TRANSPORTATION TECHNOLOGY CHOICE AND FUEL CONSUMPTION IN EGYPT:
AN ENGINEERING–ECONOMIC MODEL

by

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(1981)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS OF THE
DEGREE OF

MASTER OF SCIENCE
IN MECHANICAL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 8, 1985

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Highway transportation accounts for more than half of total commercial energy use in most developing nations, and contributes significantly to oil imports and balance-of-payments problems. A model capable of projecting the results of alternative policies with respect to highway transport is needed. The types of models in common use in the developed nations are ill-suited to policy analysis in developing nations, due primarily to their data-intensity and insensitivity to some classes of policies. This thesis presents a novel model of technology choice, costs, and fuel consumption in the highway transportation sector which has been specifically designed for use in policy studies for developing nations.

The TRATEC (Transportation Technology Choice) model is based on the familiar postulate of microeconomics — that decision-makers will behave "rationally" by making choices which minimize life-cycle cost. This assumption is the basis for a logit model of consumer choice as a function of life-cycle cost. The choice model is coupled to a model of vehicle fleet structure, mileage accumulation, fuel consumption, and costs. A novel feature of the TRATEC model is its simulation of the coupled market equilibria in the new-vehicle and used-vehicle markets. The result is a modeling structure which is sensitive both to technology characteristics and to costs (the latter including capital costs, fixed costs such as taxes, and operating and maintenance costs such as fuel).

As an example of the use of the model, a set of model input data for Egypt were developed, and the effects of several transportation policy options were modeled. The model projects that an increase in Egyptian motor fuel prices to world-market levels would result in a 14.6 percent decrease in fuel consumption from the base-case in the year 2000, with a savings to Egyptian society of 258 million (1979) Egyptian pounds per year, and an increase in Egyptian Government revenues of 1.026 billion pounds per year. Rescinding the present ban on diesel automobiles (especially taxis) at the same time is projected to give further fuel and cost savings, for a total saving of 20.6 percent in fuel consumption and 319 million (1979) pounds per year in social costs. The increase in government revenue of L.E. 1.026 billion would remain the same for this case, but a larger fraction of it would come from foreign exchange.
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I gratefully acknowledge the guidance and financial support provided by my Advisor, Professor Fred Moavenzadeh. David Geltner of M.I.T.'s transportation laboratory also provided much guidance and constructive criticism. In addition, I thank Professor Moavenzadeh's administrative assistant, Mrs. Pat Vargas, and the Mechanical Engineering Department's graduate secretary, Mrs. Sandy Williams-Tepper, for helpfulness above and beyond the call of duty. Their patience and kindness have made the lives of many graduate students, including this one, a little easier. My thanks also to Ms. Janis Weber and Ms. Carolyn Coleman of AID's Near East Bureau for their help in providing information; and to my employer, Energy and Resource Consultants, Inc. for granting the necessary leave of absence, and for making computer time and facilities available for completion of the model after my return.

Finally and most importantly, I thank my wife, Carolyn, for tolerating the whole insane adventure, for maintaining the home front while I was at M.I.T, and for endless patience and support since I have returned.

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The author is 28 years old, married, and is the father of one child — whose arrival was nearly contemporaneous with the completion of this work.
DEDICATION

To the poor of the Earth, and to all those who labor for their relief.
1.0 INTRODUCTION

With the rapid increase in oil prices during the 1970s, energy consumption — especially oil consumption — has become an important area of worldwide concern. This concern is especially pressing in the less-developed countries (LDCs), since LDC economies are generally less diversified and more dependent on oil than are the industrial nations. The increased cost of oil now poses a major debt and balance-of-payments problem for many LDCs. Although total LDC oil consumption is small compared to that of the industrial world, the LDCs' income and ability to finance increased imports are even smaller. Thus policies to conserve energy and reduce oil imports have become matters of economic survival in many LDCs.

Since transportation (and specifically automotive transportation) is usually the single largest oil-consuming sector in the LDC economy, it is a logical focus for conservation policies. This is reinforced by the fact that there is considerable room for efficiency improvement in this sector. In response to the oil-price increases, manufacturers in the industrial countries have introduced new technologies which have dramatically increased the efficiency of current highway vehicles. In the United States, for instance, the average fuel economy of new passenger cars has increased from 14 miles per gallon (MPG) in the late 60s and early 70s to a projected 27.5 MPG in 1984 (Alic et alia, 1983). These increases are likely to continue (although more slowly) in the future. Recent estimates (Price, 1982; Alic et alia, 1983, Altshuler et alia,
1984) indicate that average new-car fuel economy in the U.S. could reach 45 to 70 MPG by the year 2000. Significant (although less dramatic) fuel-economy improvements for heavy trucks have also been achieved, and more such improvements are in prospect (Energy and Environmental Analysis, 1983).

Because of this technological potential, there is considerable scope in both the industrial nations and in the developing countries for policies which would save energy by encouraging the purchase and use of more efficient vehicles. Such policies could be used in addition to or instead of policies which reduce energy consumption by reducing (or limiting the growth of) transportation demand. Demand-limiting policies are generally difficult and painful to implement in developing countries, since transportation is a basic factor in development, and there is comparatively little "luxury" transportation compared to the industrial world.

An essential requirement for the formation of effective policies is that the policy maker be able to predict what the effect of the policies is likely to be. In complex areas such as transportation, where energy use involves multiple economic and technical tradeoffs, this understanding is best gained through the use of a quantitative model. This report presents such a model, in the form of the TRATEC (TRansportation TEChnology Choice) computer code. The TRATEC code is a policy-oriented model of technology choice and fuel consumption behavior in the automotive transportation sector. It has been specifically designed to address the needs of
planners and policy-makers in less-developed countries (LDCs). Specific capabilities of the model include the following.

1. Modeling the market penetration and fuel-consumption effects of new vehicle technologies, such as diesel engines in light-duty vehicles.


3. Modeling the effects of increasing fuel prices in general on both technology choice and demand for transportation.

The model has been designed to make the best use of the transportation-sector data typically available in LDCs, and to allow the use of back-of-the-envelope or seat-of-the-pants estimates where hard data are not available. The nature and form of the output data have also been designed with LDC planners in mind. For instance, a separate calculation and tabulation of private and social costs is available. (Private costs are the costs actually paid by the consumer, while social costs are the costs to society as a whole, calculated from "shadow" prices adjusted for subsidies and market imperfections.)

In addition to the TRATEC model itself, this report also presents an example of the application of the model in evaluating alternative approaches to transportation energy conservation in Egypt. This serves both as an example of the model's utility and as an interesting study in its own right. Although Egypt is somewhat atypical for a developing country (being a net oil exporter), its transportation sector is
structurally quite similar to that of many oil-importing developing countries, and it is presently facing important policy questions with regard to fuel pricing and fuel conservation — questions of the type which the model is designed to address. In the example problem, three possible policy scenarios are defined, and the TRATEC model is used to compare these to each other and to a "base-case" scenario involving no changes in policy. The three scenarios considered are: raising fuel prices to world levels, rescinding the present ban on diesel light-duty vehicles, and the combination of both actions.

1.1 BACKGROUND

Even more than in the industrialized countries, commercial energy use in most LDCs is dominated by the transportation sector. Since virtually all transportation is oil-fueled, transport accounts for an even larger fraction of total LDC oil consumption. As in the industrialized countries, automotive transportation (trucks, buses, and passenger cars) is by far the largest subsector within the transport sector, generally accounting for more than 80 percent of the total energy consumed. Even in fairly industrialized high-income LDCs such as Argentina, Mexico, and Brazil, transportation accounted for 24 to 35 percent of total energy demand in 1977, while automotive transport — despite extensive railways in Argentina and inland waterways in Brazil — accounted for 85 to 90 percent of the energy used for transportation (Moavenzadeh, 1980). In Egypt, which is much less developed than Argentina or Brazil, transportation probably accounts for an even larger fraction of the total
energy consumed.

Because of the economic importance of automotive transportation (both directly and as a consumer of energy), a large number of models of this sector have been developed and reported in the literature. Chapter Two discusses the general classifications of these models, and reviews some of the more significant ones. In general, these models have been developed in and for industrial countries, especially the United States. These models have tended to be either very simple ones — based on gross averages and accounting identities — or very complex ones, incorporating elaborate econometric and statistical techniques. Neither type is well suited for use in developing countries: the former because they are not sensitive enough to policy variables and exogenous changes such as technological advance; and the latter because they are large, complex, and expensive (and thus beyond the limited planning budgets of most countries), and because they require extensive statistical data which are unlikely to be available.

There is thus a need for an "appropriate" developing-country transportation model — one which is simultaneously sensitive to the policy options available and simple enough to be implemented with reasonable time and funds. The major policy options available in most developing countries are control of petroleum-product prices, taxes on motor vehicles, and encouragement, discouragement, or outright ban on the import of specific types of vehicle technologies or classes of vehicles. The model should be able to reflect the effects of these actions. In
addition, given the rapid rate of change in automotive technology, the model should be able to take account of this as well — reflecting the effects of technical change on costs, efficiency, and total fuel consumption. As discussed in Chapter Two, these requirements argue strongly for a structural or technologically-based model, rather than an econometric one. Such is the type of model presented in this report.

1.2 OUTLINE OF THE MODEL

The TRATEC computer code embodies a novel model of developing-country transportation fuel-use. The model is based on an engineering/economic model of automotive technology choice, using a multinomial logit decision algorithm. This is coupled with a model of the age structure and retirement patterns in the automotive fleet. Fuel consumption, private and social costs, and related data in the automotive transport sector are computed from the size, structure, and operating patterns of the vehicle fleet. The code is intended to be an easy-to-use tool for analyzing policies in technology choice and fuel pricing for highway transportation in developing countries. Since accurate statistical data are generally lacking in such countries, the model is designed to use parameters which can readily be estimated by the user, with no requirement for sophisticated statistical techniques or extensive statistical data.

This simplification is accomplished by substituting an assumption from classical microeconomics — that of the rational, fully informed, utility-maximizing consumer — for the formalism of econometrics. Given
an exogenously specified distribution of annual mileage for a given class of vehicles, and exogenously specified vehicle characteristics, the model assumes that consumers at each point on the mileage distribution will choose the vehicle technology having the lowest discounted annual cost at that point. The vehicles so purchased then enter into a more or less conventional mechanistic model of the vehicle fleet structure, in which vehicles age, accumulate mileage, retire, and are replaced. Total fuel consumption in each year is calculated by multiplying the number of surviving vehicles of each technology from each model year by the number of miles driven per year and the (exogeneous) fuel consumption per mile for that vehicle technology and model year.

A unique feature of the vehicle fleet submodel lies in its partial simulation of the used-car market — using assumptions parallel to those of the technology choice submodel. In each year, the vehicle owners at each point in the mileage distribution are assumed to face a choice — to keep their existing (and still operational) vehicle, or to sell it, and purchase a new one. This decision is assumed to be made on economic grounds. Given present fuel prices, the (endogenously determined) market value of his present vehicle, and present (exogenous) new-vehicle prices, the owner is assumed to choose the lowest-cost option. The endogenous determination of market value is done by constructing a demand curve for used vehicles in each year, treating new vehicles as the marginal source of supply.

The twin assumptions — that consumers maximize utility, and that utility
is adequately measured by discounted cash flow — are both the model's great strength and its great weakness. These assumptions eliminate the need for large amounts of statistical data, and allow the model to deal naturally and effectively with scenarios, such as changes in technology, which are beyond the purview of conventional econometric models. On the other hand, because of these assumptions, the model is limited to analyzing situations where the vehicle purchaser can reasonably be regarded as an economic agent, reacting primarily to price signals, and with good information concerning life-cycle costs. This is generally an excellent assumption where commercial vehicles are concerned (at least in market economies), but may not be completely adequate for modeling technology choice in personal transportation, where non-economic considerations such as status and prestige have more influence. The model is thus better applicable to developing than to developed countries, since personal transportation is less important and commercial transportation relatively more important in the developing countries, and since luxury goods such as prestige and status (as distinct from transportation) may play less of a role in purchase decisions in the developing countries.

1.3 LIMITATIONS AND CAVEATS

This model, like every other, cannot produce "truth"; it can only calculate out and systematize the consequences of the data and assumptions which go into it. The most important such assumption is that the model itself is an adequate representation of reality. Some of the important limitations on this assumption — such as the requirement for economic
rationality and the assumption that utility is adequately represented by
discounted present value of cash flows — have already been discussed
above.

Even assuming the fundamental validity of the model, the results can still
be no better than the data they are calculated from. The most crucial
data for this model are the vehicle-characteristics data and fuel prices,
both of which must be specified for each future year. Vehicle
characteristics are strongly affected by technological progress, which is
unpredictable beyond the fairly near future. Recent experience has also
dramatically demonstrated the difficulty of predicting future fuel
prices. For these reasons, the model is better suited to investigating
"what-if" scenarios such as "what if — fuel prices triple in the next
five years?" or "what if — diesel cars getting 80 MPG are introduced in
1990?" than to attempting to predict total 1987 fuel consumption. This is
not a weakness in the model but a deliberate decision in its design.
Other models, generally based on some variation of the mechanistic
approach described in Chapter Two, are better suited to predicting
near-term fuel demand, at least in the absence of significant price,
technology, or policy changes in the interim.

1.4 GUIDE TO THE REMAINDER OF THE REPORT

The remainder of this report consists of six technical chapters, a summary
chapter with conclusions, and several appendices. Chapter Two, the first
technical chapter, is a review of past work in automotive fuel consumption
modeling. This chapter concentrates on models developed for the United States (where a great deal of this sort of work has been done) and on the comparatively scanty work in this area for developing countries. Chapter Two also reviews the state of the art in technology choice modeling, with examples drawn from other areas (such as industrial technology) as well as from the automotive field.

Chapter Three discusses the different types of highway vehicles now in common use, and divides them into a number of basic classes. The typical technical characteristics and usage patterns for each class are described and discussed. Past and present technological choices in each class of vehicles, and the likely trend of future developments, are also discussed. These technological choices are then combined to form a set of alternative discrete "packages" of technologies choices for use with the technology selection model. A simple engineering model of vehicle fuel consumption is developed and presented, and then used to project current and future fuel-economy for each technological "package".

Chapter Four is a formal presentation of the transportation technology selection and fuel consumption model. This chapter begins with an overview of the model, then discusses each of its component parts in detail. The mathematical form of each part is presented along with a discussion of the reasoning and assumptions behind it. Input data and input parameters for the model are also presented and discussed.

Chapter Five describes the structure and function of the computer code
which embodies the model. The overall structure of the code is diagrammed, and its characteristics are summarized. Input data requirements and output data formats are also briefly discussed. The emphasis in this chapter is on presenting an overview — greater detail on the actual use of the code is given in the user's manual, which is included as Appendix A. A sample input data deck, and a listing of the FORTRAN code for the model are also given, in Appendices B and C respectively.

Chapter Six begins the presentation of the example application of the model to evaluating alternative transportation policies in Egypt. It presents a brief overview of the Egyptian economy and transportation system, then descends into a detailed discussion of the automotive transport sector in Egypt. Data on fleet composition, technologies available, transportation demand, and other inputs to the model are presented and discussed. Where these data are lacking or incomplete, the modeling assumptions used are described.

Chapter Seven completes the discussion of the model's application with a presentation of the differing scenarios modeled, and the model results for each. In addition to a "base case" representing the continuation of present policies, these scenarios include: the "fuel-price" case, in which fuel prices are allowed to increase to world levels; the "light-duty diesel" case, in which the present ban on diesel automobiles and light trucks is lifted; and the combined or "free-market" case, in which high fuel prices and light-duty diesels are combined. The results of these
scenarios are compared and contrasted, and policy recommendations developed.

Chapter Eight, finally, presents a summary and the conclusions of the report, along with recommendations for further research and development of the model approach. Chapter Eight is followed by a bibliography and by the three appendices. These are: the users manual for the TRATEC model (Appendix A); a sample set of data files (Appendix B); and a listing of the FORTRAN code for the model (Appendix C).
Due to the economic importance of the auto industry and — more recently — to the importance of the automobile as an energy consumer, a large number of models of automobile sales, fleet size and structure, energy consumption, and so forth have been developed. Since the oil embargo and the subsequent oil price increases of 1973, attention has focused on energy consumption by the automotive sector, and a great deal of work in this area has been published. Generally, the models of automotive energy consumption found in the literature fall into two classes: econometric models and "mechanistic" or accounting-type models. Variations on these two major classes and hybrids between them are also common. The two types have different, and to a large extent complementary strengths and weaknesses. Because of this, a hybrid approach combining the advantages of each type is becoming increasingly popular.

The econometric approach to automotive fuel-consumption modeling is discussed in Section 2.1 below, while Section 2.2 discusses the mechanistic and hybrid econometric/mechanistic approaches. Since technology choice is also an important component of the TRATEC model, Section 2.3 discusses the present state of the art in technology choice modeling as well. Technology choice models have not been widely applied in the automotive field, so much of the discussion in Section 2.3 draws on models in other areas. Finally, Section 2.4 gives a summary and critical comparison of the different approaches.
2.1 ECONOMETRIC MODELS

The econometric models that have been applied in the automotive sector have generally focussed on relating some dependent variable (such as automotive fuel consumption or auto sales) to one or more independent macroeconomic variables, such as gross national product, growth rates, personal incomes, prices, etc. This relationship is expressed as a mathematical function, giving the dependent variable (e.g. fuel demand) as a function of the independent variables. The structure of the demand function is assumed \textit{a priori} by the econometrician; frequently, more than one such function is specified, with the intention being to select the function which gives the best match to the data. The unknown coefficients in the function are then estimated by multivariable regression against the available data on fuel use. A revised function, containing those terms in the original function which had statistically significant coefficients, is then prepared and used to estimate future demand from estimates of the future values of the independent variables. This "macro" modeling approach suffers from several important weakness, which are discussed below.

Because of the importance of the automobile and automotive fuel industries, a large number of econometric models of demand for vehicles and/or automotive fuel have been developed. Greene (1981) gives a good summary and review of the econometric literature up to 1978; models published since that time include those of Energy and Environmental Analysis (1982b), Pindyck (1979), and Wheaton (1980). One noticeable trend in the field has been a recent shift away from pure macro-econometric
models to a form of hybrid mechanistic/econometric approach, in which the dependent variables used are not total fuel demand but alternative, intermediate variables such as total demand for transportation, with the total fuel demand being calculated from this by a mechanistic model. Some of the reasons for this shift will be discussed below.

The pure macro-econometric models have many drawbacks for use in automotive fuel-consumption modeling. The major drawback is their phenomenological orientation — they assume that aggregate behavior in the future will follow the same patterns as that in the past, and can thus be predicted by relating past behavior and the future values of economic variables. This approach fails to consider other, non-macroeconomic variables which may be significant. The most important of these variables is technological advance. Since the technological changes in automobiles over the last decade have been revolutionary, this is a serious drawback.

As an example of the problems inherent in a purely macroeconomic approach, consider that real (deflated) 1985 fuel prices in the U.S. are not greatly different from those in 1950, while real personal income per capita is higher. On this basis, a pure macroeconomic model would predict an average fuel-economy comparable to or lower than that for 1950. In fact, as a result of technological advance, present fuel economies are double or triple those of the 50s. Many models compensate for technological trends by including time as an explanatory variable, but this approach is also flawed. Technology does not advance uniformly with time — rather, it proceeds in fits and jumps, often with long periods of little change.
punctuated by periods of dramatic progress. The result is that any model which does not account specifically for the effects of technology is limited in its predictive power.

Econometric models also have great difficulty in differentiating short-term from long-term responses. Due to the time-lag imposed by the turnover of the existing vehicle stock, long-term elasticities could be expected to be much greater than those in the short term. Most econometric models attempted to date have not succeeded in capturing this, and as a result have come up with rather low estimates of elasticity. A good example of this type is the study carried out by Energy and Environmental Analysis (1982b) using 36-month time-series data for individual families. Most families do not change cars (or housing — and thus average mileage) in such a short period.

Those models which have avoided this pitfall have used a hybrid econometric/mechanical approach, such as Wheaton (1980) and a number of the later workers identified in Greene (1981), or have used cross-national comparisons (e.g. Pindyck, 1979). Neither of these approaches is fully satisfactory: the latter because tastes, habitation patterns, and other non-macroeconomic influences on transportation may change across countries, and the former because technological advances are not susceptible to econometric prediction in any straightforward way. While it is certainly possible to conceive of purely econometric models which could account for all of these effects (by incorporating measures of tastes, habitation patterns, technological characteristics, and the
determinants of technological advance into the model), such models would be prohibitively complex — especially for use in modeling developing nations. To develop statistically meaningful estimates of the numerous parameters in such a model would require voluminous (and highly accurate) statistical data, while reliable statistical data of any sort are very scarce in the developing world.

In the area of energy price responses and energy policy, econometric models suffer from another major drawback. This is that — due to the sharp increases in energy prices in the last decade — they are constantly extrapolating beyond the limits of their data. Ceteris paribus, one would expect that a model estimated from data in which the price of gasoline changes from $.50 per gallon to $1.00 would predict the effects of another price change to, say, $.75 fairly well. There is little reason to expect that it would accurately predict the effects of a change to $2.00. Under the present circumstances, however, this is precisely the sort of prediction these models may be called on to do. This is a separate issue from the problem of technological change discussed above. The effect of technological change is to ensure that ceteris is not paribus — that even if gasoline prices return $.50 per gallon again (as they have, in real terms), fuel consumption will not return to its old level.

Another problem in modeling energy price effects results from the near-colinearity of the price increases for the major classes of transportation fuels. Since fuel prices have increased more or less in unison in most countries, meaningful estimates of cross-elasticities of
demand for different fuels are difficult to obtain. These estimates are important for policymaking, however, given the frequent occurrence of government-maintained price differentials between alternative fuels such as diesel or alcohol and gasoline.

2.2 MECHANISTIC OR ACCOUNTING MODELS

Mechanistic models, in their simplest form, are simply accounting. They begin with a known or assumed composition of the vehicle fleet, which specifies the number of vehicles in a given classification and the fuel-economy characteristics of that classification. Classification is normally by vehicle type (e.g. passenger car, heavy truck) and model year. Some assumptions about annual miles driven in each class are then made, and the total fuel consumption in each class is then calculated, with overall fuel consumption being obtained by summing the fuel consumption for each class.

The heart of the mechanistic model is an accounting identity: total fuel consumption is equal to the product of the number of vehicles, the average number of miles driven per vehicle, and the average amount of fuel used per mile. These values are then estimated or projected separately for each class of vehicles. Mechanistic models differ in the way in which this projection is done.

For most such models, the future structure of the fleet is specified by projecting new-vehicle sales for each future model year, together with
some algorithm to estimate the retirement of vehicles now in the fleet. The average fuel-economy of future vehicles is normally input exogenously, and may be developed from engineering estimates, the CAFE standards, or some other basis. Average mileage per vehicle is normally assumed constant, although some hybrid mechanistic/econometric models calculate mileage per vehicle from the fuel price and an elasticity function.

Based, as it is, on an accounting identity, the underlying form of the mechanistic model is beyond reproach on theoretical grounds. The problem with these models is always to obtain or make up sufficiently accurate data to achieve in practice a reasonable approximation of the model's theoretical accuracy. Special problems arise in determining the values for average mileage per vehicle or for total average mileage to be used. Ideally, these values should reflect changes in demand for transport based on changes in its price, or in variables such as habits and habitation patterns. Many past structural models have ignored this requirement — making crude assumptions such as constant mileage. A more defensible approach here would be to apply an econometric estimate of demand for transportation services, as was done by Wheaton (1980). Alternatively, demand for transportation services might be taken exogenously, as the output from some more sophisticated transportation planning technique, such as those which are now being used in planning highway networks.

In order for a mechanistic model to predict future fuel consumption reliably, it is necessary to have accurate and reasonably detailed projections of quantities such as future new-vehicle demand and the
average fuel economy of future vehicles, as well as the average mileage they will be driven. Since these data are unknowable except in the very near term (i.e. the next one or two years), the reliability of the these models becomes increasingly problematic beyond the near future. In developing countries, even near-term projections may be suspect, since accurate statistical data may be difficult or impossible to obtain. In this model's favor, however, is the fact that the assumptions and projections which need to be made are at least made in very concrete terms (e.g. that the average passenger car will get 29.5 MPG in 1989), so they are easier to check for reasonableness than such abstract concepts as elasticity.

Mechanistic models are well suited to predicting near-term fuel consumption, since fuel use in the near future is dominated by vehicles in existence now. Due to their simple structure and relatively concrete variables, these models are also very useful for testing "what-if" hypotheses, such as "what if diesel passenger cars attain a 35% market share in 1990?" Given the inherent uncertainties in technology, oil prices and supply, and other controlling variables, there is a good case to be made that such "what-if" hypotheses are the most sensible form of projections about the future (at least beyond the near term) in any case. The design of the TRATEC model is specifically intended to facilitate construction of such scenarios.

A number of significant mechanistic models of highway transportation in the U.S. have been constructed. Foremost among these is the Highway Fuel
Consumption Model developed by Energy and Environmental Analysis (1982c-d) for the U.S. Department of Energy. The HFCM has probably received more attention and funding than any similar model. It was intended primarily to produce highly accurate short-term projections of highway fuel demand, and, as a result, it is rather simple in basic form. However, it has been provided with an extremely detailed and up-to-date data base on the current fleet structure, fuel-consumption characteristics, and similar data. Compilation of this data-base has been enormously expensive — the Department of Energy has expended over $500,000 on the Highway Fuel Consumption Model, almost all of it on developing the data base. This expenditure was in addition to the large sums previously expended by others, such as the U.S. Census Bureau and R.L. Polk and Company, in developing the primary data.

Another, less elaborate, model than that of the DOE is the model of the U.S. heavy truck fleet developed by Jambekar and Johnson (1978, 1981). The purpose of this model was to investigate the potential environmental and fuel-consumption effects of a widespread shift to diesel engines. The model was used to evaluate a number of "what-if" scenarios concerning dieselization. This was a pure mechanistic model — total vehicle-miles travelled, fuel consumption, and the fraction of trucks using each technology were specified exogenously. As with the DOE model, the development and validation of the data base for this model seems to have occupied the overwhelming preponderance of the effort.

Some other, related mechanistic models of the automotive fleet have been
developed by the U.S. Environmental Protection Agency (1981), and by Energy and Resource Consultants (Miller et alia, 1983) to evaluate the effects of emissions policies. For these models, the data of interest are not total fuel consumption but total pollutant emissions. Since both fuel consumption and emissions are closely tied to vehicle technologies, distance travelled, and numbers, however, these models are functionally identical to the mechanistic fuel-consumption models. Although these models display widely varying degrees of elaboration and detail, all are limited in that they take most of their crucial values — diesel penetrations, total fleet size, scrappage rate, average fuel economy, etc. — as exogenous, and thus they depend heavily on the quality of the exogenous data. This is a minor drawback in the U.S., where good data are available, but could be crippling in dealing with a developing country.

2.3 MODELS OF TECHNOLOGY CHOICE

In many areas, decision-makers are faced with a choice between any of a number of possible technological alternatives. Examples of such choices include the plant engineer deciding what type and size of boiler to use in a plant and whether or not to include cogeneration facilities; a home buyer choosing between conventional gas or electric heat and solar energy; an automobile purchaser choosing between a more expensive high-efficiency car or a less-expensive but less efficient model; and a truck fleet operator choosing the type and size of engine to be used in the fleet. In all of these cases, the question of which option the decision-maker will select in which fraction of the decisions is an important one for
understanding and predicting the future energy use of a country. As a result of this, a number of sophisticated technology-selection and market-penetration models have been developed for application to various specific areas of technology. The area in which these models have been most widely applied is in industrial and commercial energy demand, especially in nationwide energy-demand studies. To date, technology-choice models have seen relatively little use in the automotive sector.

Virtually all technology choice models begin with the same basic assumptions — that the persons doing the choosing are economically rational actors with more or less complete information about the costs and characteristics of the available choices. The costs and characteristics of each of the options are supplied to the model as data, and the model then simulates the decision-making process. The decision-makers are assumed to make the "best" choice, where "best" is defined by some conventional microeconomic criterion, such as highest internal rate-of-return or lowest net present value of the life-cycle costs. In the simplest models, this choice is assumed to be strictly either/or — all decision-makers in a given class are assumed to make the same decision. More sophisticated models recognize that there is generally some dispersion in characteristics, circumstances, and/or information, so that decision-makers, even in apparently identical circumstances, can and do make different decisions. Different models deal with this dispersion in different ways.
One commonly used approach to modeling the dispersion in decision-making is to treat the technology characteristics and other data provided to the model as being the means of a set of statistical distributions of values. Each decision-maker is assumed to respond with perfect rationality to the values he or she actually perceives in his/her particular case, with the result that the decisions made display a statistical distribution, reflecting the distribution of the underlying variables they are based on. If the variable which serves as the decision criterion is assumed to be normally distributed, and if these distributions are independent, then the resulting distribution of decisions is given by the familiar probit function of econometrics. Similarly, if the underlying variable has a Weibull distribution, the resulting decisions will be described by the logit function (Theil, 1971).

Other, similar theoretical formulations can lead to the same model. In econometrics, for instance, the decision criterion is often assumed to consist of a deterministic component (which is to be modeled by the econometrician) and a random "error term". Here it is not the decision variables but (in effect) the decision-maker's utility function which is assumed to be randomly distributed, but the resulting model of consumer behavior has the same (probit or logit) form. Due to its simplicity and the relative ease of estimating its coefficients, the logit function is widely used in models of consumer choice, including many technology choice models.

The validity of both the logit and probit functions depends on the
probability distribution functions for the underlying variables (or components of the decision criterion) being independent. A more sophisticated approach would account for the fact that the underlying variables are not generally fully independent, but may be partially correlated. For instance, the factors which result in higher costs for one technology may well result in higher costs for the other competing technologies as well, and the same may be true of (say) a preference for perceived quality. This approach is seldom used in practice, however, due to the extreme computational difficulties involved in dealing with partially-correlated distributions. One major model which does use this approach is ISTUM (Industrial Sector Technology Use Model), which was developed for the U.S. Department of Energy (Energy and Environmental Analysis, 1979). This model uses a linear-programming technique to solve the decision problem. This is effective, but very expensive — a single run of the ISTUM model typically consumes several hours of time on a mainframe computer, at a cost of several thousand dollars.

Closely related to technology choice models are market-penetration models, which attempt to model the adoption of new technologies in the market place. Frequently, the two types are combined, as in the SOLSRR model of technology choice and market penetration in the home heating equipment market (Weaver, 1982). Empirically, it has been found that the conventional assumptions of economic rationality do not adequately describe what occurs when a new technology competes with an old established one. A new technology, even one with large economic advantages, will not capture all of the market immediately. Rather, its
market share will follow an S-shaped curve, beginning with a shallow slope as a few purchasers adopt it, then steepening as more and more decision-makers learn of and become familiar with the new technology, and finally tapering off to a shallow slope again as the holdouts gradually give in. The relationship between the market characteristics, the characteristics of the technologies, and the shape of the technology-adoption curve are not well understood. It is clear, however, that technologies in different markets may have radically different adoption patterns (compare, for instance, housing with microelectronics), and that the relative advantages of the technology can greatly affect the rate of adoption.

The reality of technology adoption patterns can be reconciled with the theory of the rational decision-maker in one of two ways. First, it can be assumed that decision-makers will not choose any technology they are not familiar with, and that familiarity with a new technology diffuses through the population in a manner akin to that of an infectious disease (in fact, patterns of infection during epidemics are also "S" curves, closely resembling those for technology adoption). Alternatively, it can be assumed that decision-makers are risk-averse, and that a new technology (due to lack of knowledge about its characteristics) thus carries a large cost above and beyond its apparent cost, due to the greater perceived risk of failure. This cost is rapidly reduced in subsequent years, due to the accumulation of operating experience with the new technology. Decision-makers, in choosing the new technology in subsequent years after failing to choose it initially, are simply reacting rationally to changes
in the perceived cost.

Both of these approaches have much to recommend them. The former approach is probably a reasonably good model of the actual diffusion process for many consumer goods, while the latter is probably a better reflection of decision-making in the capital-goods market. Since the automotive sector has some of the characteristics of each of these markets, it is not at all clear which one would be better from a theoretical standpoint. From a practical standpoint, however, the knowledge diffusion process is a very difficult one to simulate, while the uncertainty-cost approach is easy to incorporate into a conventional technology-choice model. For developing countries, in which the automotive market is more like that for capital goods than in most industrial nations, this approach may have a slight theoretical edge as well.

2.4 SUMMARY AND CRITICAL COMPARISON OF MODELING APPROACHES

The two major types of automotive fuel-consumption models developed to date are macro-econometric models and mechanistic models. The macro-econometric models suffer from a number of drawbacks, of which the most severe are the neglect of technological and other non-macroeconomic changes, and the frequent necessity to extrapolate outside the range of the data the model is based on. These models also have trouble in differentiating short-term from long-term responses, due in part to the long waiting time required for a long-term response to manifest. One result of this problem was that many econometric models seriously
underestimated the energy-conservation response of to the oil-price increases of the last decade.

On the positive side, however, a properly formulated econometric model is about the only way known to determine consumer responses to changes in macroeconomic variables such as GNP and prices. In order to do this successfully, it is necessary to model the correct variables: e.g. changes in demand for transportation rather than in demand for vehicles or gasoline. The former variable is endogenous to the consumer, while the latter two are dependent variables, deriving from the former but also affected by technological changes and other events.

Mechanistic models are based on the accounting identity that total fuel demand is equal to the product of average distance travelled per vehicle, average fuel consumption per unit of distance travelled, and the total number of vehicles. The great difficulty with these models is in obtaining the requisite data on each of these quantities, and especially in projecting these quantities into the future. The simplest mechanistic models take these quantities as exogenous, and such models are thus critically dependent on the accuracy of whatever techniques are used to project these exogenous data. This approach involves a strong danger of inconsistency — the projected trends in technology mix, for instance, may be based on different fuel prices and thus be incompatible with the trends for total mileage travelled, or total vehicles.

More sophisticated mechanistic models incorporate the data-projection
mechanism into the model itself. For instance, rather than accepting VMT demand as exogenous, such a model might instead take in estimates of fuel prices, VMT demand at some base price, and elasticities, and compute the actual effective VMT demand itself. Such hybrid mechanistic/econometric models have become increasingly popular. An even more sophisticated approach would include the effect of changes in fuel prices (and also new-vehicle prices) on vehicle demand, retirement decisions, and (ultimately) choice of technologies. Since technological change has proven to be a major determinant of motor-fuel demand, this last is particularly important.
3.0 AUTOMOTIVE TECHNOLOGY AND FUEL CONSUMPTION

Fuel consumption in the automotive sector is determined primarily by two interacting factors: the technical characteristics of the vehicle fleet, and the demand for the services that vehicles supply. Demand for motor fuel (as for vehicles themselves) is a "derived" demand resulting from the underlying demand for transportation services. However, the demand for transportation services, in turn, is shaped by the characteristics of the vehicles available to meet it. The different classes of vehicles (e.g. passenger cars, buses, heavy trucks) determine the shape of the demand for personal transportation, long-distance trucking, and other transportation services. Due to this interaction, the demand for transportation services can most conveniently be broken down in terms of the types of vehicles which are used to meet it — into passenger-car miles travelled, heavy-truck miles travelled, and so on.

This chapter gives an overview of the general types of vehicles and vehicle technologies in use in the developing countries, with special attention to their fuel-consumption characteristics. Section 3.1 of describes the major classes of vehicles in use in the developing countries, and discusses their characteristics and usage patterns. This section also presents the vehicle classification scheme to be used in the sections that follow. Section 3.2 then discusses the fundamentals of automotive fuel-consumption, and presents the basic relationships between vehicle weight, aerodynamics, rolling resistance, and engine and
drivetrain efficiency which determine fuel-consumption levels. In addition, this section briefly surveys the potential for improvement in each of these areas. This is followed by Section 3.3 which defines present and potential future technology "packages" for each class of vehicles considered, and estimates the fuel-consumption characteristics of each.

3.1 CLASSIFICATION OF HIGHWAY VEHICLES

Highway vehicles are manufactured in a nearly infinite variety of shapes, sizes, and designs to suit different needs. Some types of vehicles fulfill specialized needs, for which substitution is nearly impossible; other types of vehicles may have many close substitutes. Vehicles may be used for transporting freight or passengers or both, in large or small loads, for long distances or short ones or for a mixture of the two. This variety and heterogeneity of applications is matched by a similar variety in design. In order to be able to analyze this highly heterogeneous population, it is necessary to impose some structure upon it. Conventionally, the set of all highway vehicles is divided into subsets or "classes" of vehicles, such as passenger cars, trucks, buses, and so on, each of which is assumed to be relatively homogeneous. This is the approach used here.

As the term is used here, a "class" of vehicles is considered to describe both a set of physical vehicles and the purchasers, owners, and applications of those vehicles. Each class is assumed to be homogeneous
— each vehicle within each class is assumed to be completely substitutable for every other one. Substitution between classes is assumed to be impossible; thus the market for transportation services can be considered separately for each class. This is obviously an over-simplification. However, by appropriate choice of vehicle classes, the consequences of this oversimplification can be minimized.

The major criterion for vehicle classification is the vehicle's intended function. Four functional groups are defined: passenger cars, trucks, buses, and light vehicles (this latter group includes motorcycles, scooters, rickshaws, tricycles, and similar vehicles). These broad classifications can be further subdivided on the basis of size, weight, cargo capacity, and technical characteristics, as shown in Table 3.1. These classifications are discussed at length in the separate sections below.

3.1.1 Passenger Cars

Passenger cars are small, four-wheeled vehicles intended primarily for personal transport, and generally carrying between two and six persons. These are the most numerous class of highway vehicles worldwide, accounting for about 80 percent of total vehicle production (Altshuler et alia, 1984). In most developed nations, a large range of different sizes and types of passenger cars are in use. The U.S. Environmental Protection Agency recognizes four classes of passenger cars, and one major recent study (Altshuler and coworkers, 1984) defined five. In developing
Table 3.1: Vehicle classification scheme (see text for criteria defining each class)

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<tr>
<th>PASSENGER CARS</th>
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<tbody>
<tr>
<td>Small Passenger Car</td>
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<td>Large Passenger Car</td>
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<td>Taxicab</td>
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<tr>
<th>TRUCKS</th>
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<tbody>
<tr>
<td>Small Light-Duty Truck</td>
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<tr>
<td>Large Light-Duty Truck</td>
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<tr>
<td>Medium-Duty Truck</td>
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<td>Light-Heavy Duty Truck</td>
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<td>Heavy-Duty Truck</td>
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<th>BUSES</th>
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<td>Light Bus</td>
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<tr>
<td>Heavy Urban Transit Bus</td>
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<tr>
<td>Heavy Interurban/Tourist Bus</td>
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<tr>
<td>Micro or Jitney Bus</td>
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<tr>
<th>LIGHT VEHICLES</th>
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<tbody>
<tr>
<td>Motorcycles</td>
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<tr>
<td>Scooters, Tricycles, and Miscellaneous</td>
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countries, however, the range of vehicle types is much smaller. For the purposes of this work we consider only two size-based classes of passenger cars — large cars and small cars. In addition to these size-based classes, a special functional classification — taxicabs — is important in many developing nations.

