21	58.5	157x(%S)	17
Cruise	389.3	51.1	47.3	157x(%S)	17
Slow	337.5	56.7	59	157x(%S)	17
500 - 1000 Horsepower					
Full	300	24	61	157x(%S)	17
Cruise	300	17.1	80.9	157x(%S)	17
Slow	167.2	16.8	62.2	157x(%S)	17
1000 - 1500 Horsepower					
Full	300	24	61	157x(%S)	17
Cruise	300	24	61	157x(%S)	17
Slow	300	24	61	157x(%S)	17
1500 - 2000 Horsepower					
Full	472	16.8	237.7	157x(%S)	17
Cruise	623.1	24	44.6	157x(%S)	17
Slow	371.3	24	122.4	157x(%S)	17
2000+ Horsepower					
Full	399.6	21.3	95.9	157x(%S)	17
Cruise	391.7	16.8	78.3	157x(%S)	17
Slow	419.6	22.6	59.8	157x(%S)	17
GASOLINE ENGINES	Grams per Brake Horsepower Hour				
Exhaust Emissions - All HP Ratings	5.16	6.68	199	0.268	0.327
Evaporative Emissions		62.0	Grams/Hr		
Crankcase Blowby		38.3	Grams/Hr		

Notes: 1) Average sulfur concentration for marine diesel fuel = 0.8 percent.

Sources:
1) U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, 1985.
2) U.S. Department of Transportation, Port Vessel Emissions Model, 1986.
3) California Air Resources Board, Report to the California Legislature on Air pollutant Emissions from Marine Vessels.

Appendix G. Supplemental Reports

This Appendix consists of two unpublished reports produced by Energy and Environmental Analysis, Inc., under contract to Oak Ridge National Laboratory. These two reports formed the basis for the subsequent development of the Fuel Economy Model described in Volume I. They are included in order to document more completely the efforts undertaken to construct a comprehensive model of automobile fuel economy.

The supplemental reports are as follows:

Supplement 1: *Documentation of Attributes of Technologies to Improve Automotive Fuel Economy*

Supplement 2: *Analysis of the Fuel Economy Boundary for 2010 and Comparison to Prototypes*