Large cars in developing nations tend to be owned for personal transport by the elite, or official transport by business organizations and governments. They are generally high-powered and frequently luxurious. The Mercedes sedan is a good example of such a car. Large U.S.-model cars are also found in this role in some Latin American countries. Small cars, on the other hand, tend to be low-powered and utilitarian, such as the various Japanese compact cars, or the ubiquitous Volkswagen beetle. These are generally used for private transportation by the middle social classes.

Taxis in developing nations may be either regular passenger cars converted to taxi service or vehicles specially designed for that use, although the former appear to be much more common. Taxis differ greatly from other classes of passenger cars in their usage patterns, and in the fact that their owners are generally much more directly concerned with issues such as operating costs and fuel economy than are the owners of the other classes. Usage patterns in taxi service tend to be severe, with much high-speed and high-acceleration driving, and total annual mileages are very high.
Most passenger cars in use in the developing world use gasoline fuel, and generally have rather unsophisticated (and thus less efficient) engines. For instance, carburetion and simple mechanical controls (rather than fuel injection and electronic controls) are universal, except on imported luxury cars such as the Mercedes. The alcohol-fueled passenger vehicles introduced in Brasil use a similar level of technology. This technology is characterized by simplicity, robustness, comparative ease of repair, and good tolerance for low-quality fuels. Diesel-powered passenger cars are not generally used in the developing nations, despite their popularity in Europe. This may be due to the more stringent fuel-quality requirements and greater mechanical sophistication of the diesel engine. Legal restrictions on diesel automobiles are also common, however.

3.1.2 Trucks

Trucks are vehicles of four or more wheels, specialized primarily for the transport of cargo rather than passengers. As Table 3.1 indicates, they can be divided into a number of classes on the basis of payload. For the purposes of this study, we will consider four general classes of trucks: light trucks (payload up to 1000 KG); medium-duty trucks (payloads from 1000 to 5000 KG); light-heavy-duty trucks (payloads from 5 to 15 metric tons) and heavy-duty trucks (payloads generally of 15 metric tons and up). These classifications are necessarily somewhat arbitrary, as trucks are built in a continuum of sizes from rather small to very large, and they may need to be adjusted somewhat for the conditions in individual countries. The classifications used do, however, reflect important
differences in the technology, usage patterns, and ownership characteristics of different groups of trucks.

Light-duty trucks in the developing nations are primarily pickup-type vehicles, with a sprinkling of small cargo vans and utility vehicles. These may be either two-wheel or four-wheel drive. These vehicles are generally owned by individuals and small businesses (most often individual proprietors), or by farmers. They are used mostly for occasional transportation of cargo or equipment, along with personal transportation. These vehicles are used primarily for local and short-distance transportation in both urban and rural areas. Like passenger cars, they are almost entirely gasoline-fueled.

Medium-duty trucks are larger and more powerful than light-duty trucks. This class includes a mixture of vehicle types, including the larger and heavier vans and pickups, together with four-wheel drive utility vehicles such as the land-rover, and special-purpose trucks such as delivery trucks and postal vans. A significant number of these vehicles are equipped for special purposes, such as wrecking trucks, utility service trucks, and similar vehicles. These trucks are mostly owned by commercial or quasi-commercial organizations, or by governments. Most are used in local and short-distance service in urban areas. Depending on the local conditions, a significant number of medium-duty trucks may also be used in rural regions, mostly by the larger farmers and ranchers. These trucks are generally also gasoline powered, and share most technical characteristics with light trucks.
Light-heavy duty trucks and heavy-duty trucks are generally quite different in size and design from medium and light-duty trucks. These two groups are generally quite large and powerful, and — unlike the smaller trucks — are often equipped with diesel engines. Light-heavy duty trucks are almost entirely "unit" trucks, having either two or three axles on a single chassis, and equipped with a cab and any of a number of possible special-purpose or general-purpose truck bodies. These trucks are generally used in local and short-distance service (e.g. delivery) in both urban and rural areas. Depending on their age and nationality, these vehicles may be either gasoline or diesel-powered: most American-made light-heavy trucks are gasoline-fueled, while European and Japanese trucks mostly use diesel. The diesel engines used in these trucks are generally smaller and less durable than those used in true heavy-duty trucks.

Heavy-duty trucks are larger and heavier than light-heavy duty trucks. They usually consist of either a tractor-trailer or a truck-trailer combination. These trucks are primarily intended for medium and long-distance hauling of heavy loads. They are invariably equipped with high-powered, highly durable diesel engines, and are generally engineered in a more rugged and durable manner than the lighter trucks, resulting in lifetime which can exceed 1,000,000 kilometers. Ownership of heavy-duty trucks is generally concentrated in large organizations such as shipping or specialized trucking companies or parastatal organizations for freight transportation. Individual owner/drivers also play an important role in the trucking sector in some nations, notably the U.S. and Egypt.
3.1.3 Buses

Buses are vehicles designed especially for the transportation of large numbers of passengers, generally with multiple stops for loading and unloading along a more-or-less fixed route. Because of their low owning and operating costs per passenger (often combined with large government subsidies) buses play a vital role in providing everyday transportation for many people in developing nations. Three classes of bus are in common use in the developing world: heavy, generally urban, transit buses; lighter buses generally used in rural transportation; and microbuses. Because of their inflexibility and expense, the specialized interurban transit and touring buses which are well-known to drivers in the developed nations tend to see little use in developing countries, except in tourist areas. Where they are used, these buses tend to resemble the urban transit buses in technical characteristics.

Urban transit buses are well known to most urban dwellers. They are large, heavy, boxlike vehicles designed for efficient loading and unloading of large numbers of passengers. Generally diesel-powered, they normally operate on fixed urban routes with many closely-spaced stops. These buses are very durable when properly maintained, but also very expensive. They are almost invariably owned by governmental or quasi-governmental transit organizations.

Light buses are lighter in construction than the urban transit buses, and
are generally built on truck chassis. They are frequently adapted to carry significant amounts of light cargo such as market goods, livestock, and handicrafts in addition to passengers. Similar vehicles are commonly used for school buses and similar needs in the developed nations. These buses are frequently gasoline-fueled, and operate most commonly in short to medium-haul service between rural villages and local market towns or other urban centers. Depending on the country, these vehicles may be owned and operated by individual entrepreneurs, commercial transportation companies, and/or parastatal enterprises.

Microbuses are generally small buses or vans such as the VW microbus, although trucks, station wagons, and other types of vehicles may also be adapted to this service. They generally operate in "jitney" service, carrying small numbers of passengers over either fixed or semi-fixed routes. These may be either rural or urban. In countries where these vehicles are permitted, they tend to be owned and operated by individual entrepreneurs. There is considerable overlap between this category and taxicabs. Microbuses generally resemble passenger cars and light trucks in their technical characteristics.

3.1.4 Light Vehicles

Most light vehicles in the developing countries are small motorcycles, or adaptations of motorcycles, with a sprinkling of larger, faster motorcycles and other types. These are used primarily for personal transport, although some may also be adapted to transporting passengers.
for hire (e.g. motor rickshaws) and/or light cargo such as market goods and handicrafts. These vehicles are almost exclusively powered by small, lightweight gasoline engines. Fuel-efficiency is seldom a significant concern in the design of these vehicles. Nonetheless, they consume little fuel because of their small size and light weight.

Although such vehicles are popular in many developing nations due to their low cost, the low annual mileages they accumulate and their low fuel consumption per mile tend to minimize their effects on total energy use. In addition, fleet and technology data for these vehicles are nearly impossible to obtain, and there is no meaningful possibility of fuel substitution, thus there is little point in modeling them. For these reasons, light vehicles such as motorcycles are not considered further in this report.

3.2 FUEL-CONSUMPTION AND FUEL-CONSERVATION TECHNOLOGIES

To move a vehicle from place to place requires the expenditure of energy as mechanical work in order to overcome the forces of friction. Since work has units of force multiplied by distance, the average work per unit distance required to move a vehicle has units of force. This quantity can be interpreted as the average frictional force on the vehicle, and thus as the average propelling force that the engine must exert. The frictional forces on a moving vehicle are of three types: aerodynamic drag, rolling resistance, and the stopping force exerted by the vehicle's brakes. Thus,
\[ \overline{F}_{\text{prop}} = \overline{F}_{\text{drag}} + \overline{F}_{\text{rr}} + \overline{F}_{\text{brake}} \]  
\hspace{1cm} (eq. 3.1)

where \( \overline{F}_{\text{prop}} \) is the propelling force, \( \overline{F}_{\text{drag}} \) is the force of aerodynamic drag, \( \overline{F}_{\text{rr}} \) is the force of rolling resistance, \( \overline{F}_{\text{brake}} \) is the braking force, and the bar above each of the variables indicates the distance-averaged value of the variable, calculated as

\[ \overline{F} = \frac{\int_{x_1}^{x_2} F(x) \, dx}{(x_2 - x_1)} \]  
\hspace{1cm} (eq. 3.2)

The average propelling force \( \overline{F}_{\text{prop}} \) is equal to the work done on the vehicle by the engine per unit of distance travelled. \( \overline{F}_{\text{prop}} \) thus determines the average quantity of fuel consumed per unit of distance. This relationship is given by

\[ E = \frac{G_{\text{spec}} \, h_{\text{2engine}}}{\overline{F}_{\text{prop}} \, h_{\text{2trans}} - \overline{F}_{\text{acc}}} \]  
\hspace{1cm} (eq. 3.3)

where \( E \) is the average fuel economy (in units of distance per volume of fuel, such as miles per gallon or kilometers per liter), \( G_{\text{spec}} \) is the Gibbs free energy of combustion per unit volume of the fuel, \( h_{\text{2engine}} \) is the overall second-law efficiency of the engine, \( \overline{F}_{\text{acc}} \) is the average work per unit distance required to run the vehicle accessories such as air conditioners, fans, and lights, and \( h_{\text{2trans}} \) is the overall mechanical
efficiency of the vehicle's drivetrain — the clutch, transmission, differential, and so on. The work required by the accessories can be generally be treated as roughly proportional to the total work output of the engine. Defining the proportionality constant as $f_{acc}$, equations 3.3 and 3.1 can be combined to give

$$E = \frac{G_{spec} \beta_{engine} (1.0 - f_{acc}) \beta_{trans}}{F_{drag} + F_{rr} + F_{brake}} \quad (eq. 3.4)$$

which is the form that will be used in the sections which follow. The individual components of equation 3.4 are discussed in Sections 3.2.1 through 3.2.6 below.

3.2.1 Energy Content of Fuels

The work that could theoretically be produced by a chemical reaction is measured by the Gibbs free energy of reaction (the difference between the free energies of the reactants and the products under standard conditions)

$$\Delta G = \Delta H - T \Delta S = H_p - H_r - T (S_p - S_r) \quad (eq. 3.5)$$

where $G$ is the Gibbs free energy, $H$ is the enthalpy, and $S$ is the entropy, while the subscripts $p$ and $r$ refer to the products and reactants, respectively.
For automotive fuels, the reaction of interest is the complete oxidation of the fuel in air. By convention, the water produced by the reaction is assumed to be produced in the vapor phase, thus the value of $\Delta H$ used in equation 3.5 should be the lower heating value of the fuel. For practical fuels, the entropy of reaction is small, so that the Gibbs free energy is essentially the same as the lower heating value. Since this value is commonly tabulated, while the Gibbs free energy is not, the subsequent calculations will be based on the enthalpies and not the free energies of the fuels.

Table 3.2 shows the enthalpies of reaction per unit of volume for a number of common fuels, in both SI and old English units. No significant changes in the volumetric energy content of any of these fuels are in prospect.

3.2.2 Engine Efficiency

The Gibbs free energy of combustion measures the amount of work that a fuel could theoretically provide, assuming that it was oxidized in a perfectly reversible process. The actual combustion and energy-conversion process is highly irreversible, however, so that the work produced by an burning a fuel in an internal combustion energy is much less than the theoretical maximum. The engine efficiency $\eta_{\text{engine}}$ is defined as the fraction of the theoretically available work that is actually obtained. In general, $\eta_{\text{engine}}$ is strongly affected by the particular conditions of speed and load under which the engine operates. Since these vary constantly during driving, the quantity of greatest interest is the
Table 3.2: Enthalpy of combustion per unit volume for various automotive fuels

<table>
<thead>
<tr>
<th>FUEL</th>
<th>$G_{\text{spec}}$ (kJ/liter)</th>
<th>$G_{\text{spec}}$ (ft-lb/gallon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>32,490</td>
<td>90.71 x $10^6$</td>
</tr>
<tr>
<td>Light Diesel Oil (Gas Oil)</td>
<td>37,190</td>
<td>103.82 x $10^6$</td>
</tr>
<tr>
<td>Ethanol (Ethyl Alcohol)</td>
<td>21,330</td>
<td>59.55 x $10^6$</td>
</tr>
<tr>
<td>Methanol (Methyl Alcohol)</td>
<td>15,890</td>
<td>44.36 x $10^6$</td>
</tr>
</tbody>
</table>

Source: calculated from data in Taylor (1968).
average efficiency, $\overline{\eta}_{\text{engine}}$, over the driving cycle.

The overall efficiency $\overline{\eta}_{\text{engine}}$ of an internal combustion engine can be expressed as the product of two factors: the indicated efficiency $\overline{\eta}_i$ and the mechanical efficiency $\overline{\eta}_m$. The indicated efficiency measures the fraction of the total theoretical energy in the fuel that is transformed into work done by the combustion gases on the engine. In a reciprocating engine, this is the work done in pushing on the pistons. Mechanical efficiency measures the ratio of the work done on the engine by the hot gases to the engine's work output — i.e. at the engine flywheel.

The indicated efficiency is primarily determined by the engine's compression ratio and the conditions of combustion, and is typically rather low — most of the losses in an internal combustion engine are due to this cause. Typical values of $\overline{\eta}_i$ for diesel engines are in the range of 0.4 to 0.55 (Taylor, 1968), while those for gasoline spark-ignition engines are about 0.2 to 0.4, as a result of their lower compression ratios.

Mechanical efficiency is determined mostly by the mechanical design of the engine. The mechanical losses in an engine are dominated by frictional losses in the piston/cylinder and in the valve train, and can be reduced by steps which reduce sliding friction in these areas. These steps include the use of roller rather than sliding followers on camshafts, and the proper selection of lubricating oils (use of special low-friction oils is advantageous, but even using the right grade of ordinary oil shows
significant improvements). Mechanical efficiency is also affected by the need to drive various essential peripheral devices, such as the water pump and cooling fan. Other engine-driven accessories, such as air-conditioners and alternators, have a similar effect on the engine's total power output, but are accounted for separately by means of the factor $f_{acc}$. Typical values for mechanical efficiency are about 0.8 to 0.9 near full load, but this drops sharply at light loads, and reaches zero at idle.

The average overall efficiency of an internal combustion engine is a complicated function of the engine's design, its operating conditions, and the interactions between them. Under favorable operating conditions, the overall thermal efficiency for a heavy-duty direct-injection truck engine is about 40 percent (Tholen, 1983), which is comparable to the best present-day steam-electric plants. At the other end of the scale, the overall thermal efficiency of a typical spark-ignition gasoline engine at full load is about 27 percent, and this drops to about 18 percent at 1/4 load (Price, 1982). In typical urban driving, this value is about 19 percent.

Comparable efficiency values for diesel engines are about 24 to 28 percent for passenger car IDI engines (calculated from Wade et alia, 1984). Estimates by U.S. manufacturers (Energy and Environmental Analysis, 1983) give values of 27 percent for the diesel engines used in current medium-duty trucks, 31 percent for engines used in light-heavy trucks, and 35 percent for those in the heaviest trucks. The new direct-injection
diesel engines being introduced in light-duty vehicles (Wade, 1985) have efficiencies in the range of 27 to 31 percent.

The same heavy-duty manufacturers cited above projected future efficiency values of 31, 37, and 44 percent in 1992 for medium, light-heavy, and heavy-duty diesel engines, respectively, and values of 31, 39, and 46 percent, respectively in 2002. Since spark-ignition engine technology has already developed greatly in the last decade, similar improvements in gasoline engines are unlikely.

3.2.3 Efficiency of Power Transmission

The power transmission system consists of the machinery which couples the engine to the drive wheels of a vehicle. In most vehicles, this system consists of a set of transmission gears, a drive shaft, and differential gearing on the drive axle(s). The arrangement is somewhat different for front-wheel drive vehicles, but the basic components of transmission and differential gearing are the same.

Depending on its design, the power transmission system can result in significant fuel-economy losses. One set of losses is due to the power lost to friction in the transmission itself; this may amount to as little as five percent or as much as 25 percent of the power input. This effect is accounted for by the factor $\eta_{\text{trans}}$ in equation 3.4. Another, equally important effect results from the effect of the transmission on engine speed. The transmission system determines the ratio between revolutions
of the engine and revolutions of the drive wheels, and thus determines whether the engine is operating in or near the optimum speed range at normal cruising speeds or in some region of lower efficiency. Generally, operating near the optimal speed for fuel economy results in inadequate hill-climbing and acceleration power, so that transmission design involves a compromise between fuel-economy and driving characteristics. Depending on the outcome of this compromise, a vehicle's average fuel economy can be significantly affected.

Two general types of transmissions are in common use: manual transmissions and automatic transmissions. Both rely on a set of fixed-ratio gears between the engine and the drive-train, thus the number of possible ratios between the engine speed and the vehicle speed is limited to a small number (generally 3 to 5). An alternative approach — the continuously variable transmission or CVT — is now under active development by a number of manufacturers, and a few vehicles using it have been produced commercially. Use of the CVT is expected to become widespread by about 1990.

In the manual transmission, the engine is connected and disconnected from the gear train by means of a clutch operated by the driver, who is also responsible for manually selecting the gear to be used. Because there are no sliding or fluid components (other than the sliding of the clutch during engagement and disengagement), the mechanical efficiency of the manual transmission is high, generally in the range of 90 to 95 percent. The lower figure is probably more appropriate for buses and passenger
cars, while the higher value would apply to heavy trucks. Because of their simplicity, low cost, and light weight, most developing-country vehicles use manual transmissions.

In the automatic transmission, a fluid coupling connects the engine to the gear train, permitting some slip between the two. A system of automatically operated clutches in the transmission selects the gear ratio to be used, depending on the speed and the force being exerted by the engine. Earlier automatic transmissions were entirely mechanical, and relied on the slip permitted by the fluid coupling to prevent excessive jerkiness and discomfort in shifting. Because of the inefficiency of the fluid coupling, the mechanical efficiency of these transmissions was only about 75 percent. Currently, many automatic transmissions rely on microprocessor control of shifting, and include a mechanical or "lockup" clutch in addition to the fluid coupling. This clutch eliminates transmission slip except during gear-changes, and thus improves the efficiency. Typical efficiencies for these transmissions are about 85 to 90 percent.

Continuously variable transmissions generally involve some sliding or fluid components, and thus will probably not exhibit the same mechanical efficiency as a manual transmission. Typical efficiencies for these components will probably be in the range of 85 to 90 percent. However, CVTs will allow for optimal matching between the engine and drivetrain, allowing the engine to work under its most efficient conditions. This is expected to result in an increase in average engine efficiency of the
order of 15 percent (Price, 1982). The use of advanced automatic transmissions is expected to result in a similar, but smaller increase of the order of 5 to 10 percent.

3.2.4 Aerodynamic Drag

The force exerted by the atmosphere on a moving body can be approximated by the following relationship:

\[ F_{\text{drag}} = C_d A \varphi \frac{V^2}{2} \]  

(eq. 3.6)

where \( F_{\text{drag}} \) is the aerodynamic drag force, \( V \) is the body's velocity in meters per second, \( A \) is the body's frontal area in square meters, \( \varphi \) is the density of atmospheric air in kilograms per cubic meter, and \( C_d \) is the dimensionless drag coefficient, which is a characteristic of the shape of the body. In general, \( C_d \) changes as a weak function of the Reynolds number, but for practical purposes the drag coefficient of a motor vehicle can be taken as constant over a wide range of speeds. The drag coefficient of larger vehicles is affected by crosswinds, however. For trucks and buses, the value of \( C_d \) can increase by as much as 40 percent in a stiff crosswind (Cooper, 1980).

Equation 3.6 shows that the average retarding force due to aerodynamic drag, \( F_{\text{drag}} \), is a function of three parameters: the frontal area \( A \), the drag coefficient \( C_d \), and the average value of \( V^2 \), which is denoted as \( D \) for
convenience. The value of D is given by the following equation

$$D = \frac{\sqrt{V^2} \int_{X_1}^{X_2} V^2 \, dx}{(X_2 - X_1)}$$  \hspace{1cm} (eq. 3.7)

As equation 3.7 indicates, D is a function only of the driving patterns the vehicle experiences, and is thus effectively beyond the control of the designer. Similarly, the frontal area A is generally more-or-less dictated by the functional requirements of the vehicle, such as allowing driver and passengers to sit upright, containing the required cargo, and so on. Thus the most promising approach to reducing aerodynamic drag losses is through reducing the drag coefficient, $C_d$. Fortunately, there is considerable room for improvement along these lines.

The drag coefficient $C_d$ is a measure of the degree of disturbance in the surrounding air caused by the passage of a vehicle. This disturbance can be minimized by means of careful design and testing of model vehicles -- a process which is now well advanced at most passenger-car manufacturers, and which is increasingly being pursued by heavy truck manufacturers as well. Drag reductions of as much as 40 percent have been documented for both heavy trucks and passenger cars, and have been achieved by design changes having little effect on the vehicle's functionality. Further improvements, perhaps involving more extensive modifications, are in prospect.

Typical $C_d$ values for the passenger car models of the late '70s and early
'80s (many of which are still being produced) range from 0.4 to 0.55 (Price, 1982). A value of about 0.5 is estimated to be reasonably typical of the cars now in use in developing nations. However, many cars now being introduced have $C_d$ s ranging from 0.3 to 0.35, giving a 30 to 40 percent reduction in drag from the 1980 values. Concept cars with $C_d$ as low as 0.2 have been produced by a number of auto makers, and it appears certain that further reductions in drag for production vehicles will occur. One recent study (Price, 1982) suggests that the average $C_d$ for new passenger cars — presently about 0.4 — will decline to about 0.35 by 1990, and to 0.3 (considered to be the practical limit) by 1996.

Because of their length and angularity, typical drag coefficients for heavy trucks are considerably higher than those for passenger cars. For single-unit trucks with enclosed "box" bodies, typical drag coefficients under average crosswind conditions are about 0.8 to 1.0, while values for tractor-trailers about about 1.0 to 1.1 (Cooper, 1982). Double truck-trailers would have even higher drag. Drag coefficients would also be much higher for most other truck types, such as flatbeds, tankers, stake trucks, and so on, although in most cases the reduction in frontal area with these other types would offset this.

Data on drag coefficients of light trucks are unavailable, but consideration of the heavy-truck data suggests that $C_d$ s in the range of 0.5 to 0.9 are probably typical, with the upper end of the range applying to pickups, and the lower end to vans and other enclosed types. Drag coefficients for buses are typically in the range of 0.5 to 0.7 (McDonald
and Palmer, 1980).

Because of the economic importance of drag reduction in heavy trucks, a great deal of research and development in this area is being done. Translation of current development results into practice is expected to reduce drag coefficients for long-haul trucks by 50 percent over the next two decades, with much of this benefit accruing by 1990 (Energy and Environmental Analysis, 1983). For the smaller light-heavy, medium, and light-duty trucks, drag reduction is less important, since these vehicles operate mostly in urban situations and at low speeds. However, a 20 to 30 percent $C_d$ reduction in these classes still appears probable. A similar level of drag reduction for buses, especially interurban buses, is also anticipated.

3.2.5 Rolling Resistance

The force of rolling resistance, $F_{rr}$, is due primarily to frictional losses within the tires, caused by hysteresis during the tire's deformation as it contacts the road. The rate of energy loss is directly proportional to the mass of the vehicle and its speed, implying that the force $F_{rr}$ is a linear function of the vehicle's weight.

$$F_{rr} = g M_{veh} C_{rr} \quad (eq. \ 3.8)$$

where $M_{veh}$ is the mass of the vehicle in the appropriate units (pounds
mass or kilograms), while $g$ is the earth's gravity, expressed in units of force per unit mass. In SI units, $g$ is approximately 9.81 N/kg, while in the old English system it is 1.00 pounds force per pound mass. The constant of proportionality, $C_{rr}$, is known as the coefficient of rolling resistance. It is determined primarily by the type (radial or bias ply), the composition, and the inflation pressure of the tires. Typical values for $C_{rr}$ range from 0.014 to 0.010 for passenger-car and light-truck tires, with the former value being typical of bias tires and the latter of radials. Radial tires with an average $C_{rr}$ value of 0.008 are projected to be available by about 1990 (Price, 1982).

Truck and bus tires operate at higher pressures, and thus experience less loss due to hysteresis. Typical $C_{rr}$ values for heavy-duty vehicles are about 0.010 (for bias tires) to 0.06 (for radials). Heavy-duty radial tires are more susceptible to sidewall damage than bias-ply tires, however, which limits their applicability in many developing nations (Energy and Environmental Analysis, 1983). Because of the importance of rolling resistance in fuel consumption, both bias-ply and radial tires for heavy-duty vehicles are expected to undergo continuing improvements over the next twenty years. This development is projected to give an additional 4 to 8 percent improvement in fuel consumption for heavy trucks, implying a reduction in rolling resistance of the order of 20 percent.
3.2.6 *Braking Losses*

The force of the vehicle's brakes in stopping it is an indirect contributor to fuel consumption. In order to accelerate a vehicle to speed, the engine must do work on it, increasing the kinetic energy of the vehicle. Applying the brakes dissipates this kinetic energy in the form of heat. This stops the vehicle, which then requires more work to accelerate it again. The energy required to accelerate the vehicle is directly proportional to the vehicle's mass, thus

\[ F_{\text{brake}} = K M_{\text{veh}} \]  

(eq. 3.9)

where the parameter \( K \) is a function only of the driving pattern. For urban driving with much stop-and-go traffic, \( K \) is large, and thus the average braking losses are very high. This would also be the case for urban transit buses, which exhibit a continuous stop-and-accelerate pattern. In highway driving, on the other hand, \( K \) will usually be very small, since braking losses usually make up a negligible fraction of total highway fuel consumption.

Two approaches to reducing braking losses are possible: reducing the mass of the vehicle and reducing the value of \( K \). The latter can be achieved only by changes in traffic conditions (by building expressways, for instance) or in driving habits. These are beyond the scope of this Chapter. Reductions in vehicle mass can be more straightforwardly
achieved, and have the additional advantage that they reduce rolling losses as well, since these are also proportional to the vehicle's mass. Weight reduction, along with drag reduction, thus plays a central role in most manufacturers' attempts to reduce fuel consumption.

Reduced vehicle mass can be achieved either by reducing the size of the vehicle, or by building the same size vehicle out of lighter materials and more efficient structural designs. The former approach, "downsizing", is clearly possible only where the size was greater than necessary in the first place. This is true to a considerable extent in passenger cars and to a lesser extent in light trucks. However, most heavy commercial vehicles such as trucks and buses are no larger than is required by their functions.

The greatest potential for vehicle mass reduction is in passenger cars. Estimates of the degree of reduction possible vary widely, from about 25 percent to more than 50 percent at some indefinite future time. One credible recent study (Price, 1982) has estimated that the masses of medium-sized U.S. cars (comparable to the "large car" class discussed above) will be reduced 24 percent by 1990 and 30 percent by 2000 from their 1980 levels. For subcompact cars (comparable to the "small car" class) the corresponding reductions were estimated at 18 and 24 percent for 1990 and 2000, respectively.

Since about two-thirds of the weight of a heavy truck is payload, the potential for weight reduction in this class is limited. In addition, the
desire to increase payloads to the maximum possible, given legal weight and axle-loading limits, has already generated considerable pressure for weight reduction. Little, if any, additional weight reduction is expected to be feasible in this class. For light-heavy trucks, the situation is somewhat different, since the pressures for weight reduction in this class have been lower. (Most light-heavy trucks will "cube-out" or run out of cargo volume before they "gross-out" or exceed their maximum weight). Weight reductions of the order of 500 KG have been predicted for this class, resulting in about a 4 percent improvement in fuel consumption. Improvements of similar magnitude appear possible for buses as well.

3.3 VEHICLE TECHNOLOGIES AND FUEL CONSUMPTION: PRESENT AND FUTURE POSSIBILITIES

Changes in fuel-efficiency and other vehicle characteristics can occur in one of two ways. First, there are the "evolutionary" changes, resulting from incremental improvements to existing patterns. These evolutionary changes occur more or less continuously in the development of a product. Less frequent, but of greater impact, are the "revolutionary" changes which result from a major change in the "package" of technologies being applied. This section attempts to characterize both types of changes. For each class of vehicles, a number of possible alternative technology "packages", each having set cost and fuel consumption characteristics, are defined. The consumer's choice between these packages determines in large degree the characteristics of the vehicles in use. The characteristics of these packages are not fixed however — they can and do evolve over time. Estimates of the extent of this evolution and its consequences are also
3.3.1 PASSENGER CARS

Equations 3.4 and 3.6 through 3.9 can be combined to give the following expression for a vehicle's fuel economy in terms of fundamental parameters.

\[
E = \frac{G_{\text{spec}} \cdot \eta_{\text{engine}} \cdot (1.0 - f_{\text{acc}}) \cdot \eta_{\text{trans}}}{\frac{1}{2} A \cdot \rho \cdot C_d \cdot D + M_{\text{veh}} \cdot (K + g \cdot C_{rr})}
\]  

(eq. 3.10)

For a typical small passenger car, \(E\) is approximately 10.4 km/liter (25 MPG), \(M_{\text{veh}}\) is about 1200 kilograms, and \(C_d\) is about 0.5. Taking the engine thermal efficiency \(\eta_{\text{engine}}\) as 0.20 for a gasoline engine, \(\eta_{\text{trans}}\) as 0.9 for a manual transmission, \(f_{\text{acc}}\) as about 0.1, and \(C_{rr}\) as about 0.012 for good bias tires, it is possible to calculate either of the two usage-dependent factors \(D\) and \(K\) in terms of the other. A recent study (Price, 1982) has estimated that the forces of drag, rolling resistance, and braking losses contribute 28, 27, and 45 percent of the total frictional losses, respectively, in passenger cars. Using these values in combination with the data above, it is possible to calculate both \(D\) and \(K\), as follows.

\[
D = 0.28 \left[ \frac{G_{\text{spec}} \cdot \eta_{\text{engine}} \cdot (1.0 - f_{\text{acc}}) \cdot \eta_{\text{trans}}}{\frac{1}{2} A \cdot \rho \cdot C_d \cdot E} \right] = 119 \text{ m}^2/\text{s}^2 \]  

(eq. 3.11)
and

\[ K = 0.45 \left( \frac{G_{\text{spec}} \beta_{\text{engine}} (1.0 - f_{\text{acc}}) \beta_{\text{trans}}}{E M_{\text{veh}}} \right) = 0.190 \, \text{N/kg} \]  

(eq. 3.12)

Since \( D \) and \( K \) depend only on driving patterns and not on vehicle characteristics, very similar values should be applicable to large cars, taxicabs, and light trucks. Buses and heavy trucks have very different operating patterns, however, and thus require a separate calculation.

Given these values for \( D \) and \( K \), and with appropriate assumptions concerning the values of the other parameters, equation 3.10 can be used to calculate the fuel economy of any passenger car or similar vehicle, now or in the future. Tables 3.3 through 3.5 show the results of this calculation for each of the three classes of passenger cars considered, for four different vehicle technology "packages", and for a number of years between 1980 and 2000. The technology package characteristics and other assumptions used in deriving these tables are discussed below. It should be noted that the values shown are intended to be indicative of trends rather than definitive -- if they are used, they should be used with caution, and with due consideration of the special circumstances in each country.

**Technology Packages** — Most passenger cars used in the developing world use what will be called the "standard" gasoline car technology. This technology was universal until the early 70's, but has largely faded from the scene in the developed world. Its distinguishing characteristics are...
Table 3.3: Projected technical parameters and fuel economy for vehicles in class: Small Passenger Car

**Invariant Parameters**

- Average speed parameter: \( D = 236.00 \, \text{m}^2/\text{s}^2 \)
- Vehicle frontal area: \( A = 2.00 \, \text{m}^2 \)
- Braking loss parameter: \( K = 0.19 \, \text{N/kg} \)

**TECHNOLOGY PACKAGES**

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-72-
Table 3.4: Projected technical parameters and fuel economy for vehicles in class: Large Passenger Car

**Invariant Parameters**

- Average speed parameter \( D = 236.00 \text{ m}^2/\text{s}^2 \)
- Vehicle frontal area \( A = 2.70 \text{ m}^2 \)
- Braking loss parameter \( K = 0.19 \text{ N/kg} \)

**Technology Packages**

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Table 3.5: Projected technical parameters and fuel economy for vehicles in class: Taxicab

**Invariant Parameters**

- Average speed parameter \( D = 260.00 \, \text{m}^2/\text{s}^2 \)
- Vehicle frontal area \( A = 2.70 \, \text{m}^2 \)
- Braking loss parameter \( K = 0.23 \, \text{N/kg} \)

**Technology Packages**

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**High-Efficiency Gasoline**

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**Indirect-Injection Diesel**

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carbureted rather than fuel-injected engines, simple mechanical controls rather than electronics, little or no attention to aerodynamics, and a heavy stamped-steel body on a welded-steel chassis. The fuel-economy and performance of these vehicles are generally only moderate, but they are simple, robust, tolerant of poor fuels and bad conditions, and can be repaired by relatively unskilled labor.

Two major alternatives to the "standard" technology are now available in the developed world. The first, denoted as "high-efficiency" spark-ignition technology, makes use of technological advances in engine design, electronic control of fuel injection and spark timing, weight-reduction techniques, and improved aerodynamics to obtain substantially greater efficiency than is possible with the standard technology. For even greater efficiency, the spark-ignition engine may be replaced with an indirect-injection (IDI) diesel. Beginning in the latter half of the 1980s, a third alternative will be available, in the form of small direct-injection (DI) diesel engines for passenger cars. DI diesels generally exhibit thermal efficiency values which are 10 to 15 percent better than IDI engines.

The values in Tables 3.3 through 3.5 indicate the differences in engine efficiency and other characteristics that are ascribable to these different technology packages, as well as showing the projected evolution of these characteristics through time. Although most of the values shown are self-explanatory, a few words of explanation in some cases are appropriate.
The driving-pattern related parameters, \( D \) and \( K \), are assumed not to vary with time. For the small-car and large-car classes, these parameters are assumed to have the values derived above. In the case of taxicabs, however, \( D \) has been increased by 10 percent and \( K \) by 20 percent to reflect the faster and more aggressive driving of taxis. Except for this change, the taxicab and large-car classes are assumed to be identical. The lower transmission efficiencies indicated for these classes are due to the greater use of automatic transmissions in large cars, while the higher thermal efficiencies in later years reflect the use of advanced automatic and/or CVT transmissions in these classes.

The vehicle mass changes and drag coefficients shown in the tables generally follow those projected by the California Energy Commission (Price, 1982), except for the "standard" technology, which is assumed to evolve only slightly with time. The vehicle masses shown include 150 kg for the driver and passengers, as well as the mass of the vehicle itself. The extra mass of a diesel engine (compared with a gasoline engines of equal power) is estimated as 50 kg for a small car and 100 kg for a large one. This includes the additional structural mass required to support the engine, as well as that of the engine itself. The engine thermal efficiencies shown follow the Energy Commission data, but with modifications based on Wade and coworkers (1984). The values for direct-injection diesels are based in part on projections by heavy-duty diesel manufacturers, reported in Energy and Environmental Analysis (1983).
The results of these calculations indicate that average new-vehicle fuel economy will change from a 1980 value of about 10.3 km/liter (24 MPG) for small cars to between 20 and 26 km/liter (48 to 63 MPG) in 2000. For large cars, the typical fuel economy will increase from 6.8 km/l (16 MPG) to between 17 and 20 (40 to 49 MPG). These represent very large improvements in fuel economy, and may appear suspect for that reason. However, these values are in general agreement with the results of a number of other studies, including those of the California Energy Commission, Horton and Compton (1984), and Alic et alia (1983). The latter study (among the most optimistic) projects potential fuel economies as high as 84 MPG for small cars, 71 MPG for medium cars, and 49 MPG for large cars by the year 2000. The reader is cautioned again, however, that these are indicative values only, and that the values used in modeling any particular case should be based on careful consideration of individual circumstances.

3.3.2 LIGHT-DUTY TRUCKS

Light trucks closely resemble passenger cars in their technical characteristics, and can generally be expected to follow the same technical development path as passenger cars. The operational characteristics of light trucks are also similar to those of passenger cars. This is fortunate, since comparatively little information on fuel economy and similar issues is available for light trucks as a group—they have not received nearly the level of study that passenger cars have.
Tables 3.6 and 3.7 show the estimated fuel-efficiency levels for both small and large light trucks, for a number of years between 1979 and 2000. The model parameters used in calculating these efficiencies are also shown. Generally, the development of this class is expected to parallel that of the passenger cars, so that most of the technical parameters for the two classes are the same. In the absence of data which would permit a separate calculation, the two driving-pattern dependent parameters $D$ and $K$ have also been taken to be the same as those for passenger cars. The drag coefficients $C_d$ are larger for the trucks, however, reflecting the prevalence of pickup bodies, which have very high drag. Weight reduction is also expected to be less effective in light trucks than in passenger cars.

TECHNOLOGY PACKAGES — The technology packages defined for light trucks are the same as those defined for passenger cars. These are: the standard gasoline-fueled technology of the late 70's; a high-efficiency gasoline-fueled package incorporating more efficient engines, weight reduction, aerodynamic improvements (which for trucks would include enclosing the pickup bed), and radial tires; an IDI diesel package incorporating the same improvements plus a diesel engine; and finally the DI diesel package, which is identical to the IDI package except for using the more efficient direct-injection diesel.

The present-day fuel economy calculated using these assumptions is about 9 km/l (21 MPG) for small light trucks and 6 km/l (14 MPG) for large ones,
Table 3.6: Projected technical parameters and fuel economy for vehicles in class: Small Light Truck

**Invariant Parameters**

- Average speed parameter \( D = 236.00 \, m^2/s^2 \)
- Vehicle frontal area \( A = 2.20 \, m^2 \)
- Braking loss parameter \( K = 0.19 \, N/kg \)

**Technology Packages**

<table>
<thead>
<tr>
<th>( M_{veh} ) (kg)</th>
<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>( h_{\text{engine}} )</th>
<th>( h_{\text{trans}} )</th>
<th>( f_{acc} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
</tr>
</thead>
</table>

**Standard Gasoline**

- 1979: 1300, 0.60, 0.012, 0.20, 0.90, 0.10, 9.0, 21.1
- 1985: 1300, 0.60, 0.012, 0.20, 0.90, 0.10, 9.0, 21.1
- 1990: 1300, 0.60, 0.011, 0.20, 0.90, 0.10, 9.2, 21.5
- 2000: 1300, 0.60, 0.010, 0.20, 0.90, 0.10, 9.4, 22.0

**High-Efficiency Gasoline**

- 1981: 1300, 0.60, 0.011, 0.21, 0.90, 0.10, 9.6, 22.6
- 1985: 1250, 0.55, 0.010, 0.23, 0.90, 0.09, 11.5, 27.0
- 1990: 1200, 0.50, 0.009, 0.24, 0.90, 0.09, 13.0, 30.6
- 2000: 1150, 0.45, 0.008, 0.25, 0.90, 0.08, 15.0, 35.2

**Indirect-Injection Diesel**

- 1979: 1350, 0.60, 0.011, 0.24, 0.90, 0.10, 12.3, 28.8
- 1985: 1300, 0.55, 0.010, 0.24, 0.90, 0.09, 13.4, 31.4
- 1990: 1250, 0.50, 0.009, 0.25, 0.90, 0.09, 15.1, 35.5
- 2000: 1200, 0.45, 0.008, 0.26, 0.90, 0.08, 17.3, 40.7

**Direct-Injection Diesel**

- 1985: 1300, 0.55, 0.010, 0.27, 0.90, 0.09, 15.0, 35.4
- 1990: 1250, 0.50, 0.009, 0.30, 0.90, 0.09, 18.1, 42.6
- 2000: 1200, 0.45, 0.008, 0.30, 0.90, 0.08, 20.0, 46.9
Table 3.7: Projected technical parameters and fuel economy for vehicles in class: Large Light Truck

**Invariant Parameters**

- Average speed parameter $D = 236.00 \text{ m}^2/\text{s}^2$
- Vehicle frontal area $A = 3.00 \text{ m}^2$
- Braking loss parameter $K = 0.19 \text{ N/kg}$

**Technology Packages**

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<tr>
<th>Technology</th>
<th>$M_{\text{veh}}$ (kg)</th>
<th>$C_d$</th>
<th>$C_{rr}$</th>
<th>$h_{\text{engine}}$</th>
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<th>$f_{\text{acc}}$</th>
<th>$E$ (km/l)</th>
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-80-
using the standard technology. IDI diesel trucks range from 12.3 km/l (29 MPG) to 8.2 km/l (19 MPG). These values are in good agreement with studies by other workers, such as Loos and coworkers (1984), Lax (1981), and Energy and Environmental Analysis (1983). Only the last of these studies contained any future projections, and only for the larger light trucks. This study predicted a fuel-economy for large light trucks of 14 MPG (gas) and 22 MPG (IDI diesel). These are generally consistent with the projections shown here.

3.3.3 MEDIUM AND HEAVY-DUTY TRUCKS

Due to the long distances they travel and the economic importance of the large amounts of fuel they consume, heavy-duty trucks have received a great deal of study, and thus their fuel-consumption characteristics are well understood. Virtually all of this study has focussed on on-highway fuel consumption. Much less attention has been devoted to the fuel consumption characteristics of medium and light-heavy duty trucks, or to the in-city fuel consumption characteristics of heavy trucks. One significant exception to this rule is the study by Energy and Environmental Analysis (1983), which focussed primarily on urban travel. Much of the analysis which follows is based on that work.

For a heavy tractor-trailer combination at highway speeds, aerodynamic drag accounts for about 50 to 60 percent of total losses (Energy and Environmental Analysis, 1983; Cooper, 1982). Rolling friction accounts for the other 40 to 50 percent (braking losses are negligible except in hilly
terrain). Taking 50 percent as typical, and choosing typical values for of $C_{rr}$ of 0.009 (Schuring and Redfield, 1982), and $\gamma_{\text{engine}}$ equal to 0.35, $\gamma_{\text{trans}}$ equal to 0.85, and $M_{\text{veh}}$ at 30 metric tons, one can calculate total fuel consumption as

$$E = \frac{G_{\text{spec}} \gamma_{\text{engine}} (1.0-f_{\text{acc}}) \gamma_{\text{trans}}}{M_{\text{veh}} (K+gC_{rr})} \times 0.50 = 1.9 \text{ km/l} \quad (\text{eq. } 3.13)$$

For a tractor with a van trailer and no special drag-reducing devices, $C_d$ is about 1.0 and $A$ is 9.3 m$^2$. With these assumptions, $D$ can be computed as

$$D = 0.50 \left[ \frac{G_{\text{spec}} \gamma_{\text{engine}} (1.0-f_{\text{acc}}) \gamma_{\text{trans}}}{1/2 A \gamma C_d E} \right] = 468 \text{ m}^2/\text{s}^2 \quad (\text{eq. } 3.14)$$

Since braking losses are negligible in highway operation, $K$ is nearly zero.

In urban operation, drag accounts for only about 15 percent of total frictional losses (Energy and Environmental Analysis, 1983), while total fuel consumption is increased roughly 20 percent from the on-highway level (Jambekar and Johnson, 1981). Since the actual (not percentage) losses due to rolling resistance are independent of speed, this implies that rolling losses should account for 42 percent of in-city fuel consumption, leaving 43 percent to be accounted for by braking losses. The corresponding values of $D$ and $K$ for city operation are readily computed.
D = 0.15 \left[ \frac{G_{\text{spec}} \beta_{\text{engine}} (1.0 - \beta_{\text{acc}}) \beta_{\text{trans}}}{\frac{1}{2} A_y C_d E} \right] = 168 \, \text{m}^2/\text{s}^2 \quad (\text{eq. 3.15})

and

K = 0.43 \left[ \frac{G_{\text{spec}} \beta_{\text{engine}} (1.0 - \beta_{\text{acc}}) \beta_{\text{trans}}}{M_{\text{veh}} E} \right] = 0.08 \, \text{N/kg} \quad (\text{eq. 3.16})

In the United States, about 20 percent of total tractor-trailer mileage is accumulated in urban areas, with the remainder being highway travel (Energy and Environmental Analysis, 1983). Combining the city and highway values for D and K according to this same 20/80 split results in composite averages of 0.02 N/kg for K and 408 m$^2$/s$^2$ for D. These are the values used in calculating the "heavy truck" fuel economy characteristics shown in Table 3.10.

In the United States, light-heavy and medium-duty trucks operate mostly in urban areas, and the same is probably true in most developing nations. Thus, in general, braking losses will be higher and drag losses lower than for heavy trucks. Unfortunately, adequate data from which to calculate the driving-cycle dependent parameters are not available. However, approximate values for D and K for these trucks can be obtained from the corresponding values for passenger cars and heavy trucks by the application of some qualitative reasoning.

Light-heavy trucks have higher power/weight ratios than do heavy trucks, and can thus accelerate more rapidly. Medium trucks can accelerate more rapidly still. Because of this, braking losses in traffic should be
greater than for heavy trucks (due to the subsequent need to decelerate more rapidly), while average speed values should be higher. Acceleration and average speeds for these trucks are lower than for light-duty vehicles, however. Both D and K, then, should be higher than the in-city values for heavy trucks, but significantly lower than those for passenger cars. The values selected are 0.12 N/kg and 190 m²/s² for light-heavy and 0.15 N/kg and 210 m²/s² for medium trucks. These are only rough approximations, but — as shown in Tables 3.8 and 3.9 — they give adequately representative values for fuel consumption in these two classes.

TECHNOLOGY PACKAGES — Medium duty trucks are available with either gasoline or diesel engines. The gasoline-fueled trucks are cheaper and less durable, and are sold mostly where fuel-efficiency is not a significant concern. The diesel versions are more efficient and durable, and more likely to incorporate fuel-saving innovations. These characteristics are reflected in the projections in Table 3.8.

Outside the U.S., light-heavy and heavy-duty trucks are sold almost exclusively with diesel engines because of their better fuel-economy and durability. However, there is considerable variation in cost and performance between engine models in this class. Two alternative technology packages are shown in Tables 3.9 and 3.10: a lower-cost "standard" package embodying basically late-'70s technology with only the most cost-effective improvements; and a higher-cost "high-efficiency" package, incorporating more extensive (and expensive) modifications to
Table 3.8: Projected technical parameters and fuel economy for vehicles in class: Medium Truck

**Invariant Parameters**

- Average speed parameter \( D = 210.00 \ m^2/s^2 \)
- Vehicle frontal area \( A = 4.50 \ m^2 \)
- Braking loss parameter \( K = 0.15 \ N/kg \)

**Technology Packages**

<table>
<thead>
<tr>
<th>Year</th>
<th>( M_{veh} ) (kg)</th>
<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>( h_{engine} )</th>
<th>( h_{trans} )</th>
<th>( f_{acc} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
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</thead>
<tbody>
<tr>
<td>1979</td>
<td>5500</td>
<td>0.80</td>
<td>0.011</td>
<td>0.20</td>
<td>0.90</td>
<td>0.10</td>
<td>2.8</td>
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<tr>
<td>1985</td>
<td>5500</td>
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<td>0.011</td>
<td>0.20</td>
<td>0.90</td>
<td>0.10</td>
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<tr>
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**Direct-Injection Diesel**

<table>
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<th>Year</th>
<th>( M_{veh} ) (kg)</th>
<th>( C_d )</th>
<th>( C_{rr} )</th>
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Table 3.9: Projected technical parameters and fuel economy for vehicles in class: Light-Heavy Truck

**Invariant Parameters**

- Average speed parameter \( D = 190.00 \text{ m}^2/\text{s}^2 \)
- Vehicle frontal area \( A = 7.80 \text{ m}^2 \)
- Braking loss parameter \( K = 0.12 \text{ N/kg} \)

**Technology Packages**

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<th>( C_{rr} )</th>
<th>( h_{\text{engine}} )</th>
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**Advanced-Technology Diesel**

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<td>0.007</td>
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<td>0.04</td>
<td>3.9</td>
<td>9.1</td>
</tr>
</tbody>
</table>
Table 3.10: Projected technical parameters and fuel economy for vehicles in class: Heavy Truck

**Invariant Parameters**

- Average speed parameter: \( D = 408.00 \text{ m}^2/\text{s}^2 \)
- Vehicle frontal area: \( A = 9.30 \text{ m}^2 \)
- Braking loss parameter: \( K = 0.02 \text{ N/kg} \)

**Technology Packages**

<table>
<thead>
<tr>
<th>Year</th>
<th>( M_{\text{veh}} ) (kg)</th>
<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>( \eta_{\text{engine}} )</th>
<th>( \eta_{\text{trans}} )</th>
<th>( f_{\text{acc}} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
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<td>0.010</td>
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<td>0.90</td>
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<td>0.009</td>
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**Advanced-Technology Diesel**

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<th>Year</th>
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<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>( \eta_{\text{engine}} )</th>
<th>( \eta_{\text{trans}} )</th>
<th>( f_{\text{acc}} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
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</thead>
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<td>0.008</td>
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<td>0.04</td>
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<tr>
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<tr>
<td>2000</td>
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<td>0.45</td>
<td>0.90</td>
<td>0.04</td>
<td>3.9</td>
<td>9.1</td>
</tr>
</tbody>
</table>
maximize fuel economy. The former would be used where first-cost is the major concern, while the latter would tend to be employed in high-mileage applications where operating cost is the dominant consideration.

Technologies used in the "high-efficiency" trucks would include extensive drag minimization, low rolling-resistance radial tires, and (most importantly) ultra-high efficiency engines. These would include turbocharging with intercooling and advanced fuel-injection in 1985, and adiabatic engine technologies in the 1990s. Heavy trucks (but not light-heavies) would also incorporate turbocompounding during the 1990s as well.

The calculations in Tables 3.9 and 3.10 indicate that by making maximum use of fuel-stretching technologies, heavy trucks could double the fuel economy reached with the standard technology, increasing from 1.8 km/l (4.3 MPG) to 3.9 km/l (9.1 MPG). Light-heavy trucks would do almost as well, increasing from 2.3 km/l to 3.9 (5.5 to 9.1 MPG). These values appear very high, but they are no higher than other studies have indicated. Energy and Environmental Analysis (1983), for instance, projected fuel economies of 8.45 and 10.7 MPG in 1997 for heavy and light-heavy trucks, respectively.

3.3.4 URBAN AND INTERURBAN BUSES

Very little information is available concerning the fuel-consumption characteristics of buses. Although apparently reasonable values can be
derived from the analogous information for heavy trucks, these values more in the nature of educated guesses than hard data. This should be borne in mind in interpreting the results shown, and they should be treated with appropriate caution until they can be verified.

Light buses generally resemble medium and light-heavy trucks in technology and characteristics, and probably have a similar driving cycle. Average speeds are probably more like medium than light-heavy buses, so the value of D used for the light buses was taken to be the same as that for medium trucks. On the other hand, buses accelerate more slowly than medium trucks in order to maintain passenger comfort, thus a K value closer to that for light-heavy rather than medium trucks seems appropriate. As Table 3.11 indicates, use of these values produces apparently reasonable results.

Heavy urban buses operate at very low average speeds, thus the drag losses should be very small. On the other hand, the constant stopping and starting should lead to very high braking losses, thus K should be large. Typical fuel economy for 1980's urban buses is about 3.8 MPG (Chock et alia, 1984) or 1.6 km/l. Combining this fuel economy value with technical characteristics similar to those of light-heavy trucks results in a K value of 0.23 N/kg, as shown in Table 3.12.

Heavy interurban buses have an operating pattern similar to that of heavy trucks. For want of better information, the two patterns have been assumed to be the same, except for slightly more starting and stopping for
the buses. The resulting value for $D$ is $408 \text{ m}^2/\text{s}^2$ — the same as for heavy trucks — with a $K$ value of $0.10 \text{ N/kg}$, which is $0.01$ greater than that for the truck, reflecting the increased stopping and starting. The results are shown in Table 3.13. For comparison, Chock and coworkers projected a fuel economy of 4.7 MPG in the year 2000, which is seen to compare rather well with the projections for the standard technology.

**TECHNOLOGY PACKAGES** — The technology packages assumed for the light bus are the same as those for the medium truck, since the two are technically similar, and are often built on the same chassis. For the heavier buses, the technology packages shown are basically those for the light-heavy truck. This is appropriate, since engines in these buses are generally close derivatives of light-heavy truck engines, derated and adapted for rear-mounting, and would thus be expected to develop in parallel with them.

In the absence of any data or projections except those of Chock and coworkers, it is difficult to evaluate the realism or lack thereof of the values shown. Since these projections are based primarily on projected developments in heavy and light-heavy trucks, and since those projections are reasonably in agreement with those of other workers, the projections shown here would appear to be reasonable as well.
Table 3.11: Projected technical parameters and fuel economy for vehicles in class: Light Bus

**Invariant Parameters**

Average speed parameter \( D = 210.00 \, \text{m}^2/\text{s}^2 \)

Vehicle frontal area \( A = 6.00 \, \text{m}^2 \)

Braking loss parameter \( K = 0.12 \, \text{N/kg} \)

**Technology Packages**

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<tr>
<th>Year</th>
<th>Engine Type</th>
<th>( M_{\text{veh}} ) (kg)</th>
<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>Engine</th>
<th>Trans</th>
<th>( f_{\text{acc}} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
</tr>
</thead>
<tbody>
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<tr>
<td>1985</td>
<td></td>
<td>9000</td>
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<td>0.010</td>
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<td>0.15</td>
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<td>0.009</td>
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<td>0.90</td>
<td>0.15</td>
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</tr>
<tr>
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<td>8600</td>
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<tr>
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<td>0.90</td>
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<td>11.2</td>
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</table>
Table 3.12: Projected technical parameters and fuel economy for vehicles, in class: Heavy Urban Bus

**Invariant Parameters**

- Average speed parameter: \( D = 80.00 \text{ m}^2/\text{s}^2 \)
- Vehicle frontal area: \( A = 8.00 \text{ m}^2 \)
- Braking loss parameter: \( K = 0.23 \text{ N/kg} \)

**TECHNOLOGY PACKAGES**

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<th>( M_{\text{veh}} ) (kg)</th>
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<th>( C_{rr} )</th>
<th>( h_{\text{engine}} )</th>
<th>( h_{\text{trans}} )</th>
<th>( f_{\text{acc}} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
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</thead>
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<td>0.010</td>
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<td>0.80</td>
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**Advanced-Technology Diesel**

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<th>Years</th>
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<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>( h_{\text{engine}} )</th>
<th>( h_{\text{trans}} )</th>
<th>( f_{\text{acc}} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
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<tr>
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</tbody>
</table>
Table 3.13: Projected technical parameters and fuel economy for vehicles in class: Heavy Interurban Bus

**Invariant Parameters**

- Average speed parameter: \( D = 408.00 \text{ m}^2/\text{s}^2 \)
- Vehicle frontal area: \( A = 8.00 \text{ m}^2 \)
- Braking loss parameter: \( K = 0.10 \text{ N/kg} \)

**Technology Packages**

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<tr>
<th>Year</th>
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<th>( C_d )</th>
<th>( C_{rr} )</th>
<th>Engine ( h )</th>
<th>Trans ( h )</th>
<th>( f_{\text{acc}} )</th>
<th>( E ) (km/l)</th>
<th>( E ) (MPG)</th>
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**Advanced-Technology Diesel**

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<th>( C_{rr} )</th>
<th>Engine ( h )</th>
<th>Trans ( h )</th>
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<th>( E ) (km/l)</th>
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<td>0.010</td>
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<td>0.85</td>
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</table>
4.0 TECHNOLOGY CHOICE AND FUEL CONSUMPTION: AN ENGINEERING-ECONOMIC MODEL

This chapter contains a formal presentation of the mathematical model which is embodied in the TRATEC computer code. The TRATEC model is an engineering/economic model of technology choice, fleet structure, and fuel consumption by highway vehicles. This chapter presents both the formal mathematics making up the model and the reasoning behind them, along with comments on the data requirements. In addition, the chapter discusses some of the limitations and potential shortcomings of the model, and describes some possible pitfalls in its use. The chapter does not discuss the structure and operation of the TRATEC code itself. These are described briefly in Chapter Five, and at greater length in the TRATEC user's manual given in Appendix A.

In terms of the categories developed in Chapter Two, the TRATEC model is a hybrid econometric/mechanistic model, and it includes a sophisticated technology-choice submodel as one of its major components. The emphasis in the model is on the structural and technology-choice rather than the econometric aspects. Econometric variables enter into the model in the form of an estimate of the own-price elasticity of demand for transportation services (measured as demand for vehicle-miles travelled). The model differs from most other mechanistic models by explicitly incorporating technology choice, rather than taking it as exogenous. The fixed assumptions concerning new-vehicle technologies and characteristics, retirement rates, and related variables which are typical of most
mechanistic models have been replaced in the TRATEC model with a sophisticated model of technology choice and consumer demand, based on the assumption of rational, utility-maximizing consumer choice. This is, so far as the author is aware, the first application of a modern technology choice model of this type to the simulation of the automotive fleet.

The presentation of the model is divided into several sections. First and most important is the discussion of the overall structure of the model, which is given in Section 4.1. That section describes the form of the model, presents the overall sequence of calculations, and defines the role of each of the important components of the model within the overall framework. Section 4.1 also defines the symbols used in the mathematics which follow.

Sections 4.2 through 4.8 present the detailed mathematics of each of the major components of the model. Section 4.2 describes how total transportation demand for each class of vehicles and the distribution of demand within each class are determined. Section 4.3 presents the equations used to calculate financial values such as the annual cost of a given vehicle, while Section 4.4 describes the consumer choice model which translates these costs into consumer decisions. Section 4.5 presents the assumptions and mathematics behind the vehicle retirement and vehicle expected-life functions.

All of these sections lead up to Section 4.6, which presents a partial-equilibrium model of the new-vehicle and used-vehicle
marketplace. Starting with the structure of the previous year's fleet, this model estimates both the current-year fleet structure and current-year purchases of new vehicles, broken down by vehicle class and, within classes, by vehicle technology. Since this is the central and crucial component of the TRATEC model, considerable space is given to its presentation and to discussion of the assumptions and logic behind it. Section 4.7 presents the algorithms which operate on the current fleet structure to produce the ultimate results of model: estimates of total fuel consumption, total social and private costs of owning and operating the vehicle fleet, total new-vehicle sales for each technology, and total vehicles of each technology in the fleet. Since these algorithms are not complex (they involve mostly addition and multiplication), their presentation requires little space. Finally, Section 4.8 discusses the calculation of nominal values for cross-price and own-price elasticities of demand for fuel from the model results.

Following the formal presentation of the model, Section 4.9 discusses the model's data requirements and possible sources of the data required. Finally, Section 4.10 presents some concluding comments. This section focusses on the model's strengths and weaknesses, and includes a series of caveats as to the limitations of the assumptions and techniques used.

4.1 LARGE-SCALE STRUCTURE OF THE MODEL

The heart of the TRATEC model, as of all mechanistic models, is an internal representation of the distribution of vehicles and vehicle
characteristics in the vehicle fleet (the "structure" of the fleet) at a given time. As with all such models, the fleet structure at any given time is calculated by applying a defined computational algorithm to the structure of the fleet at some past time. This structure, in turn is derived from some still earlier time, and so forth — back to some assumed initial structure. Where the TRATEC model differs from other models, such as those of Miller et alia (1983), Jambekar and Johnson (1978), and the Department of Energy (Energy and Environmental Analysis, 1982c–d) is in the nature of the internal representation of the fleet structure, and in the nature and sophistication of the rules for calculating the current fleet structure from that of the past.

In the TRATEC model, the structure of the vehicle fleet is closely related to the structure of the market for transportation services. Section 4.1.1 discusses the linked representations of the vehicle fleet and the transportation market structures in the model, while Section 4.1.2 outlines the algorithms used in calculating these structures from those of the past. Section 4.1.3 lays the groundwork for the detailed mathematical discussions in Sections 4.2 through 4.7 by presenting the conventions of nomenclature, and by listing and defining the symbols used.

4.1.1 Structure of the Vehicle Fleet and the Transportation Services Market

The vehicle fleet in a given year is defined as the set of all highway vehicles in use in that year. The TRATEC model divides the fleet into smaller groupings on the basis of three technical characteristics: vehicle
class, model year (taken for simplicity as the year of manufacture), and vehicle technology type. The basis for these divisions was discussed in Chapter Three. In addition, the fleet is further subdivided to correspond with the separate segments of the market for transportation services. The transportation services market is divided by vehicle class and mileage travelled per year, resulting in a four-way division of the vehicle fleet: by class, annual mileage, type of technology, and model year.

The primary subclassification is by vehicle class. As discussed in Chapter Three, a class of vehicles is taken to be one which has substantially similar ownership and operational characteristics, so that vehicles in the class are substantially interchangeable for each other. For instance, passenger automobiles would usually form one class, while light trucks would fall into another. Other common classes include medium-duty trucks, light-heavy duty trucks, and heavy-heavy duty trucks. The classes of vehicles in common use are listed in Chapter Three.

Vehicle classes define not only the vehicle fleet, but also the demand for transportation services. Vehicles in different classes provide different types of services and these services are generally not substitutable. Thus, transportation demand is expressed in terms of demand for passenger-car vehicle-miles travelled (VMT) per year, light-truck VMT, heavy-truck VMT, and so forth, rather than as some composite number of "total" transportation VMT.

Within each class, the market for transportation services is further
divided into mileage groups. In general, transportation services are a "lumpy" commodity — in order to obtain them, one must buy a vehicle. Some vehicles are used more than other vehicles in the same class, while others are used less, depending on the amount of transportation services required by the particular owner. The model handles this by defining the market for transportation services in (say) the 5,000 mile-per-year group as being a different submarket from that for the group travelling 10,000 miles per year. Since annual mileage strongly affects both operating costs and depreciation, the economic parameters faced by vehicle purchasers in these two groups will be different, and they may (and generally do) lead to different vehicle-purchase decisions.

Overall, the distribution of annual mileages demanded within each class is assumed to be lognormal, with the mean and standard deviation of the lognormal distribution function being supplied as input parameters. For convenience in computation, however, this lognormal distribution is "discretized" into separate mileage groups. Figure 4.1 diagrams this discretization process. For simplicity, all consumers within a given mileage group are assumed to demand the same number of miles per year, and thus all vehicles within that group are assumed to accumulate the same mileage. Each mileage group is chosen to contain the same number of vehicles. Thus, given an exogenously specified demand for (say) 200 million VMT per year in the passenger automobile class, the model would subdivide this into perhaps 5 million VMT in group 1, 7 million million in group 2, and so forth up to perhaps 30 million in the highest-mileage group. Since the number of vehicles in each group is the same, individual
Figure 4.1: Example of "discretization" of the mileage distribution function. The $Q_i$ are the ten mileage groups, while the $\bar{Q}_i$ are the weighted average VMT per year within each group.
vehicles in the highest-mileage group would accumulate six times the annual mileage of those in group 1. Section 4.2 describes the calculations by which total annual VMT for each class is allocated between mileage groups.

The vehicles within a given class are subdivided by technology, and within technologies by model year. For the purposes of the model, technologies are arranged in discrete "packages", with each package having its own entry in the technology database. The cost and fuel-consumption characteristics of each technological "package" (henceforward referred to simply as "technology") are assumed to change over time, thus the need for division by model year. For instance, one technology for the passenger automobile market would be the "standard" gasoline-fueled, low-efficiency passenger car typical of the early '70s. Another package could consist of the same car with a diesel engine (and thus lower fuel consumption, but a higher price), while a third might consist of an "advanced technology" high-efficiency gasoline automobile like those of the '80s. However, the "advanced-technology" vehicle of model-year 1980 might be quite different from the one of model year 1985, (having, presumably, a lower price, but also lower efficiency), so that the cost and fuel-consumption for each year must be calculated separately.

Within the model, the smallest subgroup of vehicles considered consists of all those vehicles which are in the same class, utilize the same technology, were built in the same year, and which are used within the same mileage group. This smallest group is known as an element of the
fleets. A particular element is identified by four subscripts: \( c, \ t, \ m, \) and \( g \), corresponding to vehicle class, technology, model year, and mileage group. The program keeps separate track of the number of vehicles and the average accumulated mileage for the vehicles in each element. All the basic model calculations — cost and fuel-consumption calculations, retirement and expected life calculations, buy/sell decisions, and so forth are simulated individually for each element.

4.1.2 Outline of the Computational Algorithm

This section presents an outline and overview of the computational algorithm used in the model. It is not a detailed presentation — rather, it is intended to assist in orienting the reader. The formal mathematics of the model and the detailed reasoning behind it are presented in Sections 4.2 through 4.8, following.

Figure 4.2 is a flowchart showing the major components of the algorithm for the TRATEC model. The process is begun by reading the input data and parameters, which include specifications of total VMT demand by class for each year, the technologies available in each class, the parameters of the VMT distributions for each class, future fuel prices, and the initial composition of the vehicle fleet, among other data. Next, the model searches the technology database for data on each of the technologies specified. The input data and the technology database together make up all of the data input to the model. A full list of these data is given in Section 4.1.3, and the specific forms and units for the data are given in
BEGIN

READ INPUT DATA AND CHECK FOR ERRORS

READ TECHNOLOGY DATABASE AND CHECK FOR ERRORS

FOR EACH CLASS OF VEHICLES COVERED

SET UP INITIAL FLEET STRUCTURE

FOR EACH YEAR FROM PRESENT TO THE END OF THE MODEL

CALCULATE RETIREMENTS SINCE LAST YEAR

ADD ONE YEAR'S MILEAGE TO EACH ELEMENT OF THE FLEET

CALCULATE ANNUAL EQUIVALENT MILEAGE AND OPERATING COST FOR EACH TECHNOLOGY IN EACH MILEAGE GROUP

CHOOSE COST OF LOWEST-COST TECHNOLOGY IN EACH GROUP AS INITIAL GUESS AT MARKET PRICE

SIMULATE USED-VEHICLE SALES FROM EACH MILEAGE GROUP TO EACH OTHER MILEAGE GROUP, PLUS JUNKING DUE TO TECHNOLOGICAL OBSOLESCENCE

CALCULATE TOTAL VMT DEMANDED AT CURRENT PRICES IN EACH MILEAGE GROUP

CALCULATE TOTAL VEHICLES REQUIRED IN EACH MILEAGE GROUP TO SUPPLY NEEDED VMT. COMPARE WITH ACTUAL NUMBER OF USED VEHICLES CALCULATED IN EACH GROUP

CONVERGENCE?

Y

ADJUST ESTIMATED MARKET PRICES IN MILEAGE GROUPS WHICH HAVE NOT CONVERGED

N

ALLOCATE NEW-VEHICLE DEMAND BY TECHNOLOGY TYPE

UPDATE FLEET STRUCTURE TO REFLECT CHANGES

UPDATE TOTALS FOR FUEL CONSUMPTION, TOTAL COST, VEHICLE SALES, AND FLEET COMPOSITION

PRINT REPORT OF TOTALS FOR EACH YEAR

END
After the data are read and checked, the actual modeling process begins. The model simulates the structure and evolution of the vehicle fleet year by year for each class of vehicles. Markets for the different classes are assumed to be independent of each other, so that the simulation for one class can be carried out in isolation from all the others.

The simulation begins in the base year, taking the initial fleet structure given in the input data as the starting point for the iterative calculation. After setting up the initial fleet composition, the program begins iteratively calculating the transportation demand, fleet structure, and fuel consumption for each year, working from the input data for the current year and the fleet structure in the year before. The first step in the process is to calculate the number of vehicles in each element which are retired (removed from service) due to accidents or wearing out during the year, and then to increase the accumulated mileage for all vehicles now in the fleet by one year's annual mileage. The retirement and mileage-incrementation step is done separately for each element.

Initially, and at the beginning of each year, the fleet structure is assumed to be in equilibrium, given the VMT demand and the prices then in effect. However, the retirement and mileage incrementation processes, as well as any changes in price and VMT demand since last year, will upset this equilibrium. Thus, the next step in the process is to reestablish the equilibrium configuration through a simulation of the used-vehicle
market. This simulation is done separately for each class of vehicles.

The first step in the simulation process is to calculate the annual cost of owning and operating a new vehicle of each of the available technologies in each mileage group, and to choose the lowest cost technology for each group. If (as will usually be the case) new vehicles are the marginal source of supply for VMT in a given mileage group, this will define the market price for transportation in that group. The "price" so defined is the annual cost, including the annual cash-flow equivalent of the purchase price, of owning and operating a vehicle in the given mileage group and class. This implies that the price is the same for all vehicles in the same class and mileage group, but that the price will be different for different mileage groups — being higher for the higher-mileage groups, since depreciation and operating expenses both increase with increasing annual mileage.

After calculating the price of transportation supplied by new vehicles, the program begins an iterative calculation of the market-clearing price of transportation in each mileage group. The market for vehicles within each group is assumed to be homogeneous, however, the markets can interact by means of the buying and selling of used vehicles between groups. Thus, a consumer in (say) the 18,000 to 22,000 kilometers per year group is assumed to choose the vehicle which will give the lowest annual cost (including capital cost) at current prices when driven 20,000 kilometers per year.
If economic conditions then change, however (for instance, if the price of fuel increases), the previously purchased vehicle may no longer be optimum, and the consumer might then sell the vehicle to another group where its value (as determined by the market price of transportation in that group) is greater. If the changes in technology and/or prices are sufficiently large, the market value of an older vehicle may even become negative — in which case, the consumer is assumed to junk it (i.e. sell it at a price of zero), removing it from the vehicle fleet. An example of this type of change occurred in during the late 1970s in the U.S., when the market price of older full-sized cars plummeted as a result of increased fuel prices.

Even if market conditions are not changing rapidly, there is an active market in used vehicles. Generally, used vehicles are sold by owners in high-mileage groups to those in low-mileage groups. This phenomenon — which is widely observed — has a firm basis in economics. The differences in depreciation rates between high-mileage and low-mileage applications of used vehicles make it economically attractive for owners in the high-mileage groups to sell their used vehicles (at the market price in the low-mileage group) and buy new vehicles for themselves. This phenomenon is also observed in the model, where it occurs as a natural result of the simulation technique used. The fact that this widely-observed phenomenon occurs as a natural result of the model, without any special provision for it being made, is itself good evidence of the model's validity.
The market price for transportation services in each mileage group is calculated by an iterative process. The initial guess at the market-clearing price in each group is taken as the (equivalent annual) cost of the new vehicle technology having the lowest cost in that group. Based on these prices, the model calculates the demand for total VMT in the class as a function of the average price. This demand is used to calculate the demand for VMT in each group, and thus the number of vehicles needed.

The model then calculates the equilibrium distribution of used cars in the fleet given the prices in effect. This is done by means of a consumer-choice model which simulates the keep/sell/junk decision faced by vehicle owners in each element. The cost of each possible decision (keeping the vehicle, selling to another group and buying a new one, or junking it and buying a new one) is first calculated. This cost vector serves as input to a multinomial logit choice function, the output from which is a vector of the fraction of consumers in the group taking each choice. These fractions give the number of vehicles in this element which are retained in the group, which are sold to each of the other mileage groups, and which are junked and removed from the fleet.

Having simulated the sales from each mileage group to each of the other groups at the current prices, the model then recalculates the current structure of the fleet, and checks to be sure that no group has more vehicles than it needs. If any group has a surplus, then new vehicles are not the marginal source of supply for that group, and thus the market
price for transportation must be lower than the cost of transportation supplied by new vehicles. If this occurs, the model lowers the estimate of the corresponding price, and then repeats the intergroup sales calculation using the new prices, iterating as necessary. Convergence is achieved when the (a) each group for which the estimated market price is equal to the new-vehicle price has fewer vehicles than it needs, implying a positive demand for new vehicles, and (b) each group for which the market price is lower than the new-vehicle price has as many vehicles as it needs, implying zero demand for new vehicles. The mathematics of this process are discussed in Section 4.6.

Once the distribution of used cars between mileage groups is known, the demand for new cars is given by the difference between VMT demanded and VMT available from the current stock in each group. This demand is allocated between the vehicle technologies available in that class, using the same multinomial logit model used in the used-vehicle market simulation. The reasons for using this type of choice function are discussed in Section 4.4.

The elasticity of supply of new vehicles is taken to be infinite, so that new vehicle supplies are capable of meeting any given demand with no change in price. This model is realistic for developing nations, which account for only a small fraction of the total world demand, but would need to be re-examined before being used to model a major industrial country such as the U.S.
The addition of the new vehicles for the current year to the existing fleet structure produces the equilibrium fleet structure for the current year, given the prices of new vehicles, the previous fleet, and the level of demand. Given this structure, calculation of total fuel consumption, total cost, etc. for the current year is simply a matter of addition and multiplication over each element. These procedures are discussed in Section 4.7.

4.1.3 Symbols and Nomenclature Used in the Model

Table 4.1 shows the major categories of symbols used in the model, and lists each of the members of each category. The complexity of the model and the diversity of the effects it treats have occasioned a corresponding complexity and diversity in symbols and nomenclature. Hence, a few words of explanation are in order.

For simplicity and consistency of notation, all entities of a given type are given the same type of symbols. Block English capitals such as A and B, and Greek letters such as $\beta$ represent arrays of values, while the number of subscripts indicates the dimensionality of the array, and the subscript itself indicates what variable each dimension is associated with. A one-dimensional array is a vector, while a two-dimensional array is a matrix; higher-dimensional arrays are common in computer programming, but have no common counterparts in mathematics. As an example, $A_{c,t,g}$ indicates that $A$ is a three-dimensional array, whose dimensions correspond to variations in class (c), technology (t), and mileage group (g). Unless
TABLE 4.1: SYMBOLS AND NOMENCLATURE USED IN THE MODEL

SUBSCRIPTS

c = vehicle class
f = fuel type (gasoline, diesel, alcohol)
g = annual mileage group
m = vehicle model year
t = vehicle technology type
y = current year in the simulation

INPUT PARAMETERS

\( \gamma_c \) = Discount rate used by buyers of each class of vehicles.
\( \xi_c \) = Own-price elasticity of demand for VMT in each class.
\( \beta_c \) = Logit choice function parameter for buyers of each class of vehicles.
\( \chi_c \) = Transaction costs for used-vehicle sales in each class.
\( \Delta_c \) = New-vehicle premium (additional utility of having a new vehicle over just any vehicle) in each class.
\( \mu_c \) = Average annual mileage/vehicle, by vehicle class.
\( \sigma_c \) = Standard deviation in mileage/vehicle, by vehicle class.
TABLE 4.1: SYMBOLS AND NOMENCLATURE USED IN THE MODEL (CONTINUED)

INPUT DATA

Mileage

\[ Q_{(\text{tot})c,y} = \text{Total vehicle-miles of transportation demanded at base-year cost per mile, by vehicle class and year.} \]

Fuel Prices

\[ P_{(\text{fuel})f,y} = \text{Price of fuel ($/unit) of each type} \]

Existing fleet

\[ X_{m,c,t} = \text{Structure of existing fleet in present year.} \]
\[ S_{m,c,t} = \text{Historical sales of new vehicles from first year of model to present year.} \]

TECHNOLOGY DATABASE

\[ \mu_{t} = \text{Mean mileage at retirement for vehicles using this technology (see Section 4.5).} \]
\[ \sigma_{t} = \text{Standard deviation of mileage at retirement for vehicles using this technology.} \]
\[ Y_{(\text{av})t,2} = \text{First and last year in which each technology is available.} \]
\[ C_{(\text{init})t,m} = \text{Initial purchase cost for vehicles using this technology in model year } m. \]
\[ C_{(\text{maint})t,m} = \text{Cost of maintenance ($/distance) of vehicle using this technology built in model year } m. \]
\[ C_{(\text{fix})t,m} = \text{Fixed cost of ownership of vehicles using this technology built in model year } m. \]
\[ F_{(\text{spec})t,m,f} = \text{Specific fuel consumption (distance/unit of each type of fuel) for vehicles using this technology built in model year } m. \]
TABLE 4.1: SYMBOLS AND NOMENCLATURE USED IN THE MODEL (CONTINUED)

FUNCTIONS

\[ R(t,g,q) \] = Vehicle retamment function — gives fraction of surviving vehicles of technology t, having accumulated mileage q, that will not retire during the current year.

\[ L(t,g,q) \] = Vehicle expected life function — gives expected remaining life (in miles) of a vehicle of technology t with accumulated mileage q.

\[ C(U,n) \] = Logit model of consumer choice — input is a vector of utilities associated with each of n courses of action; output is a vector of the fraction of total choices going to each course.

\[ D(c,y) \] = Discrete cumulative lognormal distribution function (see Section 4.2)

\[ E(r,n) \] = Equivalent cash-flow function — gives a factor to convert present value in current year to a uniform annual cash flow for n years discounted at rate r.

\[ e(r,n) \] = Equivalent present worth function — gives a factor to convert an n-year cash flow to present value.

\[ A(c,t,y,g) \] = Annual cash-flow equivalent of a the purchase price of a new vehicle of technology t' in class c, purchased in year y, discounted over the expected life of the vehicle when used in mileage-group g.

\[ V(c,t,y,m,g) \] = Variable (mileage dependent) annual owning and operating cost in year y for a vehicle of technology t' in class c, of model year m, used in mileage group g.

\[ \lambda(c,y) \] = Total remaining (depreciated) value of the existing stock of vehicles of class c in year y.

\[ P_{(\ln)}(x, , ) \] = Lognormal probability distribution function.

\[ P_{(m)}(q,c) \] = Cumulative probability distribution function for annual mileage per vehicle in class c.

\[ P_{(r)}(q,t) \] = Probability distribution function for vehicle retirement as a function of mileage.

\[ \chi(q,t) \] = Cumulative probability distribution function for vehicle retirement as a function of mileage.
TABLE 4.1: SYMBOLS AND NOMENCLATURE USED IN THE MODEL (CONTINUED)

**INTERMEDIATE VALUES**

\[ Q_{(tot')}c,y \] = Total mileage demanded in class C in current year (\( Q_{(tot)c,y} \) adjusted for price elasticity)

\[ Q_{y,g} \] = Mean mileage per year in each mileage group for current class in year y.

\[ Q_i \] = Mileage at boundaries of each mileage group for class c in year y.

\[ N_{(vold)}g \] = Number of old vehicles in mileage group g for current class and year.

\[ N_{(vneed)} \] = Number of vehicles needed to meet transport demand for the current class and year.

\[ N_{(vnew)}g \] = Number of new vehicles required in each mileage group in the current class and year.

\[ P_{(newv)}g,t,c,y \] = Total annual owning/operating costs of new vehicles of technology t in class c for the current year.

\[ P_{(mkt)c,y,g} \] = Market equilibrium total owning and operating costs (including capital cost) for vehicles in class c in year y. Initially set to the minimum of \( P_{(newv)}g,t \).

\[ T_{c,t,m,y,g} \] = Average accumulated mileage per vehicle in year y for vehicles of the current class, of technology t, mileage group g, and model year m.

\[ U_n \] = Vector of utilities of alternative courses of action, input to the logit choice function.

\[ V_n \] = Vector of fraction of total consumers taking each of n alternative courses of action, output from the logit choice function.

\[ Z_{i,g} \] = Vector of values of a given vehicle in group g when sold to group i, used in computing U for the market simulation.

\[ X_{c,t,m,y,g} \] = Number of vehicles of technology t in the current class, in mileage group g, and model year m which are still in the fleet in year y.
TABLE 4.1: SYMBOLS AND NOMENCLATURE USED IN THE MODEL (CONTINUED)

**OUTPUTS**

- **C\(_{\text{tot}}\)_y** = Total cost of owning/operating in each year.
- **C\(_{\text{var}}\)_y** = Variable cost of owning/operating in each year.
- **C\(_{\text{tc}}\)_y,c** = Total cost by classes for each year.
- **C\(_{\text{vc}}\)_y,c** = Variable cost by classes for each year.
- **F\(_y,f\)** = Total fuel consumption in each year.
- **F\(_c\)_y,c,f** = Fuel consumption by vehicle class in each year.
- **S\(_{c,t,y}\)** = Sales of new vehicles in each year.
- **X\(_{c,t,y}\)** = Fleet composition in each year.
otherwise stated, subscripts should be considered to be "general", that is, a subscript variable in an equation can take on any value within the range of the subscript. Where a number of different, but similar, arrays use the same block letter, they are distinguished from each other by a subscript in parentheses. For instance, \( C_{(\text{init})} \) and \( C_{(\text{fix})} \) refer respectively to the initial cost and the fixed annual cost for a vehicle of a given technology.

Block English capitals represent arrays of input data, intermediate data, and final results, while the Greek letters represent arrays of input parameters such as interest rates. Otherwise, they can be treated in the same way. Small English block letters such as \( r \) and \( t \) denote scalar values, or subscripts, which can take on any scalar value within their respective ranges. Where a specific value of the subscript is required, such as the maximum or minimum, the appropriate qualifier is appended as a subscript within parentheses. For example, \( g_{(\text{max})} \) denotes the maximum permitted value of the subscript \( g \).

Script English letters such as \( \mathcal{C} \) and \( \mathcal{R} \) denote functions, with each function being followed by its arguments in parentheses. For instance, \( \mathcal{R} (1,r) \) is a function of two parameters: \( 1 \) and \( r \). Unless otherwise noted, functions are scalar-valued. The only exception to this rule is the consumer choice function \( \mathcal{C} \) which produces a vector result. Where a subscript appears as a function parameter, it should be understood to refer not to the the actual value of the subscript, but to the values of the array data referenced by that subscript. As an example, the function
could be equal to $X_{c,g} + Y_g$.

### 4.2 Mileage Distribution and Total Transportation Demand

The distribution of annual mileage per vehicle within a given class is assumed to follow a lognormal distribution, with the parameters of the distribution being supplied as inputs. The form of the cumulative probability distribution function for annual mileage driven is given by

$$
P_{cm}(q,c) = \int_0^q P_{ln}(x, \mu'_c, \sigma'_c) \, dx \quad \text{(eq. 4.1)}
$$

where the integrand is the lognormal probability distribution function

$$
P_{ln}(x, \mu', \sigma') = \frac{1}{\sqrt{2\pi} \sigma x} \exp \left\{ -\frac{1}{2} \left( \frac{1}{\sigma} \log \left( \frac{x}{\mu'} \right) \right)^2 \right\} \quad \text{(eq. 4.2)}
$$

The parameters $\sigma'_c$ and $\mu'_c$ are given by

$$
\sigma'_c = \sqrt{\log \left( \left( \frac{\sigma_c}{\mu_c} \right)^2 + 1 \right)} \quad \text{(eq. 4.3)}
$$

and

$$
\mu'_c = \mu_c \exp \left( -\frac{1}{2} \sigma'_c^2 \right) \quad \text{(eq. 4.4)}
$$

Where $\mu_c$ and $\sigma_c$ are the mean and standard deviation, respectively, of the VMT distribution for class $c$ (Benjamin and Cornell, 1970).
The lognormal form was chosen for analytical convenience, and because it represents the results of vehicle-mileage surveys in the United States reasonably well (c.f. U.S. Bureau of the Census, 1978). Unlike many commonly-used distributions, the lognormal distribution does not produce a finite probability of a negative mileage, which would be mathematically troublesome. However, this form is not essential to the model — a different probability distribution function could be substituted in its place, if that were considered desirable, with no effect on the overall structure.

For ease in computation, the continuous probability distribution function \( P(m) \) has been "discretized", or broken up into a number of discrete segments, as was illustrated schematically in Figure 4.1. This is done by finding the discrete mileage intervals \( Q_i \) such that

\[
P_i = P(m)(Q_i, C) \quad \text{(eq. 4.5)}
\]

for \( P_i = 0.0, \frac{1}{g_{(max)}}, \frac{2}{g_{(max)}}, \ldots, \frac{g_{(max)}-1}{g_{(max)}}, 1.0 \)

Note that \( Q_0 \) is equal to zero, while \( Q_{(max)} \) is equal to +infinity. The intervals between the \( Q_i \) are termed the mileage groups. Notice also that the cumulative probabilities

\[
P_{\text{group}} g \equiv P_g - P_{g-1} = \frac{1}{g_{(max)} \quad \text{(eq. 4.6)}}
\]
associated with each mileage group are all the same — that is, that each
group would occupy an equal interval of the probability axis in a plot of
the cumulative probability distribution. This implies that each mileage
group will contain an equal number of vehicles.

The average mileage \( Q_{c,g} \) travelled by vehicles falling within each mileage
group can be calculated as the \( q \) coordinate of the centroid of the area
under the probability distribution curve for each group. This is given by
the function \( D(c,g) \), where

\[
Q_{c,g} = D(c,g) = \frac{\int_{Q_{g-1}}^{Q_g} x P_{ln}(x, \mu'_c, \sigma'_c) dx}{\int_{Q_{g-1}}^{Q_g} P_{ln}(x, \mu'_c, \sigma'_c) dx}
\]  
(eq. 4.7)

The denominator in equation 4.7 is a constant, since

\[
\int_{Q_{g-1}}^{Q_g} P_{ln}(x, \mu'_c, \sigma'_c) dx = P_m(Q_g, c) - P_m(Q_{g-1}, c) = \frac{1}{g_{(\text{max})}}
\]  
(eq. 4.8)

The value \( Q_{c,g} = D(c,g) \) is used to approximate the actual annual mileage
driven by each member of the mileage group.

The total demand for transportation of a given type is affected by the
cost of that form of transportation; the costs of other forms of
transportation which may be substitutable; the geographic distribution of
persons, habitations, employment, industries, and natural resources; and by the social, cultural, and economic conditions of the society. Most of these considerations lie outside the scope of this model. Thus, the model requires that an estimate of the total demand for transportation in each class in each year be supplied as part of the input data. However, the model itself is capable of calculating the price of transportation within a class, and thus accounting for the effects of own-price elasticity on demand. For this reason, the estimates of total transportation demand, \(Q_{(tot)c,y}\), specified in the input are assumed to correspond to base-year prices. Total demand at actual prices in a given year is calculated by

\[
Q_{(tot')c,y} = Q_{(tot)c,y} \left( \frac{P_{(avg)c,y}}{P_{(avg)c,y_0}} \right)^{-\varepsilon_c}
\]  

(eq. 4.9)

where \(\varepsilon_c\) — the negative of the own-price elasticity of demand for transportation services in class c — is an input parameter, and \(P_{(avg)c,y}\) is the average cost of transportation per unit of distance travelled for class c in year y. This is given by

\[
P_{(avg)c,y} = \sum_{i=1}^{g_{(max)}} \frac{\sum_{i=1}^{g_{(max)}} P_{(mkt)c,y_i,g}}{Q_{c,g}}
\]

(eq. 4.10)

\(P_{(avg)c,o}\) is equal to \(P_{(avg)c,y}\) for the base year. \(P_{(mkt)c,y,g}\) is the current estimate of the market-clearing price (annual cost per year per vehicle) for transportation in group g. This quantity is calculated as part of the iterative market-simulation process.
4.3 Calculation of Owning and Operating Costs

The costs of owning and operating a motor vehicle can generally be divided into three categories: initial cost, the fixed annual costs of ownership, and variable costs such as fuel consumption and maintenance, which depend upon how many miles per year the car is driven. In order to be able to compare them accurately, these costs must be placed on the same basis. For the purposes of the model, this basis has been chosen to be the equivalent annual cost.

Fixed annual costs such as taxes, fees, and insurance are already on an annual basis, and thus require no conversion. Mileage-dependent costs for fuel and maintenance can be converted to an annual basis by multiplying the cost per mile by the annual mileage driven. For a vehicle in class c, using technology t, of model year m, and used in mileage group g, the corresponding annual variable cost in year y is given by the function

\[
V(c, t, y, m, g) = Q_{c, g} \left( C_{\text{maint}}(t, y) + \sum_{f=1}^{f_{\text{max}}} \frac{P_{\text{fuel}}(f, y)}{F_{t, m, f}} \right) \quad (\text{eq. 4.11})
\]

where \( C_{\text{maint}}(t, y) \) is the maintenance cost per mile, \( P_{\text{fuel}}(f, y) \) is the cost of fuel f in year y, and \( F_{t, m, f} \) is the fuel economy of technology t, built in model year m, for fuel y.
The initial capital cost of a vehicle can be converted into an annual cost by calculating the annual cash-flow over the expected life of the vehicle which would have the same discounted present value in the present year as initial cost. This is done by multiplying initial cost by the annual cash-flow equivalent factor, given by

$$\hat{C}(r, n) \equiv \frac{r(1+r)^n}{(1+r)^n - 1}$$  \hspace{1cm} (eq. 4.12)

In this function, \( r \) is the discount rate, and \( n \) is the expected life of the vehicle in years. The inverse of the annual cash-flow equivalent factor, denoted by \( \hat{F} \), is also useful. This factor is used to calculate the discounted present value of an annual cash flow extending over a period of \( n \) years.

$$\hat{F}(r, n) \equiv \frac{(1+r)^n - 1}{r(1+r)^n}$$  \hspace{1cm} (eq. 4.13)

In order to be able to compare the decision to purchase a new vehicle with the purchase of a used one, it is necessary to account for the fact that a new vehicle and a used vehicle are not quite the same commodity. In addition to providing transportation, a new vehicle usually comes "bundled" with other goods, which may include free maintenance under the warranty, higher status and greater satisfaction for the owner, greater reliability, and so forth. The relative importance of this new-vehicle
premium will be different for different classes of vehicles, but it is likely to be significant in all of them. For this reason, it is explicitly included in the model. To compute the capital cost of the transportation provided by a newly purchased vehicle, the price of the new vehicle should be reduced by this premium. Thus, the annual equivalent of the capital cost of transportation service from a new vehicle of model year \( m \) is given by

\[
\Delta_{c,t,y} \equiv \left\{ C_{\text{init}}(t,y) - \Delta_{c} \right\} \phi_{c,n} \tag{eq. 4.14}
\]

where \( \phi_{c} \) is the discount rate for class \( c \), \( \Delta_{c} \) is the new-vehicle premium in class \( c \), and \( n \) is the expected lifetime of the vehicle in years. The expected lifetime \( n \) is given by

\[
\begin{aligned}
\phi_{c,n} &= \frac{L(q,t)}{Q_{c,g}} \\
\end{aligned} 
\]  

(\text{eq. 4.15})

where \( L(q,t) \) is a function giving the expected remaining lifetime mileage for a vehicle of technology \( t \) which has accumulated \( q \) miles (see Section 4.5).

The total annual equivalent cost of owning and operating a new vehicle of class \( c \) and technology \( t \), purchased in year \( y \), and used in mileage group \( g \), and subtracting the new-vehicle premium \( \Delta_{c} \) is given by equation 4.16.
This value plays a key role in the model, both in the simulation of the used-vehicle market and in the new-vehicle technology choice process.

4.4 THE MULTINOMIAL LOGIT MODEL OF CONSUMER CHOICE

Classical microeconomic theory treats consumers as perfectly rational decision makers, each of whom tries to maximize his or her (or in the case of a firm or corporation, it's) satisfactions or "utility". If one assumes that all goods in a particular market (in this case, the transportation services provided by each type of technology for a given class) are homogeneous or interchangeable, then it can be shown that consumers should always choose the good (technology) that has the lowest discounted present value of life-cycle cost, or equivalently, the lowest equivalent annual cost. In practice, however, consumers of even closely substitutable goods do not always choose the one with the lowest cost. In fact, the fraction of consumers choosing good A over a closely substitutable good B, plotted as a function of ratio of the prices of the two goods, often resembles the logistic curve shown in Figure 4.3.

As discussed in Section 2.3, this fact can be reconciled with the classical theory by making any of several apparently reasonable assumptions: e.g. that consumers still maximize utility, but that the
FIGURE 4.3: Logistic Curve of Market Share as a Function of Price Ratio for Two Competing Technologies.
utility to a given consumer is not completely measured by data available to the model; or that consumers attempt to maximize utility, but make mistakes due to imperfect information. The effect of any of these assumptions is to introduce some "fuzziness" into the sharp-edged either/or decision to buy one good or another. One very useful way to model this "fuzziness" is by means of the multinomial logit function, which gives the probability that a consumer will choose a particular course of action from among a finite number of alternatives as a function of the net benefits associated with that and all other possible courses. This is given by the vector-valued function \( C_i(U,c) \), where

\[
C_i(U,c) \equiv \frac{\exp \left( -\beta_c U_i \right)}{\sum_{j=1}^{n} \exp \left( -\beta_c U_j \right)} \tag{eq. 4.17}
\]

\( U \) is a vector of the costs of each course of action, \( n \) is the number of choices available (i.e. the length of \( U \)), and \( \beta_c \) is a parameter which measures the degree of dispersal or "fuzziness" in the decision process for decision-makers in class \( c \).

The consumer-choice function is used in the model both to divide purchases of new vehicles between technology types and to establish the equilibrium distribution of used vehicles between mileage groups. The function parameter \( \beta_c \), which may be different for each class, must be supplied by the user as part of the input.
4.5 The Vehicle Retirement Model

A vehicle may be retired (removed from service) because of accident, age, wearing out, or technical obsolescence. In developing countries, where both vehicles and the capital to buy them are scarce, few vehicles are likely to be retired as a result of age alone, so long as they still have some mileage left in them. Thus, except for technical obsolescence (which is dealt with separately as part of the simulation of the used-vehicle market), vehicles will be retired almost exclusively as a result of accidents or wearing out, both of which are functions of the accumulated mileage. It is thus reasonable to consider vehicle retirement and expected remaining life as functions only of the accumulated mileage and the characteristics of the technology. This is the approach which has been taken in constructing the TRATEC model.

Assume that the probability that a vehicle will retire upon reaching a given mileage $q$ is given by the probability density function $r(q,t)$. Let $X(q,t)$ be defined as the cumulative probability distribution for retirement as a function of mileage. Then

$$X(q,t) = \int_0^q r(x,t) \, dx$$  \hspace{1cm} \text{(eq. 4.18)}$$

Next, define the retainment function $R(c,g,q,t)$ as giving the fraction
of those vehicles in mileage group g of class c, using technology t, and having accumulated mileage q in the current year which are retained in the fleet next year (i.e. which do not retire in this year). It can be shown that this function is given by

\[ R(c, g, q, t) = \frac{1 - X(q + \bar{Q}_{c,g}, t)}{1 - X(q, t)} \]  \hspace{1cm} (eq. 4.19)

where \( \bar{Q}_{c,g} \) is the annual mileage per vehicle for the class and mileage group.

The expected mileage at retirement for vehicles of technology t which have already accumulated mileage q can be calculated as the q coordinate of the centroid of the area under the probability distribution curve for retirement, with the area taken between the current value of q and q = infinity. The expected remaining mileage before retirement for those vehicles is simply the expected mileage at retirement minus the present mileage. Thus, the expected remaining mileage function \( (q, t) \) is given by

\[ L(q, t) \equiv \frac{\int_q^\infty X P_r(x) \, dx}{\int_q^\infty P_r(x) \, dx} \]  \hspace{1cm} (eq. 4.20)
It can be shown that
\[ \int_0^\infty x \cdot P(r)(x, t) \, dx = \mu_t \]  
(\text{eq. 4.21})

where \( \mu_t \) is the mean mileage at retirement for vehicles of technology \( t \). At the same time,
\[ \int_0^\infty P(r)(x, t) = X(\infty, t) = 1 \]  
(\text{eq. 4.22})

thus, since
\[ \int_0^\infty f(x) \, dx = \int_0^a f(x) \, dx - \int_a^\infty f(x) \, dx \]  
(\text{eq. 4.23})

for any function \( f(x) \), the expected remaining life function \( L(q, t) \) can be expressed as
\[ L(q, t) = \frac{\mu_t - \int_0^q x \cdot P(r)(x, t) \, dx}{1 - X(q, t)} \]  
(\text{eq. 4.24})

Which is much more convenient for computation, since the limits of the integration are all finite.

In order to establish the retirement and expected-life functions \( X \) and \( L \), it remains only to determine an analytic form for the probability density function \( P(r) \). For convenience, and because it represents the
reality reasonably well (c.f Lax, 1981), we select the lognormal distribution function

\[ \mathcal{P}_r(q, t) \equiv \mathcal{P}_l(q, \mu'_t, \sigma'_t) \]  

(eq. 4.25)

where the parameters \( \mu'_t \) and \( \sigma'_t \) are characteristics of each technology. These parameters can be calculated from the mean \( \mu_t \) and the standard deviation \( \sigma_t \) of the mileage at retirement for the technology by means of equations 4.3 and 4.4.

As a result of this formulation, the cumulative distribution function \( \chi(q, t) \) is given by

\[ \chi(q, t) \equiv \int_0^q \frac{1}{\sqrt{2\pi} \sqrt[\mu_t}] \exp \left\{ -\frac{1}{2} \left( \frac{1}{\sigma_t} \log \left( \frac{x}{\mu_t} \right) \right)^2 \right\} \, dx \]  

(eq. 4.26)

and the expected-life function \( \mathcal{L}(q, t) \) is given by

\[ \mathcal{L}(q, t) \equiv \mu_t \cdot \int_0^q \frac{1}{\sqrt{2\pi} \sqrt[\mu_t]} \exp \left\{ -\frac{1}{2} \left( \frac{1}{\sigma_t} \log \left( \frac{x}{\mu_t} \right) \right)^2 \right\} \, dx \]  

\[ \frac{1 - \chi(q, t)}{1 - \chi(q, t)} \]  

(eq. 4.27)

The integrals in equations 4.26 and 4.27 have no analytical solutions, but they can be solved in a very straightforward manner by numerical techniques.

It is important to keep in mind that the model provides for vehicle retirement as a result of either of two reasons: wearing out, or economic
obsolescence. The relationships presented in this section describe only the first of these causes. Retirement as the result of economic obsolescence is dealt with as part of the simulation of the used-vehicle market, which is discussed in the next section.

4.6 SIMULATION OF THE USED-VEHICLE AND NEW-VEHICLE MARKETS

The simulation of the used-vehicle and new-vehicle markets for a given year and class of vehicles has been outlined briefly in Section 4.1.2. This section describes the process in much greater detail, presenting both the mathematical form and the logic behind it.

The simulation proceeds in two parts. The first part consists of an iterative calculation of the quasi-equilibrium distribution of used vehicles in the fleet in the year of interest. This distribution is determined by applying the logit choice model to the decisions (to sell, keep, or junk their vehicles) faced by the owners of vehicles in the previous year's fleet. This is followed by a second part which consists of a direct calculation, also using the logit choice model, of the number of new vehicles of each technology type which are purchased for each mileage group.

4.6.1 Simulation of the Used-Vehicle Market

Consider the choices faced by the owner of a vehicle which was grouped in
element \((c,t,m,g)\) in the previous time-step (year). It is assumed that he has the option of participating in a perfect market for used vehicles in each group. In general the present value of a used vehicle in mileage group \(g\) to its owner can be calculated by capitalizing the difference between the annual owning and operating costs of the vehicle and the (annual equivalent) market price of transportation in that vehicle class and mileage group. This value is denoted by \(Z_{g,g}\) and is given by

\[
Z_{g,g} = \left( \frac{(mkt)_{c,y,g} - C(fix)_{t,m} - V_{(c,t,y,m,g)}}{\gamma_{(c,t,m,g)}} \right) ^{n_t} \text{ (eq. 4.28)}
\]

where \(n_t\), the expected lifetime of the vehicle in years, is given by equation 4.15.

The value of a given vehicle to a prospective purchaser in another group can be calculated by an analogous formula, and, given the assumption of perfect markets, the price the prospective purchaser will bid for each vehicle is equal to its value to him. However, the net benefit which the owner receives from selling his vehicle must be reduced by the amount of the transaction costs. Thus, the benefit \(Z_{g,i}\) to a vehicle owner in group \(g\) of selling his vehicle to a member of mileage group \(i\) is

\[
Z_{g,i} = \left( \frac{(mkt)_{c,y,i} - C(fix)_{t,m} - V_{(c,t,m,y,i)}}{\gamma_{(c,y,i)}} \right) ^{n_i} \text{ (eq. 4.29)}
\]

where \(\gamma_{c}\) is the transaction cost in this class, and \(n_i\) is the vehicle's
expected lifetime when employed in mileage group i.

$$n_i = \frac{\mathcal{L}(q,t)}{Q_{c,i}}$$  \hspace{1cm} (eq. 4.30)

A useful way of looking at these quantities is to consider $Z_{g,g}$ as the "offered" price for the vehicle on the used-vehicle market, while $Z_{g,i}$ is the "bid" price which buyers in group $i$ would be willing to pay for it. This formulation is useful, but not precisely accurate, since it assumes that all of the transaction costs are borne by the purchaser. This is not too far from the reality, however, since the major transaction cost is the risk of being cheated or getting a "lemon", which is in fact borne by the purchaser.

In each year, the vehicle's owner has the option of selling his vehicle to any of the other mileage groups, or keeping it for himself. He can also junk the vehicle, in which case the value to him is zero (taking the salvage value as roughly equal to the costs of disposal). In order to decide which fraction of the owners in each element will follow each course of action, the model assembles the value of each action to the owner into a vector of utilities $U$, then applies the logit choice function

$$V = C(U,c)$$  \hspace{1cm} (eq. 4.31)

to give a vector $V$ of the fraction of owners taking each course of
action. The results of the logit choice function simulate the action of the actual used-vehicle market rather well. The largest number of vehicle sales occur between groups where the "bid" price is much greater than the "offered" price, and few sales occur when the "bid" price is lower than the "offered" price. Vehicle are junked in significant quantity only when all of the "bid" prices are negative, and the value of the vehicle to its owner is negative as well.

Since the logit choice function is used in both the new-vehicle and the used-vehicle market simulations, it is necessary to express the utility vector $U$ in a consistent basis. The basis used in the model is the equivalent annual cost. To convert the net present values $Z_{g,i}$ for each course of action to equivalent annual costs, it is necessary to multiply by the equivalent annual cost factor $E(r,n_g)$, where $n_g$ is the expected life of the vehicle when used in group $g$. Thus $U$ for owners in group $g$ is given by

$$U_i = Z_{g,i} E(r_c,n_g)$$

(eq. 4.32)

The quasi-equilibrium structure of the vehicle fleet in the current year is calculated by summing the contributions from each of the elements in the current fleet to each of the elements in the equilibrium fleet. Defining $V_{g,c,t,m}$ as the probability that a vehicle which was in element $(c,t,m,g)$ in the previous year will be sold to element $(c,t,m,i)$ in the current year, the total number of vehicles in the new element
\( (c, t, m, i) \) is given by summing over all possible \( g \).

\[
X'_{c, t, m, y, i} = \sum_{g=1}^{g_{(\text{max})}} V_{i, g} X_{c, t, m, y, g} \tag{eq. 4.33}
\]

and the average cumulative mileage per vehicle for the new element is given by the weighted average mileage of all the vehicles being included in that element.

\[
T_{c, t, m, y, i} = \frac{\sum_{g=1}^{g_{(\text{max})}} V_{i, g} T_{c, t, m, y, g} X_{c, t, m, y, g}}{X'_{c, t, m, y, g}} \tag{eq. 4.34}
\]

The total number of used vehicles in each mileage group can be calculated by summing over the number in each element within the mileage group.

\[
N_{(\text{Vold})} g = \sum_{m=1}^{y_{(\text{max})}} \sum_{g=1}^{g_{(\text{max})}} X'_{c, t, m, y, g} \tag{eq. 4.35}
\]

In order for the transportation market to be in equilibrium, it is necessary that the supply of vehicles in each group be equal to the demand at the market price for that group. If new vehicles are the marginal source of supply, this requires only that the total number of used vehicles supplied in any group be less than or equal to the number demanded, since the supply of new vehicles is assumed to be completely
elastic. If new vehicles are not the marginal supply (i.e., if the market price for transportation in a given group is less than the price for transportation provided by a new vehicle in that group), then strict equality is needed between the supply of transportation from used vehicles and the demand for transportation at the current price.

The total demand for transportation in mileage group \( g \) is given by equation 4.9, as a function of the cost of transportation and an exogenous base demand. The total number of vehicles required to fill this demand is simply

\[
N(v_{\text{need}})_{c,y} = \frac{Q_{(tot')}_{c,y}}{\mu_c} \quad \text{(eq. 4.36)}
\]

where \( \mu_c \) is the mean of the mileage distribution for class \( c \).

Since the mileage groups have been chosen so that each one will contain an equal number of vehicles, the number required per group is simply

\[ N_{v_{\text{need}}/g_{(\text{max})}} \]

The procedure for establishing equilibrium in the market is an iterative one. As a first guess at the market-clearing price \( P_{(mkt)}c,y,g \), the model chooses the cost of the new-vehicle technology which gives the minimum value for \( P_{(v_{\text{new}})}c,t,y,g \). The model then calculates the resulting quasi-equilibrium fleet structure, sums the number of vehicles in each group, and calculates the number of new vehicles which would be required
for that group, using

\[ N_{(v_{\text{new})}g} = \frac{N_{(v_{\text{need})}c,y} - N_{(v_{\text{old})}c,y} g}{g_{\text{max}}} \]  

(eq. 4.37)

If \( N_{(v_{\text{new})}g} \) is greater than or equal to zero for every group, then new vehicles are the marginal source of supply for every group, and no iteration is needed. If \( N_{(v_{\text{new})}g} \) is less than zero for any \( g \), then the market price of transportation in that group is lower than that for new vehicles, and new vehicles are not the marginal supply. The program must then pick a new, lower value for the price in each such group, and iterate until \( N_{(v_{\text{new})}g} \) becomes precisely zero (i.e. the supply of used vehicles precisely equals the demand for vehicles) for each group in which the estimated market price for transportation is lower than the new-vehicle price. Since, at a sufficiently low price, owners will junk their cars (thus removing them from the fleet entirely) rather than selling them, this iteration is guaranteed to converge.

This iterative solution process is mathematically equivalent to solving a system of coupled non-linear algebraic equations. For \( g \) mileage groups, there are \( g+1 \) equations — \( g \) supply-side equations and one equation for total demand (since the demands in each group are proportional to total demand they are not independent). There are also \( g+1 \) independent variables, consisting of the total number of vehicles junked and either the price of transportation in each group or the number of new vehicles purchased in each group (note that only one of these can vary at a time,
since if the price is different from the new-vehicle price, the number of new vehicles must be zero). Numerical techniques for solving such problems are well known (Forsyth et alia, 1977). The solution technique used in the model is a variation of the secant rule.

4.6.2 Calculation of New-Vehicle Purchases

Once the quasi-equilibrium calculation for the used vehicle market is complete, allocation of the remaining unsatisfied demand between new-vehicle technologies is straightforward. \( N_{(vnew)g} \) — the number of new vehicles needed in each group — has already been calculated. So, also, have the values for \( P_{(newv)c,t,g} \) — the equivalent annual cost of owning and operating a new vehicle of each technology in each year. Given the costs associated with each choice, the logit choice function can be used to allocate the demand for new vehicles between the competing technologies. Thus, the number of new vehicles of each technology in each mileage group is given by

\[
X_{c,t,y,y,g} = V_t \cdot N_{(vnew)g}
\]  

(eq. 4.38)

where the vector \( V \) is calculated by applying the consumer choice function to a vector of the equivalent annual costs of each technology.

\[
V = C(\mu, c)
\]  

(eq. 4.39)
With the addition of the newly purchased vehicles for the current model year, the equilibrium fleet structure for this year is established. This structure can then be combined with the fuel-consumption and other data in the technology data base to calculate the final results of the model.

4.7 CALCULATING TOTALS — FUEL CONSUMPTION, COSTS, AND NEW-VEHICLE SALES

Total consumption of each type of fuel by a given class in the current year can readily be calculated from the current fleet structure and the technology characteristics, using

$$F(c)c,y,f = \sum_{g=1}^{g_{(\text{max})}} \{ \overline{Q} c,g \} \sum_{t=1}^{t_{(\text{max})}} \sum_{m=1}^{y} \frac{X c,t,m,y,g}{F_{(\text{spec})} t,m,f}$$  \hspace{1cm} (\text{eq. 4.41})$$

The total variable (mileage-dependent) costs of transportation in each class and year are given by the sum of the cost of the fuel consumed and the cost of maintenance. These are calculated as

$$C_{(\text{vc})}c,y = \sum_{g=1}^{g_{(\text{max})}} \overline{Q} c,g \left\{ \sum_{t=1}^{t_{(\text{max})}} \sum_{m=1}^{y} C_{(\text{maint})} t,m X c,t,m,y,g \right\} + \sum_{f=1}^{f_{(\text{max})}} F(c)c,y,f P_{(\text{fuel})} y,f$$  \hspace{1cm} (\text{eq. 4.42})$$
The total cash costs of transportation in each class and year are given by the sum of the variable costs, the fixed costs per vehicle, and the capital costs of the new vehicles purchased.

\[ C_{tc}^{c,y} = C_{vc}^{c,y} + \sum_{g=1}^{g(\text{max})} \sum_{t=1}^{t(\text{max})} \sum_{m=1}^{y} C_{\text{fix},t,m} X_{c,t,m,y,g} \]  
\[ + \sum_{t=1}^{t(\text{max})} S_{c,t,y} C_{\text{init},t,y} \]  

(\text{eq. 4.43})

where \( S_{c,t,y} \) is the sales of new vehicles of each technology in each class in the given year, computed as

\[ S_{c,t,y} = \sum_{g=1}^{g(\text{max})} X_{c,t,y,y,g} \]  

(\text{eq. 4.44})

Where vehicle fleets are growing rapidly, as they are in most developing nations, the cash cost value \( C_{tc} \) can be misleading, as it includes both the cost of replacing worn-out vehicles and the investment in a larger vehicle fleet. A more accurate picture of actual transportation costs is obtained by calculating the total cost on a depreciation basis, given by

\[ C_{dc}^{c,y} = C_{tc}^{c,y} - \Delta (c,y) + \Delta (c,y-1) \]  

(\text{eq. 4.45})

where \( \Delta (c,y) \) is the total depreciated value of all vehicles of class \( c \).
in year y. This is calculated as

\[
L(c,y) = \sum_{j=1}^{g(\text{max})} \sum_{t=1}^{t(\text{max})} \sum_{m=1}^{y} \frac{L(T_{c,t,m,y,g,t})}{L(0,t)} C_{(\text{init}) t, m} \quad (\text{eq. } 4.46)
\]

For stability, this calculation is made using the original capital cost of the vehicle, rather than its current market value. This is because the current market value may change abruptly as a result of changes in economic conditions, resulting in a large apparent cost due to depreciation, even though no physical changes had taken place. It was judged preferable not to permit this to occur.

Grand totals for the costs and fuel consumption of the vehicle fleet as a whole are obtained by summing the values for each class.

4.8 ELASTICITY CALCULATIONS

One of the major purposes of the TRATEC model is to permit a non-econometric estimate of the own-price and cross-price elasticities of demand for transportation fuels under various conditions. In the broader sense of the word, elasticity describes the relative change in demand for a commodity resulting from either a change in its own price or the price of some other commodity. Understood in this sense, the own-price and cross-price elasticities of demand for fuels can be obtained directly by comparing two or more runs of the model using alternative prices. In the
formal technical sense, however, the price elasticity of demand $E_{j,k}$ for fuel $j$ with respect to the price of commodity $k$ is defined as

$$E_{j,k} = \frac{\partial Q_j}{\partial P_k} \cdot \frac{P_k}{Q_j}$$  \hspace{1cm} (eq. 4.47)

Where $P_k$ is the price of commodity $k$, and $Q_j$ is the quantity of commodity $j$ demanded. $Q_j$ is assumed to be a differentiable function of $P_k$. The own-price elasticity is obtained when $j = k$, otherwise, equation 4.47 gives the cross-price elasticity of demand for product $j$ with respect to the price of commodity $k$. The value of $E_{j,k}$ at any point can be approximated as

$$Q_j(P_k + \delta) - Q_j(P_k - \delta) \cdot \frac{P_k}{Q_j}$$  \hspace{1cm} (eq. 4.48)

where $\delta$ is a small number. The approximation can be made arbitrarily close as $\delta$ approaches zero.

The results of the TRATEC model can be used to estimate elasticity values corresponding to any given set of prices $P_k$. This is done making multiple runs of the model, varying $P_k$ slightly while keeping all other prices and input data constant, and substituting the resulting values for $Q_j$ into equation 4.48. Since $Q_j$ will adjust slowly to a step-change in $P_k$, estimates of both the short-term and the long-term elasticity can be
obtained from the same model runs.

The utility of the elasticity values so obtained is limited, since they apply only at or near the specific set of prices and conditions used in the model runs. The major purpose of computing elasticity values is to estimate the demand effects of a finite change in prices — a function which is fulfilled more appropriately by the model itself. Elasticity values may also be used as input data to a larger-scale model — of energy demand in an entire economy, for instance. Such models often assume constant elasticities. In the case of automotive transportation, this assumption is questionable, and is probably valid only for rather small changes in price. Where large price changes are involved, the constant elasticity assumptions should be checked by rerunning the TRATEC model using the changed prices, and comparing the results of the TRATEC and constant-elasticity models.

4.9 DATA REQUIREMENTS AND DATA AVAILABILITY

Input data to the TRATEC model can be divided into several categories, of which the most important are the technology characteristics, the size and age structure of the vehicle fleet, vehicle usage characteristics, and economic parameters. General technological characteristics have been discussed in Chapter Three, which forms a good starting point for model development. Development of a set of country-specific technological data for Egypt is discussed in Chapter Six, and the data themselves are given in Appendix B. Technology characteristics are generally very similar from
country to country, so that the Egyptian database (with some modifications to the cost and price data to reflect local conditions) should generally be applicable to a wide range of problems.

Economic parameters such as elasticities and transaction costs should ideally be estimated by econometric means, using data for the specific country to be modeled. The requisite data, however, are seldom available, and the labor involved in any econometric study is large. Since precise values for the economic parameters are not critical to the model results, it is probably best to use reasonable estimates, and to carry out sensitivity tests on the more critical parameters. The development of such estimates for Egypt is discussed in Chapter Six. The resulting values for the economic parameters used in the Egyptian model are also given in Appendix B.

Data on the size and composition of the motor-vehicle fleet are generally among the few reliable statistics available in developing nations. Data on the age structure of the fleet may be less accessible, although in many cases a good approximation may be obtainable from a review of vehicle import records or vehicle license data. Data on vehicle sales year-by-year are usually also obtainable from the same sources, or from production records in those nations which have a domestic automotive industry.

Estimates of total vehicle-distance travelled are less accessible than are sales or fleet data. Generally, these values are estimated by estimating
the average VMT per vehicle in each class, and then multiplying by the number of vehicles in the fleet. If reasonably accurate data on fuel economy are available, this procedure can be checked by comparing the total VMT so calculated with total fuel use (because fuel is primarily imported, aggregate fuel consumption data are available in most nations).

The TRATEC model has been specifically designed to tolerate a wide range of quality in the input data, while still giving reasonable results. Reasonable estimates can be substituted for virtually any of the input data or parameters if hard data are unavailable, without producing unreasonable or inconsistent results. Of course, the accuracy of the results — i.e. their correspondence to observed reality — is a separate issue from their apparent reasonableness and consistency, and will be heavily influenced by the accuracy of the input data. For policymaking purposes, however, it is frequently only necessary to have an idea of the magnitude or direction of a trend, rather than precise predictions. Where this is the case, the even rough estimates of the input parameters will probably provide sufficient accuracy.

4.10 CONCLUDING COMMENTS

The TRATEC program, in common with every other computer model, cannot produce "truth". At best, it can only work out in elaborate detail the implications of the input data and of the assumptions which went into its design. The task and art of the computer modeler is to develop input data
which, when combined with the algorithms of the model, give results that correspond sufficiently well with future reality. Predicting and evaluating the results of alternative policies — in transportation or in any other field — is fundamentally a human task. Mathematical or computer models such as the TRATEC program can only supply a rigorous structure for thinking; they cannot substitute for thought, or for common sense. In this regard, the importance of critically analyzing the model results and their applicability to the problem at hand cannot be stressed too highly.

As with any model, the reasonableness of the results is critically dependent on the accuracy (or at least reasonableness) of the input data. As noted above, the TRATEC model has been designed to use data which are (for the most part) readily available, or for which a reasonable approximation can readily be estimated. In practice, all of the requisite data for any model will seldom be available in precisely the needed form, so that some adaptations, approximations, and estimates will be necessary. The art of computer modeling lies in knowing how and when these approximations can be used without seriously distorting the results. This art is best learned by example, or by long experience. Chapters Six and Seven provide an example of the development of a set of model input data for the case of Egypt. These sections should be carefully reviewed before proceeding with serious modeling efforts using the TRATEC model.
5.0 DESCRIPTION OF THE TRATEC COMPUTER CODE

The preceding chapter has presented the mathematical structure of the TRATEC Transportation Technology Choice model. This chapter describes the implementation of that model in the form of a computer program. It includes an overview of the operation of the program, a discussion of the numerical solution techniques employed, a brief description of the input data files, and a discussion of the output. Further information on the program and its use are given in the TRATEC User's Manual, which is provided in Appendix A.

The TRATEC model is implemented as a computer program written in ANSI 1977 standard FORTRAN. The coding makes use of the full ANSI 1977 standard — neither the earlier 1966 standard nor the ANSI 1977 Subset standard was sufficient for an efficient implementation of the model. A copy of the FORTRAN code for the program is given in Appendix C.

The program is presently configured to run on a Digital Equipment Corporation VAX 11/780 computer, and the graphic output routine uses subroutine calls which are unique to MIT's PENPLOT graphics library. These would need to be modified in order to transport the program. However, machine-dependent coding in the program as a whole has been minimized, so that it could readily be converted to run on any other computer which supports the ANSI 1977 FORTRAN standard.
5.1 STRUCTURE OF THE TRATEC COMPUTER PROGRAM

Figure 5.1 is a flowchart showing the large-scale structure of the program. The program begins by parsing the parameters passed to it from the command line, checking them for errors, and opening the input and output files. Subsequently, control passes to subroutine READIN, which reads and parses the input parameter file, processing one group of cards at a time. If no errors are detected in the input parameter file, control passes to subroutine READTC, which performs a similar process on the technology data-base file. Data for each technology are read in and stored in a temporary random-access data-base file for use by the calculation routines. Any errors in the input data are reported, and if any are found the program is aborted.

After reading in the input parameters and technology database, the program proceeds to subroutine CALCL8, which carries out the actual modeling process. Finally, control passes to subroutine REPORT, which prints the output report. If graphic output has been specified, control then passes to GRAFIC, which produces the plot files by means of calls to the MIT PENPLOT graphics package.

Subroutine CALCL8, together with the functions and subroutines which it references, make up the embodiment of the mathematical model itself, as opposed to data handling, input, and output routines. The algorithmic structure of CALCL8 is shown in Figure 5.2. Upon entry to the CALCL8, the first step is to zero out all the totals and accumulators for sales, fleet
Figure 5.1: Flowchart of the TRATEC computer program.
Figure 5.2: Flowchart of subroutine TRATEC
structure, total costs, total fuel consumption, etc. Subsequently, the program carries out the modeling process separately for each class of vehicles, keeping track of the totals for each class and of the grand totals.

The first step in the modeling process for each class is to set up the tables giving the average VMT in each mileage group. This is done by a call to subroutine PDISTN, which performs a numerical integration of the lognormal probability distribution function for annual mileage in the current class, discretizes this distribution to generate the mileage groups, and then calculates the average VMT per vehicle in each mileage group. The mathematics of this procedure are discussed in Section 4.2.

The next step in the modeling process is to set up tables of the values of the integrals

\[ \int_{0}^{q} P(\ln) (X, \mu', \sigma') \, dx \]  

(eq. 5.1)

and

\[ \int_{0}^{q} X P(\ln) (X, \mu', \sigma') \, dx \]  

(eq. 5.2)

as functions of the accumulated mileage \( q \) for each technology \( t \) available to the current class. This is done by a call to subroutine RETSET. The tables are constructed by straightforward numerical integration, using the rectangle rule (see Forsythe et alia, 1977, or any good text on numerical integration).
methods). These tables are referenced by the vehicle retainment function RETIRE and the expected-life function XLIFE during the year-by-year calculations which follow. The mathematics of these calculations are presented in Section 4.5.

The last step before entering the year-by-year simulation is to set up the initial structure of the vehicle fleet for this class. Since the user has the option of specifying either the initial structure of the fleet (based on census data, for instance) or historical sales data for vehicles, the initialization may be done in one of two ways. If the user has provided the initial fleet structure, this can be set up directly in the arrays, and the simulation can begin with the next year. Initially, each technology is assumed to be equally distributed between each of the mileage groups. The first pass through the used-vehicle market simulator, however, results in a major redistribution of technologies, with the more efficient technologies concentrating in the higher-mileage groups and vice versa.

If the user has provided historical sales data, the initialization process is somewhat more complex. In this case, the model actually simulates the development of the fleet structure, beginning from the first year for which sales data are provided. During this process, the total VMT calculation and the new-vehicle selection algorithm are constrained to as to reproduce the historical sales values, but the mileage-accumulation, retirement, and used-vehicle market simulation segments of the model operate unconstrained, thus producing a near-equilibrium fleet structure.
by the time at which the simulation proper begins.

Once the initial fleet structure is established, the program begins an iterative year-by-year simulation of the evolution of the vehicle fleet. This simulation closely follows the approach described in Sections 4.1 and 4.6, thus the description of it here will be brief. Beginning with last-year's fleet structure, the program first calculates vehicle retirements since last year using subroutine RETIRE, and then adds one year's mileage to the accumulated mileage for each element. Following this, the program calculates the equivalent annual owning and operating cost for new vehicles of each technology available in the current class. Costs are calculated separately for each mileage group, using the approach presented in Section 4.3. The cost of the lowest-cost technology in each mileage group is then taken as the market "price" of transportation services supplied by new vehicles in that group. The model then begins iteratively calculating the equilibrium market prices and fleet structure in the used-vehicle market.

The initial guess at the market price of transportation services in each group is taken as the new-vehicle price, multiplied by the ratio of last year's eventual equilibrium price to the new-vehicle price in the last year (Note that this ratio is always less than or equal to one, since the elasticity of supply of new vehicles is assumed to be infinite). This modification sets the initial guess at the price relationships between mileage groups in the current year to be the same as the final equilibrium relationships in the year just past. Since price structures tend to
persist from year to year, this promotes more rapid convergence, and thus reduces computing cost.

Beginning with the initial guess at the market prices for transportation in each group, the program then loops through every element of the fleet, calculating the number of vehicles in that element which are retained in the element, sold to another mileage group, or removed from the fleet by junking. This calculation closely follows the mathematics of Section 4.6. The actual allocation of consumer choices to each option is done by subroutine LOGIT, which implements the logit model of consumer choice described in Section 4.4.

Having calculated the new fleet structure at the current prices, the program then calculates the average price of transportation, then calculates the total VMT demand using equation 4.9. Since average VMT per vehicle is assumed to be invariant, this establishes the total number of vehicles required in the fleet to fulfill the demand. The program then adds up the number of vehicles in each mileage group and compares it with the number of vehicles required in that group to meet the demand.

If a particular group has fewer vehicles than are needed to meet demand, and if the present estimate of market price in the group is equal to the new-vehicle price, the remaining vehicles are assumed to be purchased new. Otherwise, if the present market price is below the new-vehicle price, or if there are too many rather than too few vehicles in the group, the estimated market price for transportation in this group must be
adjusted to bring the used-vehicle supply into balance with the demand. Since the price/supply relationship is highly non-linear, the correct price for each group cannot be found analytically — it must be approximated by trial and error. Adjustment is done on one price at a time, selecting the group for which supply is most out of balance with demand and adjusting its price upward or downward as necessary. Mathematically, this process is similar to finding the zero of a nonlinear multivariable function, and the same algorithms apply. The algorithm used is a generalization of the method of secants used in finding zeroes of functions of one variable (Forsyth et alia, 1977).

Once the simulation of the used-vehicle market converges, the program proceeds to calculate new-vehicle sales by technology type. This is done by applying subroutine LOGIT, the multinomial logit model of consumer choice, separately to each mileage group. The input to the choice model is a vector of the equivalent annual costs of each available new-vehicle technology, and the output is a vector of the fractions of the total new-vehicle purchases going to that technology. Addition of the new-vehicle purchases to the current fleet establishes the equilibrium fleet composition for the current year.

After the equilibrium composition is established, the model calculates and sums the total costs, fuel consumption, fleet composition, and new-vehicle sales, using equations similar to those presented in Section 4.7. These values are stored in the appropriate arrays for later use by the report-printing and graphic-output routines. If the fleet-structure
printing flag is set, and if the current year is one to be printed, the
program then prints out the detailed fleet structure and other
intermediate variables for this class. Otherwise, control returns to top
of the loop to begin calculations for the next year.

5.2 INPUT DATA

The nature and format of the input data files are described in detail in
the TRATEC User's Manual, which is provided in Appendix A. This section
summarizes the important features of the input, without descending into
detail.

Input to the TRATEC program consists of two files: an input parameter file
and a file containing the technology database. The technology database
file contains the specifications for each technology to be considered by
the model. These include: technology name, mean and standard deviation of
mileage at retirement, the years the technology is available, and the
initial cost, fixed annual cost, maintenance cost, and fuel consumption of
vehicles using that technology in each year. The input parameter file
contains the basic model specifications, economic parameters, fuel prices,
total VMT and VMT distributions for each class, data on the initial fleet
structure, and similar data. The technology database file will normally
be constant from run to run of the models, while the input parameter file
will generally be changed with each run in order to create different
scenarios.
The data-input structures for the program have been designed to be easy to use, and to provide a maximum of helpful feedback and error checking. All input data are provided as free-format lists of parameters. These lists are interpreted and parsed by a sophisticated parsing routine, which provides for convenient features such as repeated data, free-format numerical and string input, and detailed error checking. A special feature simplifies the input of tabular year-by-year data for fuel prices, total VMT, and technology characteristics. For these data, it is not necessary to input values for each year. Data can be input only for selected years, and the remaining values in the table will be filled in by linear interpolation. Other useful features include the option of specifying either market prices alone or both market prices and shadow prices (the latter to be used in the calculation of social costs), and the option of entering data on the initial fleet composition either directly, or in the form of historical sales data by vehicle technology type.

5.3 PROGRAM OUTPUT

Output from the program consists of a printed report and an optional series of graphic plots. The printed report includes tables of total fuel consumption for each type of fuel in each year, and total costs. If the social-cost flag is set in the input, the totals are reported for both private (market) costs and social cost, with the latter calculated using the shadow prices provided in the input.

In addition to the global totals, the printed report also includes totals
for fuel consumption, private costs, and social costs for each vehicle class. In addition, the program reports the total sales of vehicles using each technology in each class for each year, and the number of vehicles in the fleet using each technology in each class for each year. As an option, the program can also print out the detailed structure of the fleet and other intermediate variables in selected years. The fleet structure printout with this option is broken down by class, technology, model year, and mileage group. In addition, the new-vehicle price for each technology, the price adjustment factors, and the market price for each class and mileage group for the given year are reported under this option.

Graphic output from the program consists of a series of plots, showing the total private costs, total social costs, and total usage of each type of fuel as functions of time, both for the entire vehicle fleet and for each individual class. In addition, plots showing the size and composition of the fleet by technology type are produced for each class.
6.0 AUTOMOTIVE TECHNOLOGY AND TRANSPORTATION IN EGYPT:  
DEVELOPMENT OF THE DATA SET

The ultimate justification for the development of any model lies in its application to understanding the real world. Similarly, the ultimate test of validity for any model is in its ability to reflect and predict the important aspects of the reality being modeled. This chapter and the following one describe the application of the TRATEC model to understanding the effects of alternative transportation and fuel-pricing policies in the Arab Republic of Egypt. The present chapter discusses the existing transport situation in Egypt, and describes the development of a set of TRATEC input data for use in modeling the results of alternative transportation policies. These alternative policies, the model scenarios derived from them, and the model results for each are presented and discussed in Chapter Seven.

6.1 ROAD TRANSPORTATION IN EGYPT: AN OVERVIEW

The Arab Republic of Egypt (henceforward "Egypt" for short) has espoused a nominally socialist economic policy since the coup of 1951, although the degree of emphasis on the "socialist" aspects of this policy has varied. State control of the economy has never been complete, and has been somewhat de-emphasized in recent years. In the transportation sector, the result of these policies has been a mixture of state-controlled
("para-statal") transportation companies and private organizations, with substantial participation by private individuals as well. In long-haul trucking, for instance, the five state-controlled freight companies both compete and cooperate with a number of government-sponsored trucker's cooperatives, and with private firms. Similarly, the four government-controlled interurban bus companies are supplemented by a large number of private buses (although these are apparently not allowed to compete directly), and compete on somewhat disadvantageous terms with a large number of long-distance taxis operated by private entrepreneurs.

Roads — Although Egypt is a large nation, more than 99 percent of the population is clustered very densely in the Nile Valley and Delta regions, and the area along the Suez canal. These regions also contain virtually all of the agriculture and industry. This clustering and the favorable terrain have made a dense road network feasible, with the result that the Egyptian highway system is one of the best in Africa, and highway transportation is unusually well-developed, considering the level of per-capita income.

Vehicle Manufacturing and Imports — Unlike many developing nations, Egypt has developed a substantial domestic capacity for motor-vehicle manufacture. The state-controlled El Nasr Automotive Manufacturing Company (NASCO) produces heavy trucks, buses, and passenger cars, under a number of joint-venture agreements with various multinational firms. NASCO's market is protected by very high customs duties (100 percent ad valorem for 4 cylinder passenger cars, 150 percent for 6 cylinder cars,
and 20, 25, and 42 percent for trucks, buses, and semi-tractors, respectively). NASCO has concentrated on producing small cars (Fiat models produced under license), light buses, and medium and heavy-duty trucks. Large cars (including most taxis), light trucks, heavy buses, and semi-tractors are all imported, as are a significant number of medium and some heavy trucks. Because of the high tariffs (as well as government control of prices), domestically-produced vehicles are generally much cheaper than the imports, but the imports are perceived as having higher quality.

**Passenger Transport** — The large cities of Cairo and Alexandria have extensive public transit systems using buses. These systems include about 3000 buses total, or three-sevenths of the heavy buses in the nation. Large numbers of private cars are also driven in the cities, and taxis are another important mode of transportation. Interurban transport is by means of passenger trains, interurban buses, or intercity taxis. Interurban buses are operated by four regional public corporations, which have a legal monopoly. They face stiff competition, however, from the large numbers of interurban taxis. These operate more or less as scheduled high-speed carriers, but escape the prohibition on bus transport because of their small size (most are seven-passenger Peugeot 504s). In 1979, it was estimated that intercity taxis accounted for more passenger-kilometers travelled than the bus system, and for more than four times as many as private cars (ENTS II).

**Freight Transport** — Despite the navigability of the Nile and a moderately
extensive rail network, most long-haul freight in Egypt is moved by road. Long distance hauling is done by tractor-trailer or truck-trailer combinations which are mostly either European imports or based on European designs. Local and short-haul trucking is mostly by medium and light-heavy trucks, with some small truck-trailer combinations in use. An increasing number of pickups and other light trucks are also being imported. In 1979, the Egyptian truck fleet consisted of about 33,000 pickups, 10,700 three-ton trucks, 24,500 eight-ton trucks, 2,900 fourteen-ton trucks, 5,300 twenty-ton truck/trailer combinations, 1,150 thirty-ton truck/trailer combinations, and 3,250 tractor-trailer rigs. Most of the tractor-trailers and pickups were relatively new, having been imported after the 1973 war, while the average age of the other trucks was considerably greater.

6.2 Data Sources and Assumptions Used in the Model

In Egypt, as in most developing nations, detailed statistical data on highway transportation and fuel use are difficult to come by. The best and most comprehensive sources of detailed information on the highway transportation sector in Egypt are the reports of the Egyptian National Transportation Study or ENTS. The Phase I report of this study (ENTS I) was produced by Louis Berger International in 1977; the Phase II report (ENTS II) by Netherlands Engineering Consultants in 1981. ENTS II includes data on highway vehicle numbers, VMT, operating and maintenance costs, and many other relevant questions in considerable detail, and it forms the major foundation for the development of the data for the present model.
The ENTS II data are relatively recent, being current up to 1979 in most cases. Since detailed data are not available for years following 1979, that year has perforce been selected as the base year for the model. This allows for a rough check on the results, since aggregate fuel-consumption data for Egypt are available up to the 1982/83 fiscal year, and can be compared with the model results.

In addition to the initial year of 1979, the years 1985, 1990, and 2000 have been chosen for convenience as "benchmark" years. Estimates of technical characteristics, economic quantities, and other time-related data going into the model have been developed and tabulated only for these years, with the intervening years filled in by linear interpolation. This has been done to reduce the volumes of data to be processed, while still providing adequately detailed projections. In modeling the present Egyptian vehicle fleet, model years back to 1960 have been included.

**Macroeconomic Assumptions** — The projections developed in the ENTS II report assumed a rate of economic growth of 8 percent per year from 1979 onward. For the years of 1979 and 1980, growth was considerably above that level in nominal terms, but it fell to 9 percent in 1981 (International Monetary Fund, 1983). Inflation was also high during those years, so that an overall average real growth rate of 8 percent per year seems, if anything, slightly high.

In the four years from 1979 to 1983, the Egyptian wholesale price index
increased at an average rate of 15 percent per year. Taking this as a reasonable proxy for the rate of inflation, and assuming that this trend extended through 1985, the general price level in 1985 would be roughly double that of 1979. Thus for a commodity (such as fuel) for which the nominal price remained unchanged between 1979 and 1985, the real (deflated) price would have decreased by 50 percent.

Such high inflation levels pose a considerable problem for the economic modeler, since they rapidly become imbedded in the consumer's consciousness, leading to a "buy now" attitude which distorts purchasing decisions. The usual solution to this problem is to formulate the model in "real" terms — that is, in terms which have been adjusted for inflation. This approach is not perfect, since purchasers cannot always accurately foresee the future inflation rate — price expectations often over or under-shoot, depending on past experience — and price changes for individual commodities may be greater or less than those in the economy as a whole. However, this approach is widely used, and has the virtue of simplicity, since the modeler need not forecast the future inflation rate, but can simply continue current price levels in "real" terms.

The problem of exchange rates introduces an additional complication into modeling of international economic issues. In order to minimize the these complications all of the projections developed for this model have been developed in terms of Egyptian pounds, with no attempt to relate them to U.S. dollars. For those variable (such as international oil prices) where comparison between pounds and dollars cannot be avoided, the comparison
has been limited to the two years of 1979 and 1985. The 1979 exchange rate has been taken as the official rate of $0.70 equal to one pound. Although this is still the official rate in 1985, the market rate in the parallel currency market is approximately $1.00 equal 1.23 pounds. This latter rate is considered to represent the real opportunity cost of foreign exchange to the Egyptian economy.

6.3 DEVELOPMENT OF THE TRATEC INPUT DATA

As discussed in Chapter Five, the TRATEC model requires two separate data files: an input data file containing model specifications, economic parameters, and information on the current fleet; and a technology database file. The input data file will normally be different for each scenario, while the technology database file normally does not change from run to run. This section describes the development of the input data file for the "base-case" scenario described in Chapter Seven. With minor modifications, this file was also used for the other three scenarios and the sensitivity tests described in that Chapter. Section 6.4 below describes the development of the technology database for Egypt.

6.3.1 Vehicle Fleet Size and Composition

The ENTS II study divided Egyptian highway vehicles into nine groups for the purposes of calculating operating costs and projecting future demand. These groups were the following: passenger car, taxicab, pickup truck,
small bus, large bus, small truck, small truck/trailer, large truck/trailer, and tractor/semi-trailer. Two of these groups (large truck/trailer and tractor/semi-trailer) were considered to be functionally equivalent, although technically different, and were lumped together in most of the calculations. This report follows the same basic approach, except that the large truck/trailer and semi-trailer classes are lumped together everywhere (being treated as two alternative technologies within the same class), and that the private passenger car class has been divided into two classes: large passenger cars and small passenger cars. The resulting vehicle classification structure is shown in Table 6.1.

The ENTS II report provides extensive data on the size and composition of the highway vehicle fleet as of 1979. This information includes data on the total numbers of private passenger cars, taxis, light trucks, buses (divided into four categories), and medium and heavy trucks (divided into several weight classes). In addition, road-side interview surveys in selected areas provided information on the age breakdown of vehicles within most of the classes. Unfortunately, the classification of trucks and buses in the fleet totals differs somewhat from that in the roadside interviews, and neither is fully consistent with the classification scheme used for calculating the capital and operating costs of transportation (and adopted for this report).

Population data for medium and heavy trucks were presented in several formats. One format grouped trucks by payload capacity into pickups, 3-5 ton trucks, 5-10 ton trucks, single trucks greater than 10 tons, small (20
Table 6.1: Vehicle classifications used in the model

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Small Passenger Car</td>
<td>GVW about 1000 KG, 4 passengers. Mostly domestic (NASCO) made.</td>
</tr>
<tr>
<td>(2) Large Passenger Car</td>
<td>GVW about 1500 KG, 5+ passengers. Mostly imported (Mercedes, Peugeot).</td>
</tr>
<tr>
<td>(3) Taxicab</td>
<td>GVW about 1500 KG, up 7 passengers. Peugeot 504 is commonest.</td>
</tr>
<tr>
<td>(4) Light-Duty Truck</td>
<td>Mostly mid-size Japanese pickups, payloads up to 1000 KG.</td>
</tr>
<tr>
<td>(5) Light Bus</td>
<td>Built on medium truck chassis, 20 to 40 passengers.</td>
</tr>
<tr>
<td>(6) Heavy Bus</td>
<td>Heavy urban or interurban bus, 50+ passengers.</td>
</tr>
<tr>
<td>(7) Small Truck</td>
<td>Includes all single-unit trucks from 3 ton to 14 ton payload, most are about 8-10 tons capacity.</td>
</tr>
<tr>
<td>(8) Small Truck/Trailer</td>
<td>Mostly 8-ton trucks hauling 12-ton trailers, used in short and intermediate-distance hauling.</td>
</tr>
<tr>
<td>(9) Large Truck/Trailer</td>
<td>Two types: tractor/semi-trailer or large 14-ton truck with 16-ton trailer.</td>
</tr>
</tbody>
</table>
ton) truck-trailers, large (30 ton) truck-trailers, and semi-trailers. In adapting these data to the classification scheme used here, all single-unit trucks except pickups were lumped together into the "small truck" class, and large truck-trailers were lumped with semi-trailers. The pickup and small-truck trailer classes were carried over directly.

The bus population was given in terms of four categories: public buses, private buses, school buses, and tourist buses. Most public buses and all tourist buses are of heavy construction, so these groups were lumped together in the "heavy bus" class. According to the ENTS II report, most other private buses are of light construction, and school buses are lightly built as well. These two groups were thus combined to form the "light bus" class. No age-distribution data from the roadside interviews were provided for heavy buses. However, age-distribution data for the subset of the heavy bus fleet which is owned by the four inter-urban transport companies was available in the ENTS II report. For lack of better data, this distribution was assumed to apply to the remaining buses as well. This is probably reasonable, since both urban and interurban bus fleets are publicly owned, and can be expected to have expanded in parallel.

In addition to the numbers and vehicle classes in the existing fleet, the TRATEC model requires that the vehicle technologies in the existing fleet be specified as well. For most of the classes considered, the fleet was sufficiently homogeneous that only one technology needed to be specified. For instance passenger cars may use either gasoline or diesel
technologies, but the import of diesel cars into Egypt is banned. Thus, only the gasoline-engine technologies needed to be considered. The same stricture apparently applies to light trucks as well, so that again, only the gasoline-engine technology was considered. Gasoline and diesel engines compete only in the light bus and small truck categories, where the ENTS II report estimates that 20 percent of each class is gasoline-fueled. For want of better information, this percentage was assumed to be independent of vehicle age.

The vehicle technology assumed for existing vehicles at the start of the model was, in each case, the "standard" technology, either "standard" diesel or "standard" gasoline, or — for small trucks and light buses — both. The characteristics of each technology and the basis for classification are discussed in Section 6.4. It was assumed that few advanced-technology vehicles would be in use in 1979. For heavy-duty trucks, however, there are a choice of two "standard" technologies in Egypt — semi-trailer and large truck/trailer. Since the numbers and age distribution of both types of vehicle were available in the ENTS II report, both were included in the specification of the initial vehicle fleet.

Table 6.2 presents the picture of the numbers and age distribution of the 1979 Egyptian vehicle fleet derived from the ENTS II report, based on the considerations discussed above. The fleet structure shown in this table was used as the initial (1979) starting fleet for all of the alternative scenarios and sensitivity tests.
Table 6.2: Initial (1979) structure of the Egyptian vehicle fleet.

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Small Passenger Car</td>
<td>10*4015</td>
<td>3865</td>
<td>5153</td>
<td>12884</td>
<td>24049</td>
<td>28559</td>
<td>28559</td>
<td>22117</td>
<td>17178</td>
<td>18037</td>
</tr>
<tr>
<td>(2) Large Passenger Car</td>
<td>10*1829</td>
<td>1761</td>
<td>2348</td>
<td>5870</td>
<td>10957</td>
<td>13011</td>
<td>13011</td>
<td>10076</td>
<td>7826</td>
<td>8218</td>
</tr>
<tr>
<td>(3) Taxicab</td>
<td>10*1610</td>
<td>452</td>
<td>633</td>
<td>1447</td>
<td>10582</td>
<td>15014</td>
<td>17185</td>
<td>7507</td>
<td>9045</td>
<td>9768</td>
</tr>
<tr>
<td>(4) Light-Duty Truck</td>
<td>10*75</td>
<td>248</td>
<td>124</td>
<td>248</td>
<td>373</td>
<td>1035</td>
<td>2566</td>
<td>3642</td>
<td>9271</td>
<td>15397</td>
</tr>
<tr>
<td>(5) Light Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline Engine</td>
<td>10*32</td>
<td>32</td>
<td>53</td>
<td>63</td>
<td>53</td>
<td>83</td>
<td>209</td>
<td>125</td>
<td>262</td>
<td>355</td>
</tr>
<tr>
<td>Diesel Engine</td>
<td>10*130</td>
<td>126</td>
<td>211</td>
<td>253</td>
<td>211</td>
<td>330</td>
<td>835</td>
<td>498</td>
<td>1046</td>
<td>1418</td>
</tr>
<tr>
<td>(6) Heavy Bus</td>
<td>10*141</td>
<td>316</td>
<td>476</td>
<td>476</td>
<td>476</td>
<td>489</td>
<td>489</td>
<td>970</td>
<td>970</td>
<td>970</td>
</tr>
<tr>
<td>(7) Small Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline Engine</td>
<td>10*320</td>
<td>376</td>
<td>204</td>
<td>376</td>
<td>327</td>
<td>294</td>
<td>702</td>
<td>784</td>
<td>564</td>
<td>792</td>
</tr>
<tr>
<td>Diesel Engine</td>
<td>10*1281</td>
<td>1503</td>
<td>817</td>
<td>1503</td>
<td>1307</td>
<td>1176</td>
<td>2810</td>
<td>3136</td>
<td>2254</td>
<td>3169</td>
</tr>
<tr>
<td>(8) Small Truck/Trailer</td>
<td>10*171</td>
<td>294</td>
<td>203</td>
<td>283</td>
<td>305</td>
<td>345</td>
<td>825</td>
<td>441</td>
<td>362</td>
<td>537</td>
</tr>
<tr>
<td>(9) Large Truck/Trailer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck/Trailer</td>
<td>10*37</td>
<td>64</td>
<td>44</td>
<td>61</td>
<td>66</td>
<td>75</td>
<td>179</td>
<td>96</td>
<td>78</td>
<td>116</td>
</tr>
<tr>
<td>Tractor/Semi-trailer</td>
<td>10*10</td>
<td>481</td>
<td>153</td>
<td>23</td>
<td>74</td>
<td>153</td>
<td>408</td>
<td>611</td>
<td>459</td>
<td>787</td>
</tr>
</tbody>
</table>
6.3.2 Transportation Demand and Distance Travelled Per Vehicle

The ENTS II report presents estimates of future passenger-kilometers travelled under a number of different scenarios. The scenario chosen as the basis for this model was the "low base" scenario, which is the one considered probable (in the absence of government policy changes) by the ENTS II researchers. Since the base-case model is intended to reflect a continuation of the status quo, this choice is appropriate.

Total annual vehicle-kilometers travelled can be calculated from the estimates of passenger-kilometers travelled, using the average occupancy rates estimated in the ENTS II report. However, the estimates developed are for interurban travel only, since that was the focus of the ENTS II study. Estimates of the percentage of urban travel for each type of passenger vehicle are also given, however, so that the calculation of total annual VMT (including both urban and inter-urban operation) is straightforward. This calculation is shown in Table 6.3.

The ENTS I and II reports present estimates of average annual kilometers travelled per vehicle for different vehicle classes. Unfortunately, several different (and conflicting) estimates of these quantities are developed in different sections of the reports. The estimates of annual kilometers travelled per vehicle used in this work are shown in Table 6.4. For passenger vehicles, these estimates were obtained by dividing the estimate of total vehicle-kilometers travelled by each type of vehicle in
Table 6.3: Calculation of total passenger-vehicle VKT/year from ENTS II projections of interurban VKT

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>PCT. URBAN</th>
<th>VKT PER YEAR (MILLIONS)</th>
<th>1979</th>
<th>1983</th>
<th>1987</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Small Passenger Car</td>
<td>60</td>
<td>Interurban</td>
<td>824</td>
<td>1,319</td>
<td>2,006</td>
<td>4,287</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>2,061</td>
<td>3,298</td>
<td>5,015</td>
<td>10,718</td>
</tr>
<tr>
<td>(2) Large Passenger Car</td>
<td>60</td>
<td>Interurban</td>
<td>376</td>
<td>601</td>
<td>914</td>
<td>1950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>939</td>
<td>1,503</td>
<td>2,285</td>
<td>4,875</td>
</tr>
<tr>
<td>(3) Taxicab</td>
<td>60</td>
<td>Interurban</td>
<td>1,980</td>
<td>3,140</td>
<td>4,790</td>
<td>10,190</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>4,950</td>
<td>7,850</td>
<td>11,975</td>
<td>25,475</td>
</tr>
<tr>
<td>(5) Light Bus</td>
<td>69</td>
<td>Interurban</td>
<td>120</td>
<td>170</td>
<td>220</td>
<td>420</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>388</td>
<td>549</td>
<td>711</td>
<td>1,357</td>
</tr>
<tr>
<td>(6) Heavy Bus</td>
<td>60</td>
<td>Interurban</td>
<td>140</td>
<td>210</td>
<td>270</td>
<td>520</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>350</td>
<td>525</td>
<td>675</td>
<td>1,300</td>
</tr>
</tbody>
</table>
1979 (shown in Table 6.3) by the number of that type of vehicle in the fleet.

For freight vehicles, the ENTS reports provide little information on present or projected future VKT, so the estimation procedure used was the reverse of that for passenger vehicles. The data on current truck fleet size were combined with estimates of annual VKT per vehicle from the ENTS II report in order to calculate a reasonable value for current (1979) total annual VKT in each class. The estimates of annual VKT per vehicle used are shown in Table 6.4.

Total VKT demand for freight vehicles in future years was derived from the demand in the current year, by the use of projected changes in overall freight tonnage. The ENTS II report projects an increase in long-distance freight tonnage from 10.2 billion ton-kilometers in 1979 to 16.3 billion in 1987 and 28.1 billion in 2000. The total annual VKT in each of the medium and heavy truck classes were assumed to increase in proportion to the increase in freight. Table 6.5 shows how these values were calculated. Pickup trucks are little used for heavy freight, and have characteristics similar to passenger cars. Since no separate projections for pickups were available, their VKT was assumed to increase at the same rate as for passenger cars. The resulting VKT estimates for pickups are also shown in Table 6.5.

In addition to the mean annual distance travelled per vehicle, the TRATEC model requires an estimate of the standard deviation of the annual
Table 6.4: Estimated mean and standard deviation of annual kilometers travelled per vehicle for each class of vehicles.

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>VKT/YEAR</th>
<th>EST. MEAN/ STD. DEV.</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Small Passenger Car</td>
<td>10,277</td>
<td>0.65</td>
<td>6,680</td>
</tr>
<tr>
<td>(2) Large Passenger Car</td>
<td>10,277</td>
<td>0.65</td>
<td>6,680</td>
</tr>
<tr>
<td>(3) Taxicab</td>
<td>56,420</td>
<td>0.65</td>
<td>36,673</td>
</tr>
<tr>
<td>(4) Light-Duty Truck</td>
<td>24,309</td>
<td>0.65</td>
<td>15,800</td>
</tr>
<tr>
<td>(5) Light Bus</td>
<td>49,846</td>
<td>0.90</td>
<td>44,861</td>
</tr>
<tr>
<td>(6) Heavy Bus</td>
<td>49,709</td>
<td>0.90</td>
<td>44,738</td>
</tr>
<tr>
<td>(7) Small Truck</td>
<td>34,777</td>
<td>0.80</td>
<td>27,821</td>
</tr>
<tr>
<td>(8) Small Truck/Trailer</td>
<td>50,000</td>
<td>0.87</td>
<td>43,500</td>
</tr>
<tr>
<td>(9) Large Truck/Trailer</td>
<td>75,000</td>
<td>0.58</td>
<td>43,500</td>
</tr>
</tbody>
</table>
Table 6.5: Estimates and projections of total truck VKT/year from ENTS II data and freight tonnage projections

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(4) Light-Duty Truck</td>
<td>24,309</td>
<td>33,650</td>
<td>818</td>
<td>1,309</td>
<td>1,990</td>
<td>4,254</td>
</tr>
<tr>
<td>(7) Small Truck</td>
<td>34,777</td>
<td>38,100</td>
<td>1,325</td>
<td>1,728</td>
<td>2,131</td>
<td>3,664</td>
</tr>
<tr>
<td>(8) Small Truck/Trailer</td>
<td>50,000</td>
<td>5,300</td>
<td>265</td>
<td>346</td>
<td>426</td>
<td>733</td>
</tr>
<tr>
<td>(9) Large Truck/Trailer</td>
<td>75,000</td>
<td>4,400</td>
<td>330</td>
<td>430</td>
<td>531</td>
<td>913</td>
</tr>
</tbody>
</table>
distance travelled. No such data were available for Egypt. However, Energy and Environmental Analysis (1984) provides data for several classes of trucks in the United States from which both the mean and standard distribution of annual mileage travelled can be calculated. For the purposes of this work, it was assumed that the ratio of mean to standard deviation in Egypt would probably be comparable to that in the U.S., so that the two distributions would have similar shapes. The ratios used and the standard deviations derived from them are shown in Table 6.4.

No data on the distribution of annual mileage for passenger vehicles (cars and buses) was available. For want of better data, the ratio of mean to standard deviation for light-duty trucks taken from Energy and Environmental Analysis was used for passenger cars as well. For buses, the ratios for trucks of comparable size were used to estimate the standard deviation.

6.3.3 Economic Parameters

The TRATEC model requires that values be specified for a number of economic parameters. These parameters describe the economic decision-making process going into the purchase of each class of vehicles, and may be different for each class. The required parameters include the discount rate to be used, the own-price elasticity of demand for transportation, the transaction cost for used-vehicle sales/purchase, the value of the premium placed on a new vehicle, and the value of the parameter $\beta_c$ which describes the logit choice function. The values used
in the model are shown in Table 6.6. The derivation of these values and the reasoning behind them are presented below.

**Discount Rates** — In Egypt, as in most developing nations, the marginal productivity of capital is very high, and thus interest and discount rates would be expected to be high as well. In recent years, however, official interest rates have been below the rate of inflation, resulting in a negative real interest rate. The result of controlling the price of capital below its market value is predictable: credit must be rationed. Faced with a limited capital budget due to rationing, the individual decision-maker (if he or she behaves in an economically rational way) must allocate the available credit to the most productive investments, in effect establishing his or her own "shadow" interest rate. It is these shadow interest rates, which are estimates of the marginal productivity of capital for different classes of vehicle purchasers, which are used in the model. As Table 6.6 indicates, these rates vary considerably, being lowest for large trucks and for buses and highest for vehicles owned by private individuals.

Buses and large trucks are owned mostly by large private or parastatal organizations, which have better access to credit than smaller businesses or individuals. Smaller trucks are probably owned mostly by small and medium-sized businesses and farms, and these — along with the urban elite who purchase large cars — have better access to credit than small car and light truck buyers, most of whom are probably in the middle classes. These relationships are reflected in the values shown.
Table 6.6: Values of economic parameters used in the model.

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>$y_c$</th>
<th>$-e_c$</th>
<th>$\beta_c$</th>
<th>$y_c$</th>
<th>$\Delta_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Small Passenger Car</td>
<td>0.25</td>
<td>0.3</td>
<td>0.00528</td>
<td>288</td>
<td>411</td>
</tr>
<tr>
<td>(2) Large Passenger Car</td>
<td>0.20</td>
<td>0.2</td>
<td>0.00206</td>
<td>909</td>
<td>1,299</td>
</tr>
<tr>
<td>(3) Taxicab</td>
<td>0.16</td>
<td>0.6</td>
<td>0.00256</td>
<td>682</td>
<td>487</td>
</tr>
<tr>
<td>(4) Light-Duty Truck</td>
<td>0.25</td>
<td>0.2</td>
<td>0.00409</td>
<td>322</td>
<td>230</td>
</tr>
<tr>
<td>(5) Light Bus</td>
<td>0.16</td>
<td>0.1</td>
<td>0.00112</td>
<td>1,045</td>
<td>1,045</td>
</tr>
<tr>
<td>(6) Heavy Bus</td>
<td>0.12</td>
<td>0.1</td>
<td>0.00076</td>
<td>2,065</td>
<td>2,581</td>
</tr>
<tr>
<td>(7) Small Truck</td>
<td>0.16</td>
<td>0.2</td>
<td>0.00191</td>
<td>790</td>
<td>790</td>
</tr>
<tr>
<td>(8) Small Truck/Trailer</td>
<td>0.16</td>
<td>0.2</td>
<td>0.00136</td>
<td>1,053</td>
<td>1,053</td>
</tr>
<tr>
<td>(9) Large Truck/Trailer</td>
<td>0.12</td>
<td>0.3</td>
<td>0.00088</td>
<td>1,872</td>
<td>2,340</td>
</tr>
</tbody>
</table>
Elasticities — As noted in Chapter Two, price elasticities of demand for transportation have been investigated extensively by econometric means. Generally, these studies have indicated a long-run elasticity of -0.2 to -0.3 for consumers in developed nations, but it is unclear to what extent these results are applicable to the developing world. The ENTS II researchers assumed a long-run price elasticity of -0.5 for passenger travel, but provided little justification for this. Assessment is complicated by the fact that transportation prices in Egypt are heavily subsidized, and thus occupy less of a place in personal, family, and institutional budgets than would be the case if pricing reflected market conditions. This argues for low values of elasticity, since even very large percentage increases in price will have only minor income effects.

The elasticity values shown in Table 6.6 reflect these considerations. Since freight transportation is essential to industry, and since the total costs of freight transport are small compared to the value of the goods, the elasticity of demand for truck VMT is considered to be low. Demand for long-distance trucking is somewhat more elastic, since rail and river transport provide alternatives to trucking. The elasticity of demand for private-car transportation is probably comparable to that in the developed nations, while that for taxis is probably fairly high. This is due in both cases to the well-developed urban and interurban bus system, which provides a lower-cost alternative to passenger cars. For the same reason, however, the elasticity of demand for bus transport is considered to be very low.
**Transaction Costs and New-Vehicle Premium** — Little empirical information is available on these parameters, and the author is aware of none in developing nations. Qualitative consideration of consumer behavior, however, permits the establishment of reasonable estimates of their magnitude.

Used-vehicle transaction costs have three major components: the value of the time and effort expended by a purchaser in locating and evaluating a used vehicle, the similar value of the time and effort expended by the seller in selling it, and the risk (of being cheated, of getting a "lemon") assumed by the purchaser. This latter component is probably the most significant, especially in a developing nation where wage rates (and thus the value of time and effort) are low. This risk probably amounts to between 5 and 10 percent of the value of a new passenger car or light truck. Purchasers of larger vehicles are usually more knowledgeable mechanically (and large-vehicle maintenance tends to be better) so that the risk premium is probably lower in these classes. For the purposes of this work, the transaction cost has been taken as seven percent of the cost of a new "standard technology" vehicle for cars and light trucks, five percent for small trucks and light buses, and four percent for large truck/trailers and heavy buses. The development of cost estimates for these vehicles is discussed in Section 6.4 below.

The new-vehicle premium is used to account for the additional benefits (beyond the basic vehicle itself) that accrue to the purchaser of a new
vehicle. Some of these are direct financial benefits, such as maintenance service under warranty. Other, non-financial benefits may include the value of increased reliability from a new vehicle, greater comfort for passengers, and (for private vehicles) higher social status and prestige. The convenience of dealing with an established and reliable dealer is also valuable. Taken together, these benefits can add up to significant value. It is commonly remarked, for instance, that the value of a new car in the U.S. drops by roughly 20 percent the minute it is driven off the dealer's lot (this is due to both the new-vehicle premium and the transaction cost for used vehicles).

The new-vehicle premium is expected to be most significant in passenger cars, where it is probably at least 10 percent of the cost of a new "standard technology" vehicle. For commercial vehicles, including taxis, pickups, trucks and buses, a value of five percent of the cost has been used.

**Beta Values** — The parameter $\beta_c$ describes the shape of the logit choice function. A large value of $\beta_c$ results in a sharply divided choice function — small changes in relative price can lead to large changes in market share. Small values result in a broader range of choices. Again, there is little empirical evidence as to the magnitude of $\beta_c$. A qualitative examination of consumer behavior, however, can establish some reasonable approximations.

According to the logit choice model, given two otherwise comparable
choices, the choice exhibiting the lowest life-cycle cost will be taken in most cases. To establish the value of \( \beta \), it is necessary to estimate how great a price advantage is necessary for a given choice to be taken a given fraction of the time. Consider a simple two-choice decision A or B, and define \( V \) as the fraction going to choice A. Define \( \Delta P \) as the difference in cost between A and B. Then the logit model gives:

\[
V = \frac{e^{-\beta P_A}}{e^{-\beta P_A} + e^{-\beta (P_A + \Delta P)}} = \frac{1}{1 + e^{-\beta \Delta P}} \quad \text{Eq. 6.1}
\]

Given estimates of the price difference \( \Delta P \) needed to induce a given fraction \( V \) of consumers to take choice A, equation 6.1 can be solved for the value of \( \beta \).

\[
\beta = \frac{\ln V - \ln (1-V)}{\Delta P} \quad \text{Eq. 6.2}
\]

In the TRATEC model, the logit choice function is applied to the annual equivalent costs arising from each decision. To calculate \( \beta \) for private cars and light trucks, it was assumed that a cost differential equal to 20 percent of the annual-equivalent capital cost of a "standard" technology vehicle would result in the lower-cost technology obtaining 75 percent of the market. The same assumption was made for the smaller commercial vehicles — taxis, pickups, small trucks and light buses. Purchasers of large trucks and heavy buses are somewhat more cost-conscious. In these classes, a 15 percent cost differential was assumed to result in a 75 percent market share.
Because of the central role of the logit choice function in the model and the approximate nature of this derivation, model runs with alternative values were made to test the sensitivity of the results to changes in $\beta$. The results of these runs show that the basic conclusions of the report are not very sensitive to $B_c$, as long as it remains within a reasonable range. These results are discussed at greater length in Section 7.5.

6.3.4 Fuel Prices and Costs

Fuel prices in Egypt are subject to a large implicit subsidy, since the government oil company sells both diesel and gasoline at prices well below the world-market level. In 1979, the domestic price of gasoline was L.E. 0.11 per liter, while that for diesel fuel was L.E. 0.025 (ENTS II). These prices were increased to 0.13 and 0.30 respectively in 1980, but have not been significantly changed since that time. Because of continuing inflation, the real price of fuel (expressed in constant 1979 pounds) has declined steadily since 1980, so that it is presently about L.E. (1979) 0.065 per liter for gasoline, and L.E. (1979) 0.015 per liter for diesel fuel. The situation for diesel fuel is complicated somewhat by the fact that there are apparently two grades of fuel being sold. One of these is called "diesel fuel", the other appears to be another middle-distillate fuel called "Solar". The prices and uses for the two are similar, however, so they have both been lumped together here as "diesel fuel".

The cost to Egyptian society of a liter of fuel consumed is given by its
"shadow price". For the purposes of this report, it has been assumed that any fuel which is not consumed within Egypt would be exported at world prices, so that the shadow cost of fuel is equal to its price on the International market. Spot prices for leaded regular gasoline and for gas oil (middle distillate oil) in the Mediterranean were obtained from the OPEC bulletin (various issues). These were converted from U.S. dollars to Egyptian pounds using the exchange rates discussed in Section 6.2, and adjusted for inflation. The resulting social costs of each fuel are shown along with the Egyptian domestic prices in Table 6.7.

Table 6.7 also shows projected domestic and international fuel prices for the future years 1990 and 2000. The international prices in this table were calculated by assuming a uniform three percent-per-year increase from current fuel prices over the next fifteen years. The domestic price projections assume no change in current Government policy with regard to fuel pricing, except for continuing adjustments to account for inflation. As a result, the real domestic price of fuel is projected not to change over the next fifteen years.

The history of oil prices over the last fifteen years shows the difficulties and uncertainties inherent in long-term projections of this type. For this reason, two alternative price scenarios were constructed and compared with the results of the base case. One of these assumed a six percent-per-year increase, the other no increase in real international fuel prices. The model results for these scenarios are discussed in Section 7.5.
Table 6.7: Projected Egyptian and world-market prices of gasoline and diesel fuel, 1979 to 2000.

<table>
<thead>
<tr>
<th>Year</th>
<th>GASOLINE Egyptian</th>
<th>GASOLINE World</th>
<th>DIESEL FUEL Egyptian</th>
<th>DIESEL FUEL World</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>0.011</td>
<td>0.198</td>
<td>0.025</td>
<td>0.198</td>
</tr>
<tr>
<td>1985</td>
<td>0.065</td>
<td>0.115</td>
<td>0.015</td>
<td>0.122</td>
</tr>
<tr>
<td>1990</td>
<td>0.065</td>
<td>0.133</td>
<td>0.015</td>
<td>0.141</td>
</tr>
<tr>
<td>2000</td>
<td>0.065</td>
<td>0.179</td>
<td>0.015</td>
<td>0.190</td>
</tr>
</tbody>
</table>
It should be noted that the fuel-price projections included here involve no change in the relative prices of diesel and gasoline on the world market. Depending on future events, could well turn out to be wrong. Europe is now contemplating a major shift to unleaded gasoline for environmental reasons, and the U.S. will probably ban the use of leaded gasoline entirely by 1988. These moves will tend to increase the value of gasoline stocks relative to middle distillates, thus further rewarding any shift from gasoline to diesel fuels by exporting nations such as Egypt.

6.4 VEHICLE TECHNICAL CHARACTERISTICS — PRESENT AND FUTURE

The vehicle technical characteristics used in the Egypt model are based primarily on the results of Chapter Three, with adaptations as necessary to account for the unique characteristics of Egyptian transport. The major sources of data on these unique characteristics were the ENTS I and II reports. To conserve space, the relevant discussion in Chapter Three has not been repeated here, except as it has been modified for application to Egypt. For the same reason, only a very abbreviated account of the ENTS I and II data is presented.

Vehicle Classification and Use Patterns — The vehicle classification scheme used in the Egypt model has already been presented in Table 6.1. As noted above, this scheme follows the general pattern of the classifications used in the ENTS II report, thus simplifying the adaptation of the ENTS data to the present effort. For purposes of
discussion, the nine classes of vehicles listed in Table 6.1 have been grouped into three sets: light-duty vehicles, medium and heavy-duty trucks, and buses. These three groups are discussed separately in Sections 6.4.1 through 6.4.3 below.

Most of the data on vehicle operating and maintenance costs, lifetimes, and fuel consumption in the ENTS II report are presented as functions of the type of road, the condition of the pavement, and the speed of operation of the vehicle. In order to obtain typical or average values for maintenance and other costs, it was necessary to define the typical operating pattern for each class of vehicle in terms of the categories used in the ENTS II report. Table 6.8 shows the assumptions made for the fraction of total annual mileage accumulated under each type of operating condition for each class of vehicles. The values shown are estimates by the author. They are based primarily on limited ENTS II data on road conditions and operating patterns, supplemented by considerations of reasonability and the different ownership and operating patterns for the different classes.

6.4.1 PASSENGER CARS AND LIGHT TRUCKS

The Egypt model includes four separate classes of light-duty vehicles: small passenger cars, large passenger cars, taxis, and light-duty trucks. Of these, the ENTS II report provides estimates of capital and operating/maintenance costs for only three: small cars, taxis, and light trucks. However, since large cars are generally identical in technical
Table 6.8: Estimated percentage of total annual mileage accumulated under various driving conditions for each class

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>URBAN</th>
<th>GOOD</th>
<th>POOR</th>
<th>GRAVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Small Passenger Car</td>
<td>60</td>
<td>29</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>(2) Large Passenger Car</td>
<td>60</td>
<td>29</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>(3) Taxicab</td>
<td>60</td>
<td>29</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>(4) Light-Duty Truck</td>
<td>50</td>
<td>37</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>(5) Light Bus</td>
<td>69</td>
<td>23</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>(6) Heavy Bus</td>
<td>60</td>
<td>32</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>(7) Small Truck</td>
<td>50</td>
<td>37</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>(8) Small Truck/Trailer</td>
<td>7</td>
<td>67</td>
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characteristics to taxis, it was possible to develop reasonable values for capital and operating costs for this class as well.

Tables 6.9 through 6.12 list the technology packages assumed to be available for each class of light-duty vehicles, along with the estimated capital costs, annual fixed costs, operating and maintenance costs, and fuel economies of vehicles using each technology for each of the "benchmark" years in the model. The derivation of these values and the considerations entering into them are discussed individually below.

**Technology packages available** — Four alternative technology packages were assumed to be available for use in light-duty vehicles. As discussed in Chapter Three, these technologies include the "standard" gasoline-engine technology of the late 70's, an "advanced" gasoline-engine technology, indirect-injection diesel engines and (in the near future) direct-injection diesels. Since light-duty diesel vehicles are presently prohibited in Egypt, only the first two technologies were considered to be available in the base-case scenario. Other scenarios considered the impact of introducing IDI diesels in 1985, followed by the introduction of small DI diesels in 1990.

**Capital costs** — Capital cost estimates for small passenger cars, taxis, and pickup trucks are given in the ENTS II reports. Both the private cost and the estimated social cost (evaluated at shadow prices) for each kind of vehicle are given. The large passenger car class includes the same kinds of vehicles as the taxi class, so the cost estimates developed for
Table 6.9: Alternative technologies and technology characteristics for class: small passenger car.

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Table 6.12: Alternative technologies and technology characteristics for class: light truck.

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<td>6210.00</td>
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taxis could be applied to large cars as well. It was necessary, however, to account for the fact that customs duties for private passenger cars are twice as great as for taxicabs (100/150 percent ad valorem rather than 50/75 percent).

The costs given in the ENTS II report were assumed to apply to the "standard" gasoline-engine technology in each class in model year 1979. These costs had to be adjusted for other technologies and other model years. The price differentials between competing technologies are very difficult to determine, being influenced as they are by local market conditions, supply and demand, and marketing strategies as well as production costs. For this reason, it was necessary to make use of crude adjustment factors, based primarily on the author's judgement and on the fragmentary price-differential data available. Generally, advanced gasoline technologies were assumed to be about 10 percent more expensive than the standard technology in 1979, increasing to 20 percent by 2000 as the "advanced" technologies become more advanced. An IDI diesel engine was assumed to increase costs by another 10 percent over the cost of the advanced gasoline technology, while DI diesel engines (when they become available in 1990) are assumed to be 5 percent more expensive than the IDI diesels. For simplicity, the adjustment factors were assumed to be the same for both private and social costs.

In the case of large private cars and taxicabs, this system was complicated by the Egyptian customs rules. The "standard" technology large car was assumed to be equipped with a 6-cylinder engine, while the
"advanced" technology car would be equipped with the more fuel-efficient four. Customs duties are 50 percent greater for 6-cylinder than 4-cylinder engines. This results in the advanced technology having a lower private cost than the standard technology, even though the CIF price for the more advanced vehicle is greater. Since customs duties are a transfer payment, this does not affect the ratio of the social costs of the two technologies.

**Fixed costs** — Estimates of the fixed annual costs of operation for each class of vehicle except large private cars are given in the ENTS II report. Both private costs (including taxes) and social costs are given. For large private cars, the fixed costs of operation were estimated by adapting the cost components shown for small cars and taxis.

The cost estimates in the ENTS II report were assumed to apply to standard-technology vehicles. For the other technologies, a rough proportionality between initial capital costs and annual fixed costs was assumed.

**Operating and maintenance costs** — Estimates of both private and social operating and maintenance costs per kilometer travelled were given in the ENTS II report for all technologies except the large private car. The costs for the large car were assumed to be the same as for the taxi class. For simplicity, these costs were assumed to be the same for each technology. The costs shown in the tables do not include the cost of fuel, which is accounted for separately by the model.
Fuel economy — The ENTS II report includes estimates of fuel economy for each class of vehicles. These estimates are very crude, however, and appear inconsistent with other more reliable data. For this reason, the fuel-economy values used in the model were developed independently by the author, following the approach described in Chapter Three. For the small car, large car, and taxicab classes, the fuel-economy values used were taken directly from Chapter Three. The light truck class used in the Egypt model is a composite of the two classes of light trucks discussed in Chapter Three, with estimated fuel economies for each technology falling between those for the two size classes discussed in that chapter.

Vehicle life — The TRATEC model requires that the mean and standard deviation of the total lifetime mileage be input for each class. Data on average or expected lifetimes for each technology (under Egyptian conditions) were given in the ENTS II report. These data apply only to the standard technology vehicles, but were assumed to be representative of the more advanced technologies as well, with one exception. Because of the demonstrated durability of the diesel engine in taxi service, diesel taxicabs (but not passenger cars) were assumed to last 20 percent longer than gasoline taxis. The reason for this is that engines in taxicabs are a critical area for wear, while private vehicles (which accumulate much lower lifetime mileages) do not usually wear out their engines.

Neither the ENTS II report nor any other data source provided information on the statistical distribution of mileage at vehicle retirement under
Egyptian conditions. Such data are available for light trucks in the United States, however (Jambekar and Johnson, 1978). By assuming that the shape of the distribution (i.e. the ratio of mean to standard deviation) in Egypt is similar to that in the U.S., it was possible to calculate an approximate value for the standard deviation in Egypt. For want of better data, the same distribution was assumed to apply to passenger cars as well. The resulting values for both means and standard deviations are shown in Table 6.13, along with the similarly-derived values for trucks and buses discussed below.

6.4.2 MEDIUM AND HEAVY-DUTY TRUCKS

As indicated in Table 6.1, the Egyptian fleet model includes three classes of medium and heavy-duty trucks. These are: the "small truck" class, generally covering trucks of 3 to 10 tons payload, with 8 tons being typical; the "small truck/trailer" class, consisting trucks in the 8 to 10 ton range towing 12 ton trailers; and the "large truck/trailer" class, which includes both tractor-trailer and large truck-trailer combinations. Tables 6.14 through 6.16 show the technologies in each class, the capital, fixed, and operating/maintenance costs, and the fuel economies used in the model. The sources and derivation of these values are discussed below.

Technology packages available — The small truck class has some of the characteristics of both the medium-duty and the light-heavy duty classes discussed in Chapter Three. The major technology in this class uses diesel engines, but some gasoline engines are in use as well according to the
Table 6.13: Estimated mean and standard deviation of total lifetime kilometers travelled per vehicle for each class of vehicles.

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Table 6.14: Alternative technologies and technology characteristics for class: small truck.

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Table 6.15: Alternative technologies and technology characteristics for class: small truck/trailer.

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### Table 6.16: Alternative technologies and technology characteristics for class: large truck/trailer.

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ENTS II report. Thus, three technology packages were assumed to be available in this class: gasoline engine, standard diesel engine, and advanced diesel engine. The latter technology, which would include aerodynamic and tire modifications as well as engine improvements, is assumed to have become available in 1985.

The small truck/trailer class in the Egyptian model is basically rather similar to the light-heavy duty truck class discussed in Chapter Three, and has been assumed to utilize the same technologies. In the large truck/trailer class, semi-trailers have recently been displacing the older truck/trailer combinations in Egypt. Four technologies were assumed: standard semi-trailer, large truck/trailer (similar to a the standard semi-trailer except for higher drag and shorter lifetime), a "moderate" technology semi-trailer, and an advanced-technology semi-trailer package. The first and last of these are basically identical to the semi-trailer technologies discussed in Chapter Three, while the large truck/trailer technology is basically a larger version of standard light-heavy duty technology with a trailer attached.

The "moderate" technology semi-trailer combination represents a compromise — initial modeling runs showed that the more expensive fuel-conserving modifications projected for the advanced-technology package after 1990 would not be cost-effective in Egypt under most scenarios. This technology package thus represents a continuation of the "advanced" technology of 1990, without the later, more expensive additions.
Capital costs — The ENTS II report gives estimates of private and social capital costs for typical trucks in each class. These estimates were assumed to apply directly to the standard diesel-engine technology. For the other technologies, correction factors — based primarily on the author's judgment — were used to adjust the ENTS II cost values. For gasoline small trucks, the cost was assumed to be 20 percent less than the corresponding diesel truck. For the advanced diesel technologies, costs were assumed to be 5 to 35 percent greater than for the standard technology, except in the case of advanced-technology semitrailers after 1990. This last group (which would include very advanced and expensive technologies such as turbocompounding) was projected to cost up to 60 percent more than the standard technology.

Fixed costs — Estimates of both the private and social annual fixed costs for each class of trucks are given in the ENTS II report. Since (for trucks) these costs are primarily for overheads, salaries, and other non-technology-related factors, they were assumed to be the same for each technology.

Operating and maintenance costs — Estimates of these costs were given in the ENTS II report for each class of vehicles. For simplicity, these costs were assumed to be the same for all technologies within a given class. The two exceptions were light gasoline trucks, which have lower maintenance costs, and advanced-technology semitrailers. Maintenance costs for these vehicles were assumed to be higher, due to the complex technologies they would involve.
Fuel economy — The ENTS II report includes estimates of fuel economy for each class of medium and heavy-duty trucks. These estimates are seriously deficient, however, being based on limited and obsolete data, which took account only of vehicle weight and not other critical factors such as aerodynamic drag and engine efficiency. For this reason, the fuel economy estimates used in the model were developed independently by the author, using the methods of Chapter Three. The engine efficiencies, aerodynamic and operating parameters, and most other values used in the calculations were taken directly from Chapter Three. Typical weights for each class of vehicles were taken directly from the ENTS II report, however, since this report includes considerable information on axle loadings and vehicle weights.

Vehicle life — As with light-duty vehicles, the ENTS II report provides typical or mean values for mileage at retirement, but no information on the statistical distribution. The typical values given in ENTS II were taken to apply to the diesel technologies only; lower values were assumed for gasoline-vehicle life, due to the inferior durability of heavy-duty gasoline engines. In addition, the lifetime mileage for the large truck/trailer combination was reduced somewhat from that given in ENTS II, since these trucks would be expected to be slightly less durable than a tractor/trailer combination.

The standard deviation of the lifetime mileage distribution was estimated in the same way as for light-duty vehicles. Data from Jambekar and
Johnson (1978) were used to calculate the ratio of mean to standard deviation for trucks of comparable types in use in the U.S. These ratios were then multiplied by the mean lifetime mileage for each class in Egypt to give the approximate standard deviation. The mean and standard deviation values used in the model are shown in Table 6.13.

6.4.3 BUSES

The Egyptian model includes two classes of buses: a heavy bus class which is used primarily by urban and interurban transit companies; and a class of light buses such as school buses, which are used for incidental transport. The light-bus class is basically identical to that discussed in Chapter Three, while the heavy-bus class represents a composite of the heavy urban and heavy interurban bus classes described in the same chapter. The ENTS II data do not allow separation of urban and interurban operation, so these two classes have been lumped together in the model. The technologies available in each class, the capital, fixed, and operating/maintenance costs, and the fuel-economy values used in the model are shown in Tables 6.17 and 6.18. The sources and derivation of these values are discussed below.

Technology packages available — The technology packages assumed for the light bus class are the same as those for the small truck class, discussed above. This is appropriate, since these buses are built on truck chassis, and utilize the same engines and many other components. Similarly, the technologies available in the heavy bus class are the same as those for
Table 6.17: Alternative technologies and technology characteristics for class: light bus.

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Table 6.18: Alternative technologies and technology characteristics for class: heavy bus.

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light-heavy trucks, and for the same reason.

**Capital costs** — The cost estimation procedure for buses closely followed the procedure for medium and heavy trucks, discussed above. Estimates of the private and social capital costs for standard technologies in each class were taken from the ENTS II report. These were adjusted, using the same judgement-based factors as for trucks, for the other technologies.

**Fixed costs** — Annual fixed costs for each class of vehicles are given in the ENTS II report. As discussed above for heavy-duty trucks, these costs were assumed to be the same for all technologies within a given class.

**Operating and maintenance costs** — These costs were also given in the ENTS II report. Except for gasoline light buses, which have somewhat lower maintenance costs, they were assumed to be the same for all technologies within a class.

**Fuel economy** — As noted above, fuel-economy estimates for all classes of vehicles were given in the ENTS II report, but these estimates are seriously deficient. As a result, estimated fuel-economy values were developed independently by the author, following the methods of Chapter Three. For the light bus class, the fuel economies used were taken directly from that chapter. For heavy buses, the estimates were obtained by combining the heavy urban and heavy interurban bus classes discussed in Chapter Three, assuming that 50 percent of total operation fell in each category.
Vehicle life — The estimation of means and standard deviations for the distribution of mileage at retirement precisely paralleled the approach used for medium and heavy-duty trucks. Typical mileage at retirement was taken from the ENTS II data, then combined with U.S. data from Jambekar and Johnson (1978) to give an approximate standard deviation. Jambekar and Johnson do not give separate retirement data for buses, so the data for the corresponding truck classes (medium and light-heavy) were used instead. The resulting values are shown in Table 6.13.
7.0 EGYPTIAN FUEL CONSUMPTION: SCENARIO DESCRIPTIONS AND MODEL RESULTS

The TRATEC computer model of technology choice and fuel consumption was described in Chapters Four and Five. Chapter Six discusses the development of a set of TRATEC input data for the specific case of Egypt. This data set was used in conjunction with the TRATEC model to examine the effects of alternative fuel-pricing and technology policies on total fuel consumption and total cost of highway transportation in Egypt. The effects of two basic policy changes were considered: increasing Egyptian domestic fuel prices to international levels, and permitting the import and domestic production of diesel light-duty vehicles.

Four policy scenarios, reflecting all possible combinations of these policies, were developed and modeled using the TRATEC code. Several additional model runs were made with variant parameters, in order to test the sensitivity of the results to the assumptions made and to estimate the own-price and cross-price elasticities of demand for fuels. The scenarios developed, the model results, and their implications for policy are presented in this chapter.

7.1 ALTERNATIVE POLICY SCENARIOS

As noted in Chapter Six, the Egyptian Government maintains an extensive system of price controls and subsidies for various commodities, including
gasoline and diesel fuel. These fuels are not explicitly subsidized, but are instead sold at low fixed prices by the State-owned oil company, resulting in an implicit subsidy. This practice is possible only because Egypt is presently a net oil exporter. The implicit subsidy for transportation fuel (as for most petroleum products in Egypt) is very large; the price of diesel fuel in Egypt was only about 15 percent of the world market price in 1982, while the price of gasoline was about three-quarters of the world price (Fox, 1982).

As discussed in Chapter Six, the world price of oil (in U.S. dollars) has declined significantly since 1982, while the nominal price of fuel in Egypt has remained fixed. This is offset, however, by the continuing Egyptian inflation and by the strength of the dollar, both of which have tended to raise the world oil price when expressed in Egyptian pounds. Overall, current (early 1985) Egyptian fuel prices appear to be even lower (compared to world prices) than in 1982. The ratio of Egyptian retail to world spot-market gasoline prices, expressed at current free-market exchange rates, is about 0.56, while the ratio of diesel prices is about 0.11.

The price of diesel fuel in Egypt is much more heavily subsidized than is the price of gasoline. This presumably reflects a Government perception that light-duty cars and trucks (the major users of gasoline) are less deserving of subsidy than are the diesel-powered heavy-duty trucks and buses. The widespread use of diesel-powered automobiles and light trucks would obviously tend to upset this policy. Apparently because of this,
the importation of diesel passenger cars is forbidden (ENTS II), and none appear to be being produced domestically. It is not clear whether this policy applies to light trucks as well, although this would seem likely, since light trucks can double as passenger vehicles. Certainly no diesel-powered light trucks were accounted for in the ENTS II data. In this report, it has been assumed that the ban applies to light-duty diesel vehicles of all types. This assumption is not critical to the results, however, as light trucks account for a comparatively small fraction of the light-duty fleet in Egypt.

The four policy scenarios developed correspond to changes in none, either one, or both of the policies discussed above. The first, base-case scenario assumes a continuation of the status quo with regard to both fuel prices and light-duty diesel vehicles. Specifically, the real or deflated price of fuel is assumed to remain constant from 1985 through 2000, which is the end of the model period. The fuel prices assumed in this scenario are L.E (1979) 0.065 per liter for gasoline and L.E. (1979) 0.15 per liter for diesel fuel. These values correspond to current Egyptian fuel prices, after adjusting for the inflation since 1979.

The second, or free-market scenario assumes a phased increase in Egyptian fuel prices, beginning in 1985 and proceeding in even increments until 1990, at which time Egyptian and world prices would be the same. Egyptian fuel prices under this scenario would still be lower than those in most nations, since it is assumed that they would increase only to the level of the spot-market price, while most nations impose sales and use taxes which
increase the retail price of fuel considerably above the spot price. At the same time, this scenario assumes the market availability of light-duty diesel vehicles, since — with the elimination of the subsidy system — the reason for this ban would have disappeared. Since diesel vehicles are also substantially more fuel-efficient, the removal of the ban would also be consonant with a government policy to reduce energy consumption. Initially, only light-duty IDI diesels are assumed to be available, beginning in 1985. Light-duty DI diesels are assumed to be available in the market beginning in 1990.

Two additional scenarios explore the relative effects of the fuel price changes and the elimination of the ban on diesels. The first is the fuel price scenario, which assumes a phased increase in fuel prices, but continues the ban on light-duty diesels. The second scenario is the light-duty diesel scenario, which assumes that the ban on light diesels is lifted in 1985, but that real fuel prices continue at the 1985 level. Except for their effects on the light-duty vehicle classes, the fuel-price scenario is identical to the free market scenario, while the light-duty diesel scenario is identical to the base case. Results for all four scenarios are presented and discussed in Section 7.2. However, separate results for the heavy-duty vehicle classes (trucks and buses) in the fuel-price and light-duty diesel scenarios are not presented, since these would only duplicate the results of the base-case and free-market scenarios.
7.2 MODEL RESULTS AND DISCUSSION

Sections 7.2.1 through 7.2.4 below present the model results for each of the four scenarios considered. They are followed by a synthesis section, 7.2.5, in which these results are compared, contrasted, and discussed, with special attention to their implications for total cost of transportation, fuel consumption, and export earnings. Section 7.2.6 presents the results of additional runs, made to test the sensitivity of the model results to the assumptions used.

7.2.1 Base-Case Scenario

The base-case scenario assumes a continuation of the status quo, with respect to both fuel prices and light-duty diesels. Figure 7.1 is a plot of total gasoline consumption by vehicle class for this scenario, over the period from 1979 to 2000. Figure 7.2 contains a plot of projected diesel fuel consumption over the same period. These plots are cumulative by class — meaning that the distance between the line for a given class and the next lower line corresponds to fuel consumption by that class, while the position of the uppermost line indicates total fuel consumption by all classes of vehicles. As the figures indicate, total diesel and gasoline consumption are expected to increase dramatically between 1979 and 2000. Gasoline consumption is projected to increase by more than three times during that period. More than half of this increase will be due to taxicabs, which consumed 60 percent of the gasoline used in Egypt in 1979,
Figure 7.1: Projected gasoline consumption vs. time for the base-case scenario.

Figure 7.2: Projected diesel fuel consumption vs. time for the base-case scenario.
and are projected to consume 56 percent of the total in 2000.

All of the lines shown on the plots are based on calculations by the TRATEC program and involve projection forward from 1979. Figure 7.1 also shows several individual points, indicating actual Egyptian gasoline consumption in calendar years 1979 and 1980, and in fiscal years 1981-82 and 1982-83. As the Figure indicates, the model's projections are generally close to, but somewhat lower than, the actual values. This is reasonable, since the model developed does not account for consumption by motorcycles and other light vehicles, or by non-highway uses such as agriculture, aviation, and marine use. Considering these limitations, there appears to be a good correspondence between the model results and reality in the period for which data are available. The provides some assurance that the model results are reasonable. This assurance is increased by the fact that the model parameters have not been adjusted in any way to attempt to match the data — the model projections were developed independently of the actual fuel consumption data.

The accuracy of the projections for diesel fuel consumption cannot be assessed in the same way, since diesel consumption by highway vehicles cannot be separated from other uses for diesel fuel (e.g. stationary, railway, inland marine, and marine diesels), and for distillate oil (which is used in power plants and industry as well as for motor fuel). The significance of these non-highway uses is much greater for diesel fuel than for gasoline.
Overall diesel fuel consumption in Egypt in 1982-83 was approximately 3.7 billion liters (Dod, 1983), which is more than twice the amount projected for highway use by the TRATEC model. The ENTS-II study included a rough estimate of total highway diesel consumption in 1979, arriving at a value which is about 40 percent lower than projected by the TRATEC model. However, as noted in Chapter Six, the ENTS II study used seriously deficient estimates of truck and bus fuel economy, which would invalidate any fuel consumption estimates based on them. As a result, there is presently no credible estimate of highway diesel fuel consumption in Egypt with which to compare the model's projections, and thus no way to confirm their validity, other than by careful checks of internal consistency. These have been carried out.

Figures 7.3 and 7.4 are plots of the model's cost projections for the base-case scenario. Figure 7.3 shows the calculated private costs, while Figure 7.4 shows the corresponding social costs calculated. These costs are also shown in Table 7.1, along with estimates of the total (implicit and explicit) government subsidy for highway transportation. This subsidy is calculated as the difference between private and social costs.

As discussed in Chapter Four, private costs are the costs as perceived by the consumer, calculated from actual prices. These are the costs which influence the technology choice decision. Social costs are estimates of the costs to society as a whole, and are based on estimates of the "shadow" prices of goods, rather than actual prices. In a perfectly competitive economy with no external effects, shadow and actual prices
Figure 7.3: Total projected private cost of transportation vs. time for the base-case scenario.

Figure 7.4: Total projected social cost of transportation vs. time for the base-case scenario.
Table 7.1: Fuel-Consumption, cost, and government subsidy results for the base-case scenario (in billions of liters and billions of Egyptian pounds).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>FUEL CONSUMPTION</th>
<th>TOTAL COST</th>
<th>GOVERNMENT SUBSIDY</th>
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<td>GASOLINE</td>
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<td>TOTAL</td>
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<td>1.12</td>
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</tr>
<tr>
<td>1980</td>
<td>1.46</td>
<td>1.23</td>
<td>2.69</td>
</tr>
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<td>1981</td>
<td>1.60</td>
<td>1.33</td>
<td>2.94</td>
</tr>
<tr>
<td>1982</td>
<td>1.74</td>
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<tr>
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<td>1.87</td>
<td>1.54</td>
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<tr>
<td>1984</td>
<td>2.06</td>
<td>1.63</td>
<td>3.70</td>
</tr>
<tr>
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<td>2.25</td>
<td>1.72</td>
<td>3.97</td>
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<td>1986</td>
<td>2.41</td>
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<tr>
<td>1987</td>
<td>2.57</td>
<td>1.88</td>
<td>4.46</td>
</tr>
<tr>
<td>1988</td>
<td>2.73</td>
<td>1.97</td>
<td>4.70</td>
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<td>2.88</td>
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</tr>
<tr>
<td>1990</td>
<td>3.03</td>
<td>2.15</td>
<td>5.18</td>
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<tr>
<td>1991</td>
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<td>5.42</td>
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<td>2.33</td>
<td>5.65</td>
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</tr>
<tr>
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</tr>
<tr>
<td>1998</td>
<td>4.14</td>
<td>2.84</td>
<td>6.98</td>
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<td>4.27</td>
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<td>7.19</td>
</tr>
<tr>
<td>2000</td>
<td>4.39</td>
<td>3.01</td>
<td>7.39</td>
</tr>
</tbody>
</table>

TOTAL 63.94 46.17 110.11 50.12 57.01 6.89

PRES. VALUE* 30.44 23.34 53.33 23.08 26.28 3.65

*(discounted to 1985 at 15 percent)
would be the same. This is not the case in Egypt, however.

As discussed in Chapter Six, the major differences between social and private costs in this calculation are due to the tax on vehicles, a premium for foreign exchange, and the subsidy on fuel. The social cost of most vehicles is taken as somewhat below the private cost, based on calculations in the ENTS-II report, while the social cost of fuel is taken as the international price, which is much greater than the private cost. The effect of the fuel subsidy is dominant, resulting in social costs which are substantially greater than the private ones, and thus in a net government subsidy of the automotive sector.

Figures 7.3 and 7.4 contain three separate cost curves each. The lowest curve reflects only operating and maintenance costs, which are primarily fuel, oil, and repairs. The second curve in each plot is the total cost of transportation, calculated on an accrual basis. This value includes operating and maintenance costs and depreciation of the capital stock due to vehicles wearing out. The distance between the O&M cost curve and the second curve gives total depreciation. Finally, the uppermost curve in each figure shows the total cost of transportation calculated on a cash basis. This includes both the O&M cost and the capital cost of all new vehicles purchased in each year. Since the Egyptian vehicle fleet is growing rapidly, the total capital cost of new vehicles is considerably greater than the depreciation of the existing fleet. The cash-basis total cost is useful primarily for evaluating capital investment and financing requirements. As an estimate of the actual cost of transportation to the
Egyptian economy, the accrual-basis cost is more accurate. For this reason, all of the costs presented in the text and tables below have been calculated on an accrual basis.

Figures 7.3 and 7.4 both show the accrual-basis and cash-basis curves crossing in 1979, indicating that depreciation exceeds new purchases in that year. This is an artifact of the simulation process, and is not significant. It is due to the readjustment of fleet structure to an equilibrium level in the first year of the simulation, and results from imperfect knowledge of the detailed structure of the vehicle fleet.

Figures 7.5 through 7.13 show the projected size and structure of the vehicle fleet as a function of time, for each of the nine classes of vehicles included in the model. Both the total number of vehicles and the breakdown by vehicle technology are shown, in the same cumulative format used for the fuel-consumption projections. As the figures indicate, total numbers of all classes of vehicles are expected to increase rapidly over the period covered by the model. As would be expected, given the low fuel prices assumed to be in effect, the lower-efficiency but lower-cost "standard" technologies are projected to be dominant in most vehicle classes, since the greater efficiency of the advanced technologies does not outweigh their greater initial costs. The only exceptions to this rule are in the large car and taxicab classes, where the advanced gasoline technologies are projected to dominate.

The reason for the ascendance of advanced technology in the taxi and
Figure 7.5: Projected numbers and composition of the small passenger car class vs. time for the base-case scenario.

Figure 7.6: Projected numbers and composition of the large passenger car class vs. time for the base-case scenario.
Figure 7.7: Projected numbers and composition of the taxicab class vs. time for the base-case scenario.

Figure 7.8: Projected numbers and composition of the light truck class vs. time for the base-case scenario.
Figure 7.9: Projected numbers and composition of the small bus class vs. time for the base-case scenario.

Figure 7.10: Projected numbers and composition of the large bus class vs. time for the base-case scenario.
Figure 7.11: Projected numbers and composition of the small truck class vs. time for the base-case scenario.

Figure 7.12: Projected numbers and composition of the small truck/trailer class vs. time for the base-case scenario.
Figure 7.13: Projected numbers and composition of the large truck/trailer class vs. time for the base-case scenario.
large-car classes has little to do with fuel economy. Rather, it is due to the structure of the import duties on passenger cars, which are 50 percent greater for six-cylinder than for four-cylinder vehicles. The "standard" technology for these classes was assumed to have a six-cylinder engine, while the "advanced" technology was assumed to have a more efficient four-cylinder powerplant. The difference in import duties on the two is more than enough to offset the greater C.I.F. cost of the advanced technology, so that the sales price of an advanced technology car in Egypt would actually be lower than for the standard technology.

7.2.2 Free-Market Scenario

The free-market scenario assumes a phased increase in Egyptian domestic fuel prices, beginning in 1985 and ending in 1990 with Egyptian prices at world levels. In addition, light-duty diesel vehicles are assumed to be available on the market beginning in 1985.

Figures 7.14 through 7.17 present the model's projections of fuel consumption, private costs, and social costs for this scenario. Detailed numerical comparisons between these projections and those for the base-case scenario are given in Tables 7.2 and 7.3. Table 7.2 shows the differences in fuel consumption between the free-market and the base-case scenario, while Table 7.3 shows the private and social costs. Table 7.3 also shows the increase in Egyptian Government revenue compared to the base case which is projected to occur in this scenario. Since all the scenarios are identical up to 1984, Tables 7.1 and 7.2 contain data only
Figure 7.14: Projected gasoline consumption vs. time for the free-market scenario.

Figure 7.15: Projected diesel fuel consumption vs. time for the free-market scenario.
Figure 7.16: Total projected private cost of transportation vs. time for the free-market scenario.

Figure 7.17: Total projected social cost of transportation vs. time for the free-market scenario.
Table 7.2: Comparison of projected fuel consumption for the free-market and base-case scenarios, 1985 - 2000.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>GASOLINE</th>
<th>DIESEL</th>
<th>TOTAL FUEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BASE-CASE</td>
<td>FREE-MKT &amp; CHANGE</td>
<td>BASE-CASE</td>
</tr>
<tr>
<td>1985</td>
<td>2.25</td>
<td>1.91</td>
<td>-15.04</td>
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<tr>
<td>1986</td>
<td>2.41</td>
<td>1.90</td>
<td>-21.09</td>
</tr>
<tr>
<td>1987</td>
<td>2.57</td>
<td>1.90</td>
<td>-26.10</td>
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<tr>
<td>1988</td>
<td>2.73</td>
<td>1.92</td>
<td>-29.63</td>
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<td>2.88</td>
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<tr>
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<td>1.99</td>
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<td>4.14</td>
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<tr>
<td>2000</td>
<td>4.39</td>
<td>2.07</td>
<td>-52.79</td>
</tr>
</tbody>
</table>

TOTAL  | 53.89  | 31.36 | -41.81     | 37.87  | 47.76 | 26.10     | 91.76     | 79.12 | -13.78
Table 7.3: Comparison of projected costs and changes in government revenue for the free-market and base-case scenarios, 1985 - 2000.

**TOTAL COST OF TRANSPORTATION/CHANGE IN GOVERNMENT OIL REVENUE**
(in billions 1979 Egyptian pounds)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>BASE-CASE</th>
<th>FREE-MKT % CHANGE</th>
<th>SOCIAL COSTS</th>
<th>BASE-CASE</th>
<th>FREE-MKT % CHANGE</th>
<th>CHANGE IN GOVT. REVENUE</th>
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<td></td>
<td></td>
<td></td>
<td>FOREIGN</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DOMESTIC</td>
<td></td>
<td></td>
<td>TOTAL</td>
</tr>
<tr>
<td>1985</td>
<td>1.596</td>
<td>1.592</td>
<td>-0.004</td>
<td>1.748</td>
<td>1.756</td>
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</tr>
<tr>
<td>1986</td>
<td>1.732</td>
<td>1.786</td>
<td>-0.054</td>
<td>1.901</td>
<td>1.892</td>
<td>0.009</td>
</tr>
<tr>
<td>1987</td>
<td>1.871</td>
<td>1.983</td>
<td>-0.112</td>
<td>2.057</td>
<td>2.021</td>
<td>0.036</td>
</tr>
<tr>
<td>1988</td>
<td>2.009</td>
<td>2.198</td>
<td>-0.189</td>
<td>2.216</td>
<td>2.160</td>
<td>0.056</td>
</tr>
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<td>2.155</td>
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<td>-0.270</td>
<td>2.383</td>
<td>2.305</td>
<td>0.078</td>
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<tr>
<td>1990</td>
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<td>-0.354</td>
<td>2.553</td>
<td>2.446</td>
<td>0.107</td>
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<td>1991</td>
<td>2.450</td>
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<td>-0.378</td>
<td>2.731</td>
<td>2.604</td>
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<td>2.910</td>
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<td>2.924</td>
<td>0.167</td>
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<td>1994</td>
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<td>3.273</td>
<td>3.087</td>
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<tr>
<td>1995</td>
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<td>-0.492</td>
<td>3.458</td>
<td>3.247</td>
<td>0.211</td>
</tr>
<tr>
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<td>4.010</td>
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<tr>
<td>2000</td>
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<td>4.388</td>
<td>4.069</td>
<td>0.319</td>
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<td><strong>TOTAL</strong></td>
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<td></td>
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<td>8.954</td>
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</tbody>
</table>

**PRESENT VALUE**

| YEAR | 13.683 | 15.231 | 15.278 | 14.710 | 0.569 | 0.573 | 1.925 | 2.348 |
|      |        |        |        |        |       |       |       |       |
| 1985 |        |        |        |        |       |       |       |       |
| 1986 |        |        |        |        |       |       |       |       |
| 1987 |        |        |        |        |       |       |       |       |
| 1988 |        |        |        |        |       |       |       |       |
| 1989 |        |        |        |        |       |       |       |       |
| 1990 |        |        |        |        |       |       |       |       |
| 1991 |        |        |        |        |       |       |       |       |
| 1992 |        |        |        |        |       |       |       |       |
| 1993 |        |        |        |        |       |       |       |       |
| 1994 |        |        |        |        |       |       |       |       |
| 1995 |        |        |        |        |       |       |       |       |
| 1996 |        |        |        |        |       |       |       |       |
| 1997 |        |        |        |        |       |       |       |       |
| 1998 |        |        |        |        |       |       |       |       |
| 1999 |        |        |        |        |       |       |       |       |
| 2000 |        |        |        |        |       |       |       |       |
for the years from 1985 to 2000.

Figures 7.14 and 7.15 plot the projected gasoline and diesel fuel consumption over time. The salient feature of Figure 7.14 is the dramatic change in gasoline consumption between 1984 and 1985, followed by fifteen years of little or no increase in total consumption. Year-2000 gasoline consumption in this scenario is projected to be less than half of the level projected in the base-case scenario. This is due primarily to a dramatic shift to diesel fuel by taxicabs, and secondarily to similar (but less dramatic) shifts by other classes of light-duty vehicles.

As Figure 7.15 indicates, the decrease in gasoline consumption is partly offset by an increase in the use of diesel fuel by light-duty vehicles, especially taxis. Total diesel fuel consumption in this scenario is projected to increase by about 26 percent over that in the base-case by the year 2000. This increase comes in spite of some rather significant price-induced increases in the efficiency of heavy-duty vehicles. However, the net effect of the decrease in gasoline and the increase in diesel fuel consumption is a substantial reduction in total fuel consumption, amounting to about 20 percent of total automotive fuel consumed by the year 2000. As Table 7.2 indicates, this is would result in the saving of about 1.5 billion liters of fuel per year by the end of the century, and a total savings of 12.6 billion liters between 1985 and 2000.

Table 7.3 compares total private and social costs calculated for this scenario with those for the base-case scenario. As would be expected,
private costs are significantly higher for this case, reflecting the elimination of the implicit subsidy on fuel. Social costs, however, are lower, reflecting the higher efficiency of the technologies selected as a result of the higher cost of fuel, as well a price-induced reduction in demand. The greater operating efficiency even outweighs the higher capital costs of more efficient vehicles, resulting in a net decrease in costs on both a cash and an accrual basis. The net savings to Egyptian society amount to 1979 L.E. 320 million per year (on an accrual basis). Since the 1979 pound was worth about two 1985 pounds, this is about 640 million current pounds per year.

Table 7.3 also show the effects on the Egyptian Government's budget. This effect is even more dramatic than the effect on social costs. The increase in government revenue comes from two sources — foreign-exchange revenues from the sale abroad of fuel which is not consumed in Egypt, and increased revenue due to the higher domestic price of fuel. Each of these components is shown in the table, along with the total change in revenues. Increased sales of gasoline abroad would amount to L.E. (1979) 413 million in 2000, although this would be offset by a L.E. 150 million decrease in sales of diesel fuel for a net gain of L.E. (1979) 263 million per year. In addition, revenues to the Government oil company from internal fuel sales would increase by L.E. (1979) 762 million, giving a total increase in Government revenue of more than one billion 1979 pounds per year in 2000 (ignoring any secondary effects of these price changes). The total increase from 1985 to 2000 would be almost nine billion 1979 pounds, with a net present value (in 1985) of roughly 4.7 billion 1985
Egyptian pounds. For comparison, the Government's 1984 budget deficit was estimated at 5.4 billion current pounds (U.S. Embassy, 1985), or about 2.7 billion 1979 pounds.

Figures 7.18 through 7.26 show the projected numbers and makeup of each class of vehicles in the fleet as functions of time. Except for the largest trucks, the total number of vehicles projected for each class is nearly indistinguishable from that projected for the base-case. Since the number of vehicles is assumed to be directly proportional to total VMT, this indicates that the fuel savings projected have not, for the most part, been achieved at the expense of a reduction in transportation service, but are the result of providing a comparable level of service more efficiently. This is reflected in the division between different technologies in each class. Figures 7.18 through 7.26 show the more-efficient technologies exhibiting significant gains in market share (relative to the base case shares shown in Figures 7.5 through 7.13) in every class.

For large, long-distance trucks — the class in which the reduction in transportation demand is the greatest — the model projects a reduction in total vehicles (and total VMT) of 8.24 percent in 2000 for the free-market case compared to the base case, compared with a 17.3 percent reduction in fuel consumption. This comparatively large reduction in VMT is due to the greater elasticity of demand assumed for this class, due to the competition from rail and inland marine transportation modes. In every other class, the total fuel savings is at least triple that which would be
Figure 7.18: Projected numbers and composition of the small passenger car class vs. time for the free-market scenario.

Figure 7.19: Projected numbers and composition of the large passenger car class vs. time for the free-market scenario.
Figure 7.20: Projected numbers and composition of the taxicab class vs. time for the free-market scenario.

Figure 7.21: Projected numbers and composition of the light truck class vs. time for the free-market scenario.
Figure 7.22: Projected numbers and composition of the small bus class vs. time for the free-market scenario.

Figure 7.23: Projected numbers and composition of the large bus class vs. time for the free-market scenario.
Figure 7.24: Projected numbers and composition of the small truck class vs. time for the free-market scenario.

Figure 7.25: Projected numbers and composition of the small truck/trailer class vs. time for the free-market scenario.
Figure 7.26: Projected numbers and composition of the large truck/trailer class vs. time for the free-market scenario.
due to demand reductions alone, with the remaining savings coming from increased efficiency. For taxis, the total fuel savings is projected as 29.9 percent in the year 2000, of which 5.35 percent is due to reduced demand and 24.55 percent is due to increased efficiency.

7.2.3 Fuel-Price Scenario

The fuel-price scenario incorporates the same assumptions concerning fuel prices as the free-market scenario, but assumes a continuation of the ban on light-duty diesel vehicles. It thus serves to indicate what portion of the savings projected for the free-market scenario are the result of price changes, and what portion are due to the availability of alternative technologies. Figures 7.27 through 7.30 show the TRATEC model's projections of total fuel consumption, private costs, and social costs for this scenario. In addition, Tables 7.4 and 7.5 compare these projections with those for the base case.

Figures 7.27 and 7.28 show projected gasoline and diesel fuel consumption by all classes over time. These plots are not greatly different from those of the base case in shape, although consumption of both gasoline and diesel fuel is projected to be somewhat lower. Compared to the base case, gasoline consumption in the year 2000 is projected to be about 13 percent lower, while diesel consumption is projected to be 17 percent less. This gives a total savings of 14.6 percent of the total fuel consumed in the base case, or somewhat over one billion liters per year.
Figure 7.27: Projected gasoline consumption vs. time for the fuel-price scenario.

Figure 7.28: Projected diesel fuel consumption vs. time for the fuel-price scenario.
Figure 7.29: Total projected private cost of transportation vs. time for the fuel-price scenario.

Figure 7.30: Total projected social cost of transportation vs. time for the fuel-price scenario.
Table 7.4: Comparison of projected fuel consumption for the fuel-price and base-case scenarios, 1985 - 2000.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>GASOLINE BASE-CASE FUEL-PRC &amp; CHANGE</th>
<th>DIESEL BASE-CASE FUEL-PRC &amp; CHANGE</th>
<th>TOTAL FUEL BASE-CASE FUEL-PRC &amp; CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.25 2.25 0.00</td>
<td>1.72 1.72 0.00</td>
<td>3.97 3.97 0.00</td>
</tr>
<tr>
<td>1985</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>2.41 2.39 -0.75</td>
<td>1.80 1.78 -1.05</td>
<td>4.22 4.18 -0.88</td>
</tr>
<tr>
<td>1987</td>
<td>2.57 2.53 -1.63</td>
<td>1.88 1.83 -2.39</td>
<td>4.46 4.37 -1.95</td>
</tr>
<tr>
<td>1988</td>
<td>2.73 2.66 -2.49</td>
<td>1.97 1.89 -3.96</td>
<td>4.70 4.55 -3.11</td>
</tr>
<tr>
<td>1989</td>
<td>2.88 2.77 -3.62</td>
<td>2.06 1.94 -5.73</td>
<td>4.94 4.71 -4.50</td>
</tr>
<tr>
<td>1990</td>
<td>3.03 2.88 -4.85</td>
<td>2.15 1.98 -7.91</td>
<td>5.18 4.86 -6.12</td>
</tr>
<tr>
<td>1991</td>
<td>3.18 2.99 -5.91</td>
<td>2.24 2.03 -9.24</td>
<td>5.42 5.02 -7.29</td>
</tr>
<tr>
<td>1992</td>
<td>3.32 3.09 -7.01</td>
<td>2.33 2.08 -10.52</td>
<td>5.65 5.18 -8.45</td>
</tr>
<tr>
<td>1993</td>
<td>3.47 3.20 -7.95</td>
<td>2.42 2.14 -11.58</td>
<td>5.89 5.33 -9.44</td>
</tr>
<tr>
<td>1994</td>
<td>3.61 3.29 -8.75</td>
<td>2.50 2.19 -12.42</td>
<td>6.12 5.49 -10.25</td>
</tr>
<tr>
<td>1996</td>
<td>3.88 3.47 -10.53</td>
<td>2.68 2.30 -14.09</td>
<td>6.56 5.77 -11.98</td>
</tr>
<tr>
<td>1997</td>
<td>4.01 3.56 -11.26</td>
<td>2.76 2.35 -14.83</td>
<td>6.77 5.91 -12.71</td>
</tr>
<tr>
<td>1999</td>
<td>4.27 3.73 -12.56</td>
<td>2.92 2.46 -16.03</td>
<td>7.19 6.19 -13.98</td>
</tr>
</tbody>
</table>

TOTAL: 53.89 49.67 -7.83 37.87 33.86 -10.60 91.76 83.53 -8.97
Table 7.5: Comparison of projected costs and changes in government revenue for the fuel-price and base-case scenarios, 1985 - 2000.

**TOTAL COST OF TRANSPORTATION/CHANGE IN GOVERNMENT OIL REVENUE**  
*(in billions 1979 Egyptian pounds)*

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PRIVATE COSTS</th>
<th>SOCIAL COSTS</th>
<th>CHANGE IN GOVERNMENT REVENUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BASE-CASE FREE-MKT &amp; % CHANGE</td>
<td>BASE-CASE FREE-MKT &amp; % CHANGE</td>
<td>FOREIGN DOMESTIC TOTAL</td>
</tr>
<tr>
<td>1985</td>
<td>1.596 1.596 0.000</td>
<td>1.748 1.748 0.000</td>
<td>0.000 0.000 0.000</td>
</tr>
<tr>
<td>1986</td>
<td>1.732 1.800 -0.068</td>
<td>1.901 1.889 0.012</td>
<td>0.005 0.076 0.081</td>
</tr>
<tr>
<td>1987</td>
<td>1.871 2.009 -0.138</td>
<td>2.057 2.029 0.028</td>
<td>0.011 0.158 0.169</td>
</tr>
<tr>
<td>1988</td>
<td>2.009 2.228 -0.219</td>
<td>2.216 2.174 0.042</td>
<td>0.019 0.246 0.265</td>
</tr>
<tr>
<td>1989</td>
<td>2.155 2.459 -0.304</td>
<td>2.383 2.324 0.059</td>
<td>0.030 0.338 0.368</td>
</tr>
<tr>
<td>1990</td>
<td>2.302 2.692 -0.390</td>
<td>2.553 2.473 0.080</td>
<td>0.044 0.433 0.477</td>
</tr>
<tr>
<td>1991</td>
<td>2.450 2.870 -0.420</td>
<td>2.731 2.635 0.096</td>
<td>0.056 0.468 0.524</td>
</tr>
<tr>
<td>1992</td>
<td>2.597 3.048 -0.451</td>
<td>2.910 2.797 0.113</td>
<td>0.070 0.503 0.573</td>
</tr>
<tr>
<td>1993</td>
<td>2.744 3.228 -0.484</td>
<td>3.091 2.961 0.130</td>
<td>0.084 0.540 0.624</td>
</tr>
<tr>
<td>1994</td>
<td>2.891 3.407 -0.516</td>
<td>3.273 3.126 0.147</td>
<td>0.098 0.579 0.677</td>
</tr>
<tr>
<td>1995</td>
<td>3.039 3.587 -0.548</td>
<td>3.458 3.290 0.168</td>
<td>0.113 0.617 0.730</td>
</tr>
<tr>
<td>1996</td>
<td>3.185 3.768 -0.583</td>
<td>3.643 3.455 0.188</td>
<td>0.130 0.657 0.787</td>
</tr>
<tr>
<td>1997</td>
<td>3.326 3.949 -0.623</td>
<td>3.823 3.621 0.202</td>
<td>0.146 0.698 0.844</td>
</tr>
<tr>
<td>1998</td>
<td>3.470 4.135 -0.665</td>
<td>4.010 3.790 0.220</td>
<td>0.163 0.740 0.903</td>
</tr>
<tr>
<td>1999</td>
<td>3.617 4.321 -0.704</td>
<td>4.200 3.961 0.239</td>
<td>0.180 0.784 0.964</td>
</tr>
<tr>
<td>2000</td>
<td>3.759 4.506 -0.747</td>
<td>4.388 4.130 0.258</td>
<td>0.198 0.828 1.026</td>
</tr>
</tbody>
</table>

|      | TOTAL 42.743 49.603 -6.860 | 48.385 46.403 1.982 | 1.347 7.665 9.012 |
| PRES. VALUE | 13.683 15.429 -1.746 | 15.278 14.825 0.454 | 0.436 2.103 2.389 |
Private and social costs for the fuel-price scenario are shown in Figures 7.29 and 7.30, and compared with those for the base case in Table 7.5. Table 7.5 also show the increase in Egyptian Government revenue resulting from this scenario. As would be expected, total private costs for this scenario are significantly greater than those for the base-case, while total social costs are lower, due to price-induced conservation and the use of more efficient technologies. However, both private and social costs for this scenario are somewhat greater than those for the free-market scenario, due to the unavailability of fuel-efficient diesel light-duty vehicles. This increases private costs by L.E. (1979) 80 million per year in the year 2000, and social costs by L.E. 60 million compared to the free market case. There are still net social savings of L.E. (1979) 260 million per year for this scenario compared to the base case, however.

The effect on government revenue for this scenario is nearly the same as that for the free-market case, since fuel prices in both cases are equal to the world price after 1985. However, less of the increased revenue is derived from foreign sources, and more from domestic sources than in the free-market case. This is due to the fact that domestic fuel consumption is higher and export sales are lower than for the free-market scenario. Increased gasoline sales abroad amount to L.E. (1979) 104 million in 2000 for this scenario compared to the base case, while increased diesel sales are L.E. 94 million. The increase in revenue due to increased domestic fuel prices amounts to L.E. (1979) 828 million in 2000, for a total increase in Government revenue of L.E. (1979) 1.026 billion per year in
that year.

Figures 7.31 through 7.34 show the numbers and makeup of the four classes of light-duty vehicles in the model as they are projected to evolve in this scenario. The development of the heavy-duty vehicle fleets in this scenario is identical to that in the free-market case, and has not been repeated. Compared with the base case, these plots show a significantly greater penetration of advanced technologies, and a corresponding reduction in the market share held by the "standard" technology. This reduction is not as great as projected in the free-market scenario, however. With the elimination of light-duty diesels as an option, most of the market share for the diesels has been assigned by the model to the advanced gasoline technologies. A fraction, however, is assigned to the standard technology, resulting in a slightly higher penetration for this technology than in the free market scenario.

7.2.4 Light-Duty Diesel Scenario

In the light-duty diesel scenario, diesel passenger cars and light trucks are assumed to be available on the market in 1985, but no changes in fuel price are assumed to occur. Figures 7.35 through 7.38 display the model's projections of fuel consumption, private costs, and social costs for the this scenario. These results are compared with those of the base-case in Tables 7.6 and 7.7. Projections of the total number and technology mix for each class of vehicles considered are shown in Figures 7.39 through 7.42.
Figure 7.31: Projected numbers and composition of the small passenger car class vs. time for the fuel-price scenario.

Figure 7.32: Projected numbers and composition of the large passenger car class vs. time for the fuel-price scenario.
Figure 7.33: Projected numbers and composition of the taxicab class vs. time for the fuel-price scenario.

Figure 7.34: Projected numbers and composition of the light truck class vs. time for the fuel-price scenario.
Figure 7.35: Projected gasoline consumption vs. time for the light-duty diesel scenario.

Figure 7.36: Projected diesel fuel consumption vs. time for the light-duty diesel scenario.
Figure 7.37: Total projected private cost of transportation vs. time for the light-duty diesel scenario.

Figure 7.38: Total projected social cost of transportation vs. time for the light-duty diesel scenario.
Table 7.6: Comparison of projected fuel consumption for the light-duty diesel and base-case scenarios, 1985 - 2000.

**TOTAL FUEL CONSUMPTION FOR ALL CLASSES**
(in billions of liters)

<table>
<thead>
<tr>
<th>Year</th>
<th>Gasoline Base-Case</th>
<th>Diesel Base-Case</th>
<th>% Change</th>
<th>Gasoline Diesel Base-Case</th>
<th>Diesel Diesel Base-Case</th>
<th>% Change</th>
<th>Total Base-Case</th>
<th>Diesel Base-Case</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>2.25</td>
<td>1.91</td>
<td>-15.04</td>
<td>1.72</td>
<td>2.00</td>
<td>16.40</td>
<td>3.97</td>
<td>3.91</td>
<td>-1.41</td>
</tr>
<tr>
<td>1986</td>
<td>2.41</td>
<td>1.89</td>
<td>-21.51</td>
<td>1.80</td>
<td>2.22</td>
<td>23.41</td>
<td>4.22</td>
<td>4.12</td>
<td>-2.30</td>
</tr>
<tr>
<td>1987</td>
<td>2.57</td>
<td>1.88</td>
<td>-26.95</td>
<td>1.88</td>
<td>2.43</td>
<td>29.26</td>
<td>4.46</td>
<td>4.31</td>
<td>-3.23</td>
</tr>
<tr>
<td>1988</td>
<td>2.73</td>
<td>1.88</td>
<td>-31.02</td>
<td>1.97</td>
<td>2.63</td>
<td>33.72</td>
<td>4.70</td>
<td>4.51</td>
<td>-3.88</td>
</tr>
<tr>
<td>1989</td>
<td>2.88</td>
<td>1.89</td>
<td>-34.35</td>
<td>2.06</td>
<td>2.82</td>
<td>37.09</td>
<td>4.94</td>
<td>4.71</td>
<td>-4.54</td>
</tr>
<tr>
<td>1990</td>
<td>3.03</td>
<td>1.86</td>
<td>-38.67</td>
<td>2.15</td>
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<td>40.62</td>
<td>5.18</td>
<td>4.88</td>
<td>-5.76</td>
</tr>
<tr>
<td>1991</td>
<td>3.18</td>
<td>1.85</td>
<td>-41.81</td>
<td>2.24</td>
<td>3.21</td>
<td>43.17</td>
<td>5.42</td>
<td>5.06</td>
<td>-6.68</td>
</tr>
<tr>
<td>1992</td>
<td>3.32</td>
<td>1.85</td>
<td>-44.30</td>
<td>2.33</td>
<td>3.38</td>
<td>45.21</td>
<td>5.65</td>
<td>5.23</td>
<td>-7.43</td>
</tr>
<tr>
<td>1993</td>
<td>3.47</td>
<td>1.86</td>
<td>-46.28</td>
<td>2.42</td>
<td>3.55</td>
<td>46.86</td>
<td>5.89</td>
<td>5.42</td>
<td>-8.05</td>
</tr>
<tr>
<td>1994</td>
<td>3.61</td>
<td>1.89</td>
<td>-47.76</td>
<td>2.50</td>
<td>3.71</td>
<td>48.10</td>
<td>6.12</td>
<td>5.60</td>
<td>-8.49</td>
</tr>
<tr>
<td>1995</td>
<td>3.74</td>
<td>1.91</td>
<td>-48.97</td>
<td>2.59</td>
<td>3.86</td>
<td>48.96</td>
<td>6.34</td>
<td>5.77</td>
<td>-8.92</td>
</tr>
<tr>
<td>1996</td>
<td>3.88</td>
<td>1.94</td>
<td>-49.94</td>
<td>2.68</td>
<td>4.00</td>
<td>49.66</td>
<td>6.56</td>
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</tr>
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<td>-50.85</td>
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<td>4.14</td>
<td>50.00</td>
<td>6.77</td>
<td>6.11</td>
<td>-9.78</td>
</tr>
<tr>
<td>1998</td>
<td>4.14</td>
<td>2.01</td>
<td>-51.38</td>
<td>2.84</td>
<td>4.27</td>
<td>50.23</td>
<td>6.98</td>
<td>6.28</td>
<td>-10.03</td>
</tr>
<tr>
<td>1999</td>
<td>4.27</td>
<td>2.06</td>
<td>-51.64</td>
<td>2.92</td>
<td>4.40</td>
<td>50.39</td>
<td>7.19</td>
<td>6.46</td>
<td>-10.14</td>
</tr>
<tr>
<td>2000</td>
<td>4.39</td>
<td>2.11</td>
<td>-51.93</td>
<td>3.01</td>
<td>4.52</td>
<td>50.43</td>
<td>7.39</td>
<td>6.63</td>
<td>-10.31</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>53.89</strong></td>
<td><strong>30.78</strong></td>
<td><strong>-42.89</strong></td>
<td><strong>37.87</strong></td>
<td><strong>54.18</strong></td>
<td><strong>43.06</strong></td>
<td><strong>91.76</strong></td>
<td><strong>84.96</strong></td>
<td><strong>-7.42</strong></td>
</tr>
</tbody>
</table>
Table 7.7: Comparison of projected costs and changes in government revenue for the light-duty diesel and base-case scenarios, 1985 – 2000.

TOTAL COST OF TRANSPORTATION/CHANGE IN GOVERNMENT OIL REVENUE
(in billions 1979 Egyptian pounds)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PRIVATE COSTS</th>
<th>SOCIAL COSTS</th>
<th>CHANGE IN GOVT. REVENUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BASE-CASE % CHANGE</td>
<td>BASE-CASE % CHANGE</td>
<td>FOREIGN DOMESTIC TOTAL</td>
</tr>
<tr>
<td></td>
<td>1.596 1.592 0.004</td>
<td>1.748 1.756 -0.008</td>
<td>0.004 -0.018 -0.014</td>
</tr>
<tr>
<td></td>
<td>1.732 1.714 0.018</td>
<td>1.901 1.905 -0.004</td>
<td>0.008 -0.027 -0.019</td>
</tr>
<tr>
<td></td>
<td>1.871 1.838 0.033</td>
<td>2.057 2.054 0.003</td>
<td>0.014 -0.037 -0.023</td>
</tr>
<tr>
<td></td>
<td>2.009 1.970 0.039</td>
<td>2.216 2.212 0.004</td>
<td>0.018 -0.045 -0.027</td>
</tr>
<tr>
<td></td>
<td>2.155 2.103 0.052</td>
<td>2.383 2.371 0.012</td>
<td>0.023 -0.053 -0.030</td>
</tr>
<tr>
<td></td>
<td>2.302 2.239 0.063</td>
<td>2.553 2.533 0.020</td>
<td>0.033 -0.063 -0.030</td>
</tr>
<tr>
<td></td>
<td>2.450 2.375 0.075</td>
<td>2.731 2.702 0.029</td>
<td>0.042 -0.072 -0.030</td>
</tr>
<tr>
<td></td>
<td>2.597 2.513 0.084</td>
<td>2.910 2.873 0.037</td>
<td>0.051 -0.080 -0.029</td>
</tr>
<tr>
<td></td>
<td>2.744 2.653 0.091</td>
<td>3.091 3.048 0.043</td>
<td>0.059 -0.087 -0.028</td>
</tr>
<tr>
<td></td>
<td>2.891 2.793 0.098</td>
<td>3.273 3.224 0.049</td>
<td>0.067 -0.094 -0.027</td>
</tr>
<tr>
<td></td>
<td>3.039 2.933 0.106</td>
<td>3.458 3.400 0.058</td>
<td>0.076 -0.100 -0.024</td>
</tr>
<tr>
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<td>3.185 3.073 0.112</td>
<td>3.643 3.577 0.066</td>
<td>0.085 -0.106 -0.021</td>
</tr>
<tr>
<td></td>
<td>3.326 3.209 0.117</td>
<td>3.823 3.751 0.072</td>
<td>0.095 -0.112 -0.017</td>
</tr>
<tr>
<td></td>
<td>3.470 3.345 0.125</td>
<td>4.010 3.927 0.083</td>
<td>0.104 -0.117 -0.013</td>
</tr>
<tr>
<td></td>
<td>3.617 3.492 0.125</td>
<td>4.200 4.116 0.084</td>
<td>0.111 -0.121 -0.010</td>
</tr>
<tr>
<td></td>
<td>3.759 3.631 0.128</td>
<td>4.388 4.297 0.091</td>
<td>0.120 -0.125 -0.005</td>
</tr>
<tr>
<td>TOTAL</td>
<td>42.743 41.473 1.270</td>
<td>48.385 47.746 0.639</td>
<td>0.910 -1.257 -0.347</td>
</tr>
<tr>
<td>PRES. VALUE</td>
<td>13.683 13.354 0.329</td>
<td>15.278 15.154 0.125</td>
<td>0.359 -0.195 0.014</td>
</tr>
</tbody>
</table>
Figure 7.39: Projected numbers and composition of the small passenger car class vs. time for the light-duty diesel scenario.

Figure 7.40: Projected numbers and composition of the large passenger car class vs. time for the light-duty diesel scenario.
Figure 7.41: Projected numbers and composition of the taxicab class vs. time for the light-duty diesel scenario.

Figure 7.42: Projected numbers and composition of the light truck class vs. time for the light-duty diesel scenario.
Figure 7.35 shows the total gasoline consumption projected by the model for this scenario. As was also true of the free-market scenario, gasoline consumption is projected to increase rapidly up to 1985, after which it declines slightly and then stays more-or-less constant for the remainder of the model period. This change is due to a massive shift to diesel engines by taxicabs, which is projected to occur as soon as they become available on the market. This is accompanied by a less abrupt but still significant shift by the other light-duty classes. The shift to diesels is made all the more dramatic by the fact that under the present pricing structure (which is assumed to continue unchanged in this scenario) the price of diesel fuel is about one-fifth that of gasoline.

Since the fuel pricing structure in this scenario is the same as that for the base case, the model projects little price-induced tendency toward the use of energy-conserving technologies. The exception is the massive change to diesels in the light-duty classes, which is due to the heavy subsidy on diesel fuel in the precent pricing structure. The result of this change is projected to be a 52 percent decrease in gasoline consumption and a 50 percent increase in diesel consumption in the year 2000, compared to the base-case. This results in a net fuel savings of 10 percent, or 760 million liters per year in 2000. This is roughly half of the savings projected for the free-market scenario. Most of the fuel savings are concentrated in the taxicab class, due to its size and the great advantages of diesels in this class. Savings on taxicab fuel alone are projected to amount to 600 million liters per year in 2000, or more than 80 percent of the total savings projected for this scenario.
As would be expected, projected private costs for this scenario are slightly lower than for the base-case, due to the availability of more efficient vehicles using less costly fuel. The net decrease in private costs is about L.E. (1979) 130 million per year in 2000, or about 3.5 percent of the total cost of the base-case scenario. Social costs are also projected to be slightly lower — by about 90 million 1979 pounds per year in 2000.

Government revenues are reduced somewhat under this scenario. This is as would be expected, considering the massive shift from less-subsidized gasoline to more-subsidized diesel fuel in the light-duty class. Overall, the reduction in gasoline usage frees some 2.28 billion liters per year by the year 2000 to be sold abroad, bringing in L.E. (1979) 408 million in that year. The increased diesel usage, however, reduces exportable diesel fuel by 1.51 billion liters, at a cost of L.E. (1979) 290 million. This gives a net increase in foreign exchange income of L.E. 118 million per year in 2000. However, domestic revenue from fuel sales is predicted to decrease by L.E. 126 million from the base case, due to the price difference between diesel and gasoline. The net effect is a loss to the Government of about 5 million pounds per year in the year 2000, relative to the base case. Total losses over the period from 1985 to 2000 are projected as L.E. (1979) 347 million, with a net present value in 1985 of about 14 million 1979 pounds (28 million 1985 pounds).

7.2.5 Scenario Comparisons and Discussion
Approaches to conserving energy (or any other scarce resource) can be divided into two basic types. The first type of approach is reduce consumption of the useful services that energy provides. This approach has been referred to as "freezing in the dark". The second type of approach calls for making more efficient use of energy, in order to supply the services required at a lower consumption level. The first type of approach is generally cheap, simple, and quick to implement, but can cause considerable economic damage. The second often takes longer, and requires the adoption of new technologies, but is usually much more effective.

The potential for energy conservation through use of more efficient technologies clearly depends on level of technology which is presently in use, and on the efficiency of the alternative technologies. Other things being equal, a nation such as Egypt, in which fuel prices are well below world levels, is likely to employ less efficient technologies than a nation where prices are higher. There is thus a considerable potential for increased efficiency, and thus for substantial energy savings with little cost in energy services (in this case, transportation) foregone. This is borne out by the projections presented in Sections 7.1 through 7.4 above.

To further emphasize this point, Table 7.8 shows the total vehicle-kilometers travelled, total fuel consumption, total social cost of transportation, average fuel economy, and average social cost per kilometer travelled projected for each class of vehicles in each scenario.
Table 7.8: Comparison of fuel consumption, vehicle kilometers travelled, social cost, average fuel economy, and average cost per kilometer for each class of vehicles in each scenario, 1990 and 2000.

<table>
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<tr>
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Table 7.8: Comparison of fuel consumption, vehicle kilometers travelled, social cost, average fuel economy, and average cost per kilometer for each class of vehicles in each scenario, 1990 and 2000 (continued).

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<th>Vehicle-Kilometers</th>
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<th>Average Cost Per VKT</th>
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Table 7.8: Comparison of fuel consumption, vehicle kilometers travelled, social cost, average fuel economy, and average cost per kilometer for each class of vehicles in each scenario, 1990 and 2000 (continued).

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<th>Year 2000</th>
<th>Social Cost 1979 L.E. &amp; Change</th>
<th>Fuel Consumption liters % Change</th>
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<td>Base-Case</td>
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<td>4.51E+08</td>
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Table 7.8: Comparison of fuel consumption, vehicle kilometers travelled, social cost, average fuel economy, and average cost per kilometer for each class of vehicles in each scenario, 1990 and 2000 (continued).

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</table>


for model years 1990 and 2000. The percentage change in each quantity from
the projections for the base-case scenario is also shown. It is clear
from the table that reductions in transportation services consumed
(represented by vehicle-kilometers) account for only a small fraction of
the projected cost and fuel savings — especially in the longer term.
Increased efficiency, as indicated by the changes in fuel-economy and
cost-per-kilometer, accounts for the great preponderance of total
savings.

The increase in average the fuel-efficiency of each class is due to the
preferential selection of higher-efficiency technologies by the consumers
in that class. This is indicated in Table 7.9, which shows the fraction
of each class of vehicles using each of the available technologies in 1990
and 2000. A major shift in the vehicle mix between scenarios is apparent.

The skeptical reader may well question whether so large a shift in the
technology mix is reasonable, or indeed feasible, given the substantial
lead-times and investment requirements in the automotive industry. With
regard to the movement from "standard" light duty technology to "advanced"
technology, the answer is clearly "yes" — the automotive fleets in Europe
and the U.S. have undergone precisely such a change since 1979. A major
shift from "standard" to "advanced" heavy-duty truck and bus technology is
apparent in these areas as well.

The reasonableness of the large shift to light-duty diesel technologies
projected for the free-market and base-case scenarios is less clear-cut.
Table 7.9: Breakdown of vehicles in each class by technology: 1990 and 2000.

<table>
<thead>
<tr>
<th>Year 1990</th>
<th>Base-Case number</th>
<th>Free Market number</th>
<th>Fuel Price number</th>
<th>Light-duty diesel number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>percent</td>
<td>number</td>
<td>percent</td>
<td>number</td>
</tr>
<tr>
<td>SMALL PASSENGER CARS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Small Gas Car</td>
<td>481193</td>
<td>77.1</td>
<td>433304</td>
<td>70.4</td>
</tr>
<tr>
<td>Adv Small Gas Car</td>
<td>142608</td>
<td>22.9</td>
<td>131712</td>
<td>21.4</td>
</tr>
<tr>
<td>Small IDI Diesel Car</td>
<td>0</td>
<td>0.0</td>
<td>45090</td>
<td>7.3</td>
</tr>
<tr>
<td>Small DI Diesel Car</td>
<td>0</td>
<td>0.0</td>
<td>5233</td>
<td>0.9</td>
</tr>
<tr>
<td>TOTAL SMALL PASSENGER CAR</td>
<td>623801</td>
<td>615339</td>
<td>615404</td>
<td>623424</td>
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<tr>
<td>LARGE PASSENGER CARS</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Large Gas Car</td>
<td>129424</td>
<td>46.7</td>
<td>113848</td>
<td>41.1</td>
</tr>
<tr>
<td>Adv Large Gas Car</td>
<td>147956</td>
<td>53.3</td>
<td>122007</td>
<td>44.0</td>
</tr>
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<td>37218</td>
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<tr>
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<td>0.0</td>
<td>3901</td>
<td>1.4</td>
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<td></td>
</tr>
<tr>
<td>Std Gas Taxi</td>
<td>89442</td>
<td>32.7</td>
<td>42530</td>
<td>16.1</td>
</tr>
<tr>
<td>Adv Gas Taxi</td>
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<td>67.3</td>
<td>104153</td>
<td>39.3</td>
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<td>0.0</td>
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<td>40.7</td>
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<tr>
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<td>0.0</td>
<td>10407</td>
<td>3.9</td>
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<tr>
<td>TOTAL TAXICAB</td>
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<td>265559</td>
<td>278519</td>
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<td>LIGHT TRUCKS</td>
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<td></td>
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<tr>
<td>Std Gas Lt Truck</td>
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<td>74.7</td>
<td>63880</td>
<td>62.4</td>
</tr>
<tr>
<td>Adv Gas Lt Truck</td>
<td>26643</td>
<td>25.3</td>
<td>25146</td>
<td>24.6</td>
</tr>
<tr>
<td>IDI Diesel Lt Truck</td>
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<td>0.0</td>
<td>11721</td>
<td>11.5</td>
</tr>
<tr>
<td>DI Diesel Lt Truck</td>
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<td>0.0</td>
<td>1604</td>
<td>1.6</td>
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<tr>
<td>TOTAL LIGHT TRUCK</td>
<td>105171</td>
<td>102351</td>
<td>103306</td>
<td>104793</td>
</tr>
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</table>
Table 7.9: Breakdown of vehicles in each class by technology: 1990 and 2000 (continued).

<table>
<thead>
<tr>
<th>Year 1990</th>
<th>Base-Case</th>
<th>Free Market</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number</td>
<td>percent</td>
</tr>
<tr>
<td>SMALL BUSES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lgt. Gas Bus</td>
<td>1337 7.8</td>
<td>1516 9.0</td>
</tr>
<tr>
<td>Std Lgt. Diesel Bus</td>
<td>11938 69.4</td>
<td>10246 60.7</td>
</tr>
<tr>
<td>Adv Lgt. Diesel Bus</td>
<td>3925 22.8</td>
<td>5130 30.4</td>
</tr>
<tr>
<td>TOTAL SMALL BUS</td>
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<td>16892</td>
</tr>
<tr>
<td>LARGE BUSES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Heavy Bus</td>
<td>12585 76.0</td>
<td>10265 63.1</td>
</tr>
<tr>
<td>Adv Heavy Bus</td>
<td>3975 24.0</td>
<td>5993 36.9</td>
</tr>
<tr>
<td>TOTAL LARGE BUS</td>
<td>16560</td>
<td>16258</td>
</tr>
<tr>
<td>SMALL TRUCKS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-T Gas Truck</td>
<td>3631 5.1</td>
<td>3650 5.3</td>
</tr>
<tr>
<td>Std 8-T Diesel Truck</td>
<td>56112 78.4</td>
<td>48717 70.5</td>
</tr>
<tr>
<td>Adv 8-T Diesel Truck</td>
<td>11809 16.5</td>
<td>16701 24.2</td>
</tr>
<tr>
<td>TOTAL SMALL TRUCK</td>
<td>71552</td>
<td>69068</td>
</tr>
<tr>
<td>SMALL TRUCK/TRAILER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std 20-T Truck/Trlr.</td>
<td>7289 73.1</td>
<td>5331 55.8</td>
</tr>
<tr>
<td>Adv 20-T Truck/Trlr.</td>
<td>2683 26.9</td>
<td>4226 44.2</td>
</tr>
<tr>
<td>TOTAL SMALL TRUCK/TRAILER</td>
<td>9972</td>
<td>9557</td>
</tr>
<tr>
<td>LARGE TRUCK/TRAILER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std 30-T Truck/Trlr.</td>
<td>5157 62.2</td>
<td>4192 53.9</td>
</tr>
<tr>
<td>Std Semi-Trailer</td>
<td>2986 36.0</td>
<td>3106 39.9</td>
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<tr>
<td>Mod Semi-Trailer</td>
<td>151 1.8</td>
<td>467 6.0</td>
</tr>
<tr>
<td>Adv Semi-Trailer</td>
<td>0 0.0</td>
<td>15 0.2</td>
</tr>
<tr>
<td>TOTAL LARGE TRUCK/TRAILER</td>
<td>8294</td>
<td>7780</td>
</tr>
</tbody>
</table>
Table 7.9: Breakdown of vehicles in each class by technology: 1990 and 2000 (continued).

<table>
<thead>
<tr>
<th>Year 2000</th>
<th>Base-Case number percent</th>
<th>Free Market number percent</th>
<th>Fuel Price number percent</th>
<th>Light-duty diesel number percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMALL PASSENGER CARS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Small Gas Car</td>
<td>811970 76.3</td>
<td>632213 60.5</td>
<td>756650 72.7</td>
<td>673613 63.4</td>
</tr>
<tr>
<td>Adv Small Gas Car</td>
<td>252677 23.7</td>
<td>234085 22.4</td>
<td>284378 27.3</td>
<td>208771 19.6</td>
</tr>
<tr>
<td>Small IDI Diesel Car</td>
<td>0 0.0</td>
<td>111712 10.7</td>
<td>0 0.0</td>
<td>117537 11.1</td>
</tr>
<tr>
<td>Small DI Diesel Car</td>
<td>0 0.0</td>
<td>66642 6.4</td>
<td>0 0.0</td>
<td>62869 5.9</td>
</tr>
<tr>
<td>TOTAL SMALL PASSENGER CAR</td>
<td>1064647</td>
<td>1044652</td>
<td>1041028</td>
<td>1062790</td>
</tr>
</tbody>
</table>

| LARGE PASSENGER CARS         |                          |                            |                           |                                 |
| Std Large Gas Car            | 183570 39.0              | 122517 25.9                | 167926 35.8               | 130634 27.7                     |
| Adv Large Gas Car            | 286809 61.0              | 205244 43.4                | 301472 64.2               | 193293 41.1                     |
| Large IDI Diesel Car         | 0 0.0                    | 92753 19.6                 | 0 0.0                     | 95558 20.3                     |
| Large DI Diesel Car          | 0 0.0                    | 52308 11.1                 | 0 0.0                     | 51294 10.9                     |
| TOTAL LARGE PASSENGER CAR    | 470379                   | 472822                     | 469398                    | 470779                          |

| TAXICABS                     |                          |                            |                           |                                 |
| Std Gas Taxi                 | 168639 36.2              | 30385 6.9                  | 65655 14.8                | 48733 10.4                     |
| Adv Gas Taxi                 | 297667 63.8              | 135253 30.6                | 376656 85.2               | 85357 18.2                     |
| IDI Diesel Taxi              | 0 0.0                    | 160058 36.3                | 0 0.0                     | 223103 47.6                    |
| DI Diesel Taxi               | 0 0.0                    | 115651 26.2                | 0 0.0                     | 111869 23.8                    |
| TOTAL TAXICAB                | 466306                   | 441347                     | 442311                    | 469062                          |

| LIGHT TRUCKS                 |                          |                            |                           |                                 |
| Std Gas Lt Truck             | 137130 76.8              | 84502 48.8                 | 109529 63.3               | 105843 59.4                     |
| Adv Gas Lt Truck             | 41458 23.2               | 47638 27.5                 | 63464 36.7                | 32141 18.0                     |
| IDI Diesel Lt Truck          | 0 0.0                    | 22609 13.1                 | 0 0.0                     | 24646 13.8                     |
| DI Diesel Lt Truck           | 0 0.0                    | 18411 10.6                 | 0 0.0                     | 15484 8.7                      |
| TOTAL LIGHT TRUCK            | 178588                   | 173160                     | 172993                    | 178114                          |
Table 7.9: Breakdown of vehicles in each class by technology: 1990 and 2000 (continued).

<table>
<thead>
<tr>
<th>Year 2000</th>
<th>Base-Case number</th>
<th>Base-Case percent</th>
<th>Free Market number</th>
<th>Free Market percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SMALL BUSES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lgt. Gas Bus</td>
<td>2432</td>
<td>9.0</td>
<td>2042</td>
<td>7.6</td>
</tr>
<tr>
<td>Std Lgt. Diesel Bus</td>
<td>18426</td>
<td>68.0</td>
<td>11848</td>
<td>43.9</td>
</tr>
<tr>
<td>Adv Lgt. Diesel Bus</td>
<td>6241</td>
<td>23.0</td>
<td>13081</td>
<td>48.5</td>
</tr>
<tr>
<td><strong>TOTAL SMALL BUS</strong></td>
<td>27099</td>
<td></td>
<td>26971</td>
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</tr>
<tr>
<td><strong>LARGE BUSES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Heavy Bus</td>
<td>20812</td>
<td>79.6</td>
<td>9649</td>
<td>37.4</td>
</tr>
<tr>
<td>Adv Heavy Bus</td>
<td>5348</td>
<td>20.4</td>
<td>16122</td>
<td>62.6</td>
</tr>
<tr>
<td><strong>TOTAL LARGE BUS</strong></td>
<td>26160</td>
<td></td>
<td>25771</td>
<td></td>
</tr>
<tr>
<td><strong>SMALL TRUCKS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-T Gas Truck</td>
<td>3863</td>
<td>3.6</td>
<td>2434</td>
<td>2.4</td>
</tr>
<tr>
<td>Std 8-T Diesel Truck</td>
<td>75172</td>
<td>70.7</td>
<td>36215</td>
<td>36.0</td>
</tr>
<tr>
<td>Adv 8-T Diesel Truck</td>
<td>27226</td>
<td>25.6</td>
<td>61953</td>
<td>61.6</td>
</tr>
<tr>
<td><strong>TOTAL SMALL TRUCK</strong></td>
<td>106261</td>
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<td><strong>SMALL TRUCK/TRAILER</strong></td>
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<tr>
<td>Std 20-T Truck/Trlr.</td>
<td>10884</td>
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<td>2256</td>
<td>16.2</td>
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<tr>
<td>Adv 20-T Truck/Trlr.</td>
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<td>26.6</td>
<td>11681</td>
<td>83.8</td>
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<tr>
<td><strong>TOTAL SMALL TRUCK/TRAILER</strong></td>
<td>14821</td>
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<td>13937</td>
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<tr>
<td><strong>LARGE TRUCK/TRAILER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std 30-T Truck/Trlr.</td>
<td>8143</td>
<td>66.2</td>
<td>4339</td>
<td>38.4</td>
</tr>
<tr>
<td>Std Semi-Trailer</td>
<td>4016</td>
<td>32.6</td>
<td>4342</td>
<td>38.5</td>
</tr>
<tr>
<td>Mod Semi-Trailer</td>
<td>146</td>
<td>1.2</td>
<td>2372</td>
<td>21.0</td>
</tr>
<tr>
<td>Adv Semi-Trailer</td>
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<td>0.0</td>
<td>238</td>
<td>2.1</td>
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<tr>
<td><strong>TOTAL LARGE TRUCK/TRAILER</strong></td>
<td>12305</td>
<td></td>
<td>11291</td>
<td></td>
</tr>
</tbody>
</table>
Despite many projections of a very large market share for these vehicles following the oil price increases of 1979, light-duty diesels make up only about 10 percent of the light-duty fleet in Europe (although this share is increasing), and two or three percent in the United States. It is reasonable to question, therefore, whether projections shown here for Egypt may not be similarly overblown.

Several characteristics of light-duty diesel vehicles have acted to limit their sales in Europe and the U.S. Compared to gasoline vehicles, diesels are perceived as being smoky, smelly, and lower in power. These problems are especially acute at high altitudes if the diesel engine is not turbocharged. Diesels are also much harder to start under very cold conditions. The relative affluence of consumers in these countries enables them to pay a premium in increased fuel consumption to avoid these inconveniences. Diesel sales in the United States have also been hampered by a poor reputation for reliability, which is the result of numerous well-publicized problems with one particular engine model. Other diesels, which generally exhibit very good reliability, have apparently been tarred with the same brush, and their sales have suffered as a result.

Presently however, new diesel technology, in the form of electronic controls, improved fuel systems, and turbocharging is resulting in significant improvements in diesel performance. The same improvements are also reducing the smoke, smell, and noise associated with diesel engines. As a result, many observers, including the author, expect a substantial increase in diesel sales in the developed world. In Egypt, also, most
consumers are not affluent by Western standards, and thus can afford to pay less to avoid minor inconveniences. Perhaps more importantly, the Egyptian climate is such that cold-starting is not an issue, and Egyptian topography is devoid of the high altitudes which degrade diesel performance. For these reasons, diesel penetration in Egypt would be expected to be greater than that in Europe or the U.S. over the long run.

Diesels are also very well suited to use in taxicabs, due to their excellent fuel economy at idle and at part-load, and they have demonstrated superior durability in this use. Diesel taxicabs are in use in many European cities. Since taxicabs make up a very large fraction of the Egyptian light-duty fleet, it does not appear unreasonable to project a substantial market penetration. The precise degree of this penetration will probably be dependent on many factors, however, including government and auto-manufacturer policies, the development of an adequate service network for light-duty diesels, and other factors which are difficult to include in a general model such as this one. The reasonableness of the market-penetration projections shown in Table 7.9 must thus remain an open question.

7.2.6 Sensitivity Tests

In several cases, adequate data to define important model parameters were not available, and estimates — based on the author's judgement and any data that were available — had to be used. The two most important parameters for which this was true were the logit choice function...
parameter $\beta_c$, and the rate of increase in international fuel prices. In order to assess the sensitivity of the model results to errors in estimating these values, several model runs using alternative values were made.

In order to examine the effects of different values for $\beta_c$, the base-case and free-market scenario models were re-run with values for $\beta_c$ which were half those used in the base model, thus doubling the width of the logit distribution. This is a very large change — probably much greater than would be produced by any realistic values for $\beta_c$.

The overall results of these runs are shown in Table 7.10. As the table indicates, the model runs with $\beta_c$ halved showed a net savings of 1.42 billion liters of fuel per year in 2000 for the free-market scenario over the base-case scenario, compared to 1.52 billion liters for the model using the original values. Net social savings over the base-case for the free-market scenario were calculated as 291 million 1979 pounds per year in 2000, compared to 320 million for the original model. The increase in government revenues for the free-market scenario was calculated as 1,016 million pounds per year in 2000, compared to 1,027 million pounds per year in the base model. It is apparent from these comparisons that even very large changes in $\beta_c$ have little effect on the important results of the model.

The major function of the TRATEC model is to assess the tradeoff between increased fuel costs and increased capital costs for vehicles. It is thus
Table 7.10: Results of model runs to test sensitivity to key parameters: free market vs. base-case scenario.

<table>
<thead>
<tr>
<th></th>
<th>Basic Model</th>
<th>High Price</th>
<th>Low Price</th>
<th>Reduced Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Net Cost/Revenue Change - Year 2000 (billion 1979 L.E.)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private cost</td>
<td>+0.67</td>
<td>+1.10</td>
<td>+0.37</td>
<td>+0.69</td>
</tr>
<tr>
<td>Social Cost</td>
<td>-0.32</td>
<td>-0.62</td>
<td>-0.14</td>
<td>-0.29</td>
</tr>
<tr>
<td>Government Revenue</td>
<td>+1.03</td>
<td>+1.76</td>
<td>+0.54</td>
<td>1.02</td>
</tr>
<tr>
<td><strong>Net Fuel Savings - Year 2000 (billion liters)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>2.32</td>
<td>2.63</td>
<td>2.09</td>
<td>2.41</td>
</tr>
<tr>
<td>Diesel</td>
<td>-0.79</td>
<td>-0.69</td>
<td>-0.90</td>
<td>-0.99</td>
</tr>
<tr>
<td>Total</td>
<td>1.53</td>
<td>1.94</td>
<td>1.19</td>
<td>1.42</td>
</tr>
</tbody>
</table>
to be expected that the model results would be fairly sensitive to changes in projected fuel or capital costs. Since capital costs must be specified separately for each vehicle technology — a laborious task — it was decided to test the model's sensitivity to changes in this tradeoff by varying the fuel costs instead. Two separate runs of the model were made, using the same assumptions as for the free-market scenario, except for changes in the assumed rate of increase in international fuel prices. One run, the "high-cost" case, assumed that real fuel prices would increase at a six-percent annual rate, instead of the three-percent rate assumed in the free-market scenario. Another, the "low-cost" case, assumed no increase at all in world fuel prices after 1985.

The results of these calculations are also given in Table 7.10. As the table indicates, the benefits of adopting free-market fuel pricing and technology policies vary considerably depending on what assumptions are made about future world prices. This is most evident in the calculations of private costs, social costs, and government revenues. For the low-price case, savings in all of these areas are about half those calculated for the initial model, while the savings for the high-price case are about 70 percent greater. This is not surprising — it is obvious that the cost of subsidizing fuel prices must vary strongly with the amount of the subsidy. Interestingly, the savings in fuel consumption between the three cases is less affected by the assumed world price of fuel. This is due to the fact that domestic fuel prices — even in the low-price case — are projected to increase considerably from their present subsidized levels, resulting in significant conservation efforts.
8.0 SUMMARY AND CONCLUSIONS

This report describes and documents the TRATEC Transportation Technology Choice computer code, and gives an example of its application. The TRATEC code embodies a novel model of technology choice and fuel consumption in highway transportation. Both the model and the code embodying it have been designed with special attention to the needs of policymakers and planners dealing with the developing nations. Special features of the model which suit it to developing-country planning and policy evaluation requirements include: minimal requirements for statistical data, the ability to make use of reasonable estimates for key parameters when the requisite data are not available, and the use, wherever possible, of parameters having concrete meanings, so that estimated values can readily be checked for reasonableness. In addition, the TRATEC code calculates both total costs of transportation and total fuel consumption, allowing ready cost-benefit comparisons, and is capable of calculating both "private" and "social" or "shadow" costs — the latter being calculated from shadow prices input by the user.

The TRATEC model was used to investigate the effects of changes in fuel pricing and technology policies in the Arab Republic of Egypt. Two policy changes were considered: raising Egyptian domestic prices for gasoline and diesel fuel to world levels; and permitting the import and domestic manufacture of light-duty diesel vehicles. A set of model input data was constructed, describing the vehicle fleet, the economic conditions, and
the available vehicle technologies in Egypt. The development of this data set is described in Chapter Six. Four alternative policy scenarios were modeled: a "base-case" scenario which continues the status quo; the "fuel-price" scenario, in which fuel prices are increased to World levels; the "light-duty diesel" scenario, in which the import and manufacture of light-duty diesel vehicles begins in 1985; and the "free-market" scenario, combining both of these changes. These scenarios, and the model results for each of them, are presented and discussed in Chapter Seven.

The results of the modeling indicate that all three scenarios could be expected to reduce highway fuel consumption significantly. Taking the shadow cost of fuel equal to the international price, this would result in a significant decrease in total cost to Egyptian society. The results of the fuel-price and free-market scenarios also indicate a substantial increase in revenue for the Egyptian government as a result of eliminating the implicit subsidy on transportation fuel. For the free-market scenario, the model projects a 20 percent decrease in fuel consumption from the base-case by the year 2000, saving 1.5 billion liters of fuel per year. This is calculated to produce savings in social costs (at shadow prices) of 320 million 1979 Egyptian pounds per year in 2000, and an increase in Government revenues of 1.03 billion 1979 pounds per year. One 1979 Egyptian pound is worth about two current (1985) pounds, so that the savings would be about L.E. 2 billion per year in current units. For comparison, this is about 38 percent of the Egyptian government deficit in 1984, and about four percent of Egyptian GNP.
Sensitivity tests using alternative assumptions show these results to be robust, although the value of the fuel saved varies considerably depending on what assumptions are made concerning future World fuel prices. Even assuming no change in International fuel prices after 1985, the model projects an increase in Government revenue of about L.E. (1979) 500 million per year by the year 2000. It is concluded that Egypt could secure substantial economic benefits by rationalizing fuel prices and introducing light-duty diesel vehicles. The major use for light-duty diesels would be in the taxi fleet, presently accounts for more than half of Egypt's gasoline consumption.
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APPENDIX A: TRATEC PROGRAM USER'S MANUAL
1.0 INTRODUCTION

The TRATEC (TRansportation TECnology Choice) program is a computer model of technology choice and fuel consumption by highway vehicles. It is specifically intended to be used by economic planners and other persons concerned with planning and policy-making for developing nations. The TRATEC model differs from other highway fuel consumption models in having relatively modest data requirements — thus it is well suited to modeling conditions in the less-developed countries, for which detailed data on the automotive fleet are generally lacking. In addition to its modest data requirements, the TRATEC model includes a number of design features to increase its utility to the development planner. These features include the projection and tabulation of total and variable costs, vehicle sales, and vehicle fleet size and composition as well as fuel-consumption data. An optional separate tabulation of private costs (as indicated by market prices) and of social costs (reflected in the planner's shadow prices) is available. The input data and the structure of the model are also such that the major policy options open to developing-country planners can readily be simulated.

This User's Manual describes the operation of the program and the format of the input and output data, and presents some helpful advice on the use of the model. For information concerning the algorithms used, the reasoning behind the algorithms, a discussion of the strengths and weaknesses of TRATEC as compared to other fuel-consumption models, and an

The TRATEC model is presently installed and operational on the VAX 11/780 computer in the Joint Computing Facility (JCF) at the Massachusetts Institute of Technology. This document describes the use of the program as it is implemented on the JCF VAX 11/780, and, by extension, on any other Digital Equipment Corporation VAX-series computer which uses the VAX/VMS operating system. Use of the model on other computers or with other operating systems may involve some differences in detail from what is described here.
2.0 SUMMARY OF THE MODEL

Figure 2.1 is a flowchart showing the large-scale structure of the program. The program is called up by means of a command line, which includes the specification of a number of optional parameters. It begins by parsing the parameters passed to it from the command line, checking them for errors, and opening the input and output files. Subsequently, control passes to subroutine READIN, which reads and parses the input data file, processing one group of cards at a time. If no errors are detected in the input data file, control passes to subroutine READTC, which performs a similar process on the technology database file. Data for each technology are read in and stored in a temporary random-access database file for use by the calculation routines. Any errors in the input data are reported, and if any are found the program is aborted.

After reading in the input data and the technology database, the program proceeds to subroutine CALCL8. CALCL8 and the functions and subroutines that it calls are the embodiment of the TRATEC model itself, as opposed to the data-handling, input, and output routines which make up the remainder of the program. The algorithmic structure of CALCL8 is shown in Figure 2.2 A detailed presentation of the mathematics of the model and the implementation of those mathematics in the program is given in Weaver (1985).

CALCL8 processes the input data, simulates the evolution of the vehicle
BEGIN

PARSE COMMAND LINE

OPEN FILES

SUBROUTINE READIN (read input file)

ERRORS?

Y

ERRORS?

N

SUBROUTINE READTC (read tech. database)

ERRORS?

Y

ERRORS?

N

SUBROUTINE CALCL8 (carry out the model) (see Fig. 2.2)

SUBROUTINE REPORT (print report)

GRAPHICS?

Y

SUBROUTINE GRIFIC (plot output data)

N

END

Figure 2.1: Flowchart of the TRATEC computer program.
Figure 2.2: Flowchart of subroutine TRATEC
fleet through the period of the model, and calculates and keeps track of totals for costs, fuel consumption, sales, and fleet composition. These values are printed out by subroutine REPORT. If graphic output has been specified, control then passes to GRAFIT, which produces the plot files by means of calls to the MIT PENPLOT graphics package. These files can then be converted to graphic output on any hardcopy graphics device by use of the MIT/JCF PLOT facility.
3.0 ACCESSING THE PROGRAM

The following discussion is specific to the implementation of TRATEC under VAX/VMS. Other computers and/or other operating systems will have a different access procedure. This discussion also assumes some familiarity with the VAX/VMS operating system and its utilities. Users unfamiliar with this system should consult the VMS system documentation.

The TRATEC program is invoked by typing TRATEC, followed by any of a number of optional specifications and flags. All of the specifications and flags have default values, which are used if you do not explicitly specify a value for that option. The form of the command line is:

```
TRATEC [/option1/option2 ... ]
```

The available options are:

<table>
<thead>
<tr>
<th>OPTION</th>
<th>DEFAULT VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>/INPUT=&lt;filespec&gt;</td>
<td>/INPUT=TRATEC.INP</td>
</tr>
<tr>
<td>/OUTPUT=&lt;filespec&gt;</td>
<td>/OUTPUT=&lt;input&gt;.OUT</td>
</tr>
<tr>
<td>/DATABASE=&lt;filespec&gt;</td>
<td>/DATABASE=TEKBASE.INP</td>
</tr>
<tr>
<td>/[NO]GRAPHICS [=filespec]</td>
<td>/NOGRAPHICS</td>
</tr>
<tr>
<td>/[NO]ECHO</td>
<td>/ECHO</td>
</tr>
<tr>
<td>/[NO]TCECHO</td>
<td>/NOTCECHO</td>
</tr>
<tr>
<td>/[NO]FLEETPRINT [=N]</td>
<td>/NOFLEETPRINT</td>
</tr>
<tr>
<td>/MAXITER=N</td>
<td>/MAXITER=50</td>
</tr>
</tbody>
</table>
/INPUT=<filespec> Filespec is the name of the input data file for the program. The format of this file is discussed in Section 4.0 below. This file should be prepared before invoking TRATEC. If no file type extension is given, a default extension of .INP is used. If /INPUT is not specified, a default value of TRATEC.INP is used.

/OUTPUT=<filespec> Filespec is the specification of the output file for TRATEC to write to. If no file-type extension is specified, a default value of .OUT is used. If /OUTPUT is not specified, the default output file name will be the same as that of the input data file, with the .OUT file type extension substituted.

/DATABASE=<filespec> Filespec is the specification for the technology data-base input file. The format of this file is discussed in Section 5.0 below. The file itself should be prepared before invoking TRATEC. If the file-type extension is not specified, a default value of .INP is used. If /DATABASE is not specified, a default file specification of TEKBASE.INP is used.

/[NO]GRAPHIC [=filespec>] This parameter turns on or off the production of a graphic output file. Filespec is the specification of the intermediate file to which graphic output is to be written. This file can then be displayed on any of the graphics output devices using the JCF's PLOT command. If the file-type extension is not specified, a default extension of .PLT is used. If filespec is not given, the default graphic output file name is the same as the input file name, with a file-type extension of .PLT. The default is /NOGRAPHIC.

/[NO]ECHO If /ECHO is specified, the contents of the input data file will be echoed to the output file as they are read, while if /NOECHO is specified, only input error messages will be written to the output. The default is /ECHO.

/[NO]TCECHO If /TCECHO is specified, the contents of the technology data base file will be echoed to the output file as they are read, while if /NOTCECHO is specified, only error messages will be written to the output. The default is
/NOTCECHO.NEWPAGE

COMMAND OPTION DESCRIPTIONS (CONTINUED)

/ [NO] FLEETPRINT [=N]
If specified, /FLEETPRINT causes intermediate data from
the simulation process to be printed out in selected
years. The absolute value of N give the interval (in
years) at which data are printed. If N is positivem,
the whole internal representation of the fleet structure
during the calculation is printed out (this produces a
great deal of output), while if N is negative, only a
sumary output is produced. If N is not specified, a
default value of -10 is used. /NOFLEETPRINT causes
fleet printing not to be done. The default is
/NOFLEETPRINT.

/ MAXITER=N
If specified, /MAXITER gives the maximum number of
iterations of the used-vehicle market simulation routine
which are permitted in any given year. The default is
MAXITER=50. Conditions requiring more iterations than
this are unusual, and the validity of the input data
should be checked before increasing this limit.
4.0 **FORMAT OF THE DATA INPUT FILE**

The data input file to the TRATEC model contains all of the model data and parameters except for data specifying the characteristics of the individual utilities. The input file is organized in groups of lines, with each group being separated from the other groups by one or more blank lines. Each group contains a list of parameters. Individual parameters are identified by their order in the list, i.e., parameter 1, parameter 2, and so forth. All of the lines in the group are concatenated together before being processed, so that the two groups:

```
parameter1 parameter2 parameter3
```

and

```
parameter1
parameter2
parameter3
```

are equivalent. The list of parameters is processed by a parsing routine which arranges them into a standard form, according to its own rules. This means that the user has considerable freedom in spacing and formatting the parameter list, so long as the order of the parameters is maintained. Section 4.1 below discusses the rules the parser uses to interpret the input.

The first parameter in each group must be the **group identifier**. This is a
character string which specifies the type of data being provided in the group. The program recognizes the following groups:

- MODEL
- CLASSES
- ECON
- FUELPRICE
- TOTVMT
- VMTDISTN
- SALES
- FLEET
- END

The format of each group is described in Sections 4.2 through 4.10 below.

One each of groups MODEL, CLASSES, ECON, FUELPRICE, TOTVMT, VMTDISTN, and END must be specified in the data file. One or more of groups SALES or FLEET may be specified as well. SALES and FLEET are different ways of specifying the initial fleet composition used by the model. The two groups are mutually exclusive; if any SALES group is included, no FLEET groups can be, and vice versa. The order of the groups in the file is not important, except that the MODEL group must be the first group in the file, the CLASSES group must be second, and the END group must be the last one in the file (any groups following the END group are ignored). The other groups can be placed in any order anywhere between the CLASSES and the END groups.
4.1 PARAMETER FORMATS AND PARSING

The parser interprets a parameter as being any contiguous string of characters other than blank, comma, asterisk (*), or quote ("), or quote (") in the input. Parameters are set off from each other by one or more blanks, or by any combination of zero or more blanks with a comma or asterisk. The end of a line in the input has the same effect as a single blank in separating parameters. Parameters containing imbedded blanks, commas, asterisks, or ends-of-line can be produced by enclosing the parameter in quotes, as in

"This is a very long parameter, which shows the use of quotation marks."

The quotation mark itself can be included in a string by doubling it, as in

"This string contains a "" mark."

Parameters are separated by any number of blanks, with or without an end-of-line (note that a wholly blank line, however, denotes the end of the group). They can also be separated by a comma, with or without blanks or ends-of-line. A succession of two or more commas in a row signifies one or more null parameters. Null parameters are parsed in the same way as a single blank.
Thus, the two inputs

\texttt{parameter1, , parameter4}

and

\texttt{parameter1 ** ** parameter4}

are yield the same result when parsed.

The asterisk (*) indicates a \textit{repeat count}. When it is used to separate two parameters, the first parameter must be interpretable by FORTRAN as a positive integer number. This number is then taken to be the number of repetitions of the parameter following the asterisk. The first parameter itself is not included in the list of parameters returned from the parser.

For instance, the input line

\texttt{parameter1, 4*parameter2}

is parsed in the same way as

\texttt{parameter1, parameter2, parameter2, parameter2, parameter2, parameter2}

This can save considerable typing when entering long lists of parameters which are all the same. The asterisk separating the two parameters may be preceded or followed by any number of blanks, or by an end-of-line. If a comma follows the asterisk without an intervening parameter, this is taken to mean that the parameter to be repeated is the null parameter.

The TRATEC program expects a parameter to be one of four different
possible types: character, real number, integer, or logical flag. A character parameter can contain any sequence of characters. Except in the titles, however, any alphabetic characters are converted to upper case, so that "parameter1", "PARAMETER1" and "PaRaMeTeR1" are all interpreted as "PARAMETER1". A real number parameter must contain a string which FORTRAN can interpret as being a real (floating point) number, and an integer parameter must contain a string which can be interpreted as a legal integer according to the rules of FORTRAN. If the input routines are unable to interpret the parameter according to the appropriate rules, they will print an error message and return the parameter as zero. Note that blanks and null parameters are legal for both real and integer numbers, since they are interpreted in FORTRAN as zeroes.

A logical flag parameter must contain a string from one of the following two groups: "Y", "YES", "T", "TRUE", ".T.", or ".TRUE.", all of which signify TRUE, or turning on the logical flag; or "N", "NO", "F", "FALSE", ".F." or ".FALSE.", all of which signify FALSE, or turning the flag off. Blanks and nulls are illegal for logical parameters.

The parser goes through the input, separating parameters into individual character strings and returning an ordered list of them to the input routine. The input routine then tries to interpret each string according to its expectation of the type of parameter that should be at each position in the list. If you forget and leave out one parameter in a group, or put in one too many, the input routine will be trying to interpret the subsequent parameters in the wrong way. This will probably
generate a lot of error messages. The input routines will also complain if they find too few parameters in a given group (but not if they find too many). The best way to locate errors of this type is to turn on the /ECHO or /TCECHO flags in the command line.
4.2 FORMAT FOR GROUP: MODEL

The **MODEL** group contains parameters specifying the basic setup of the model, such as the number of classes, the number of fuels, and the beginning and ending years. Because these data are required in order to interpret the data in the other groups, this group must be the first one in the file. Any errors in the specification of this group may also cause the succeeding groups to be misinterpreted, generating a great deal of error output.

The **MODEL** group takes six parameters in addition to the group identifier, in the following order.

```
MODEL <nclass>, <firstyr>, <presentyr>, <lastyr>, <nfuels>, <scflag>
```

The first parameter must be the group identifier, **MODEL**, which may be either lower or upper case. The other parameters are described on the following page.
### PARAMETER DEFINITIONS FOR GROUP: MODEL

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCLASS</td>
<td>integer</td>
<td>Number of vehicle classes included in the model (1 &lt; NCLASS &lt; 10).</td>
</tr>
<tr>
<td>FIRSTYR</td>
<td>integer</td>
<td>Number of the earliest model year to consider in modeling the vehicle fleet structure. This is the earliest year for which historical sales data are provided with the SALES group, or the earliest model year for which current fleet-structure data are provided using the FLEET group.</td>
</tr>
<tr>
<td>PRESENTYR</td>
<td>integer</td>
<td>Number of the present year. This is the first year for which the model will simulate the used-vehicle market, new-vehicle sales, etc. SALES and FLEET data must be provided from FIRSTYR to PRESENTYR - 1. PRESENTYR must be between FIRSTYR and LASTYR.</td>
</tr>
<tr>
<td>LASTYR</td>
<td>integer</td>
<td>Number of the last year to be covered by the model. The quantity (LASTYR - FIRSTYR) must be greater than zero, and less than 50.</td>
</tr>
<tr>
<td>NFUELS</td>
<td>integer</td>
<td>The number of different fuels to be considered in the model. Generally, this will be either 2 (gasoline and diesel) or 3 (gasoline, diesel, alcohol). NFUELS may not be greater than 3, and must be compatible with the FUELPRICE card, and with the fuel-consumption data in the technology database.</td>
</tr>
</tbody>
</table>
4.3 FORMAT FOR GROUP: CLASSES

The CLASSES group specifies each class of vehicles to be considered in the model, and specifies which technologies are to be considered available to each class. These data are needed in order to properly interpret the remaining input — thus, the CLASSES group must be the second group specified in the input file (after MODEL). The CLASSES group takes an indefinite number of parameters. The parameters are grouped together by class, as shown below, with the number of classes being equal to NCLASS.

CLASSES <classname1>, <nctech1>, <technamel1>, ... <technamen1>,
<classname2>, <nctech2>, <technamel2>, ... <technamen2>,
  ...  ...  ...  ...
<classnameN>, <nctechN>, <technamelN>, ... <technamenN>

The first parameter must be the group identifier, CLASSES, which may be either lower or upper case. The other parameters must be supplied in groups, where the number of groups is equal to NCLASS. The number of TECHNAMEs specified in each group must be equal to NTECH for that group.
PARAMETER DEFINITIONS FOR GROUP: CLASSES

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLASSNAME</td>
<td>character</td>
<td>Twenty-character descriptive identifier for this class.</td>
</tr>
<tr>
<td>NCTECH</td>
<td>integer</td>
<td>Number of competing technologies available in this class (1 &lt; NCTECH &lt; 4).</td>
</tr>
<tr>
<td>TECHNAME</td>
<td>character</td>
<td>Twenty-character descriptive identifier for each technology available in this class. The number of TECHNAMEs in each group must be equal to NCTECH for that group. TECHNAMEs must be unique to each class, and the total number of technologies for all classes must be less than or equal to 30. TECHNAME is matched against the technology identifiers in the technology data-base file, and a matching technology must be found or an error results.</td>
</tr>
</tbody>
</table>
4.4 FORMAT FOR GROUP: ECON

The ECON group specifies the values of economics-related parameters such as discount rates and new-vehicle premiums. Parameters are specified separately for each class of vehicles, since the economic values used in decision-making by (say) heavy truck buyers may be very different from those for buyers of (say) passenger cars. This group takes a number of parameters equal to \((5 \times \text{NCLASS})\) in addition to the group identifier.

\[
\text{ECON} <\text{discount}_1>, <\text{elasticity}_1>, <\text{beta}_1>, <\text{transcost}_1>, <\text{premium}_1>, \\
<\text{discount}_2>, <\text{elasticity}_2>, <\text{beta}_2>, <\text{transcost}_2>, <\text{premium}_2>, \\
\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \\
<\text{discount}_N>, <\text{elasticity}_N>, <\text{beta}_N>, <\text{transcost}_N>, <\text{premium}_N>
\]

The first parameter is the group identifier, ECON, which may be either lower or upper case. The other parameters must be supplied in groups, where the number of groups is equal to NCLASS.
PARAMETER DEFINITIONS FOR GROUP: ECON

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISCOUNT</td>
<td>real</td>
<td>Annual discount rate (in decimal) used by vehicle purchasers for this class in making purchase decisions. Apparent discount rates can range from 0.1–0.2 per year for heavy trucks to as much as 0.5 per year for passenger cars.</td>
</tr>
<tr>
<td>ELASTICITY</td>
<td>real</td>
<td>Negative of the own-price elasticity of demand for transportation services in this vehicle class. Demand for transportation is normally rather inelastic, so this will normally fall in the range from 0.1 to 0.5.</td>
</tr>
<tr>
<td>BETA</td>
<td>real</td>
<td>Beta parameter to use in the logit choice model for this class (See Weaver, 1985, section 4.4). The larger this value, the steeper the &quot;S&quot; curve of market-share versus cost advantage becomes.</td>
</tr>
<tr>
<td>TRANSOCOST</td>
<td>real</td>
<td>The equivalent cost (in money units) of the time, trouble, and risk to both the buyer and seller of selling a used vehicle. This should generally be about 0.02 to 0.10 of the typical cost of a new vehicle in the class. Increasing this value decreases the instability of the used-vehicle market, reducing computational costs.</td>
</tr>
<tr>
<td>PREMIUM</td>
<td>real</td>
<td>The equivalent value (in money units) of the extra benefits (in addition to transportation) which come from buying a new vehicle (rather than just any vehicle) in this class. These benefits include additional comfort, status, reliability, warranty service, reduced risk, etc.) This should typically be about 0.1 to 0.2 of the cost of a typical new vehicle in the class.</td>
</tr>
</tbody>
</table>
4.5 FORMAT FOR GROUP: FUELPRICE

The FUELPRICE group specifies the name of each of the types of fuel whose consumption is to be considered in the model, as well as the price per volume-unit (per gallon or per liter) of each fuel for each year covered by the model. The FUELPRICE group takes an indefinite number of parameters, depending on the value of NFUELS and whether or not social costs are to be considered.

```
FUELPRICE <fuelname1>, <fuelname2> ... <fuelnameN>, 
<year1>, <pfuel1>, [<spfuel1>], ... <pfuelN>, [<spfuelN>], 
<year2>, <pfuel1>, [<spfuel1>], ... <pfuelN>, [<spfuelN>],

... ...

<yearN>, <pfuel1>, [<spfuel1>], ... <pfuelN>, [<spfuelN>]
```

The first parameter is the group identifier, FUELPRICE, which may be either lower or upper case. The other parameters consist of the names of the fuels, followed by one or more groups specifying fuel prices for each fuel by year. As a convenience to the user, it is not necessary to specify data for all years. Data for missing years will be filled in by linear interpolation (where the missing year falls between two years for which data are specified) or by extending the data for the highest (lowest) year specified when the missing year falls above (below) the range of specified data.
### PARAMETER DEFINITIONS FOR GROUP: FUELPRICE

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUELNAME</td>
<td>character</td>
<td>A fifteen character descriptive identifier for each fuel. The number of FUELNAMEs must be equal to the number of fuels being considered, given by NFUELS. These fuel names should be consistent with the fuel consumption values specified in the technology database.</td>
</tr>
<tr>
<td>YEAR</td>
<td>integer</td>
<td>Number of the year (date) to which the fuel price data which follow apply. It is not necessary to specify data for all years covered by the model. If data for some years are not specified, they will be filled in by linear interpolation or extrapolation, as discussed above.</td>
</tr>
<tr>
<td>PFUEL</td>
<td>real</td>
<td>The market price (i.e. the actual cost to the consumer) per unit of volume (gallons or liters) for each fuel in year YEAR. The number of values for PFUEL for each year must be equal to NFUELS.</td>
</tr>
<tr>
<td>SPFUEL</td>
<td>real</td>
<td>The shadow price (the actual resource cost to society as a whole) for each fuel in year YEAR. This price may be greater or less than the corresponding PFUEL. If the social-cost computation flag is set, then SPFUEL must be specified, otherwise, it must not be.</td>
</tr>
</tbody>
</table>
4.6 FORMAT FOR GROUP: TOTVMT

The TOTVMT group specifies the total demand for transportation services (expressed as vehicle miles travelled or VMT) for each class of vehicles considered in the model and for each year. As discussed in Weaver (1985), the model adjusts these values to reflect changes due to the own-price elasticity of demand. Thus, the input values should reflect projected VMT demand data assuming present prices — they should not reflect changes in VMT demand due to changes in the cost of automotive transportation. The TOTVMT group takes an indefinite number of parameters, depending on the value of NCLASS.

```
TOTVMT <year1>, <vmt1>, <vmt2> ... <vmtN>
<year2>, <vmt1>, <vmt2> ... <vmtN>
:    :    :    :
:    :    :    :
<yearN>, <vmt1>, <vmt2> ... <vmtN>
```

The first parameter is the group identifier, TOTVMT, which may be either lower or upper case. The other parameters consist of one or more groups specifying total VMT in each class by year. As a convenience to the user, it is not necessary to specify data for all years. Data for missing years will be filled in by linear interpolation (where the missing year falls between two years for which data are specified) or by extending the data for the highest (lowest) year specified when the missing year falls above (below) the range of specified data.
**PARAMETER DEFINITIONS FOR GROUP: TOTVMT**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>YEAR</td>
<td>integer</td>
<td>Number of the year (date) to which the VMT demand data which follow apply. It is not necessary to specify data for all years covered by the model. If data for some years are not specified, they will be filled in by linear interpolation or extrapolation, as discussed above.</td>
</tr>
<tr>
<td>VMT</td>
<td>real</td>
<td>The total VMT demand (in vehicle-miles per year) for each class in year YEAR. The number of values given for VMT in each year must be equal to NCLASS.</td>
</tr>
</tbody>
</table>
4.7 FORMAT FOR GROUP: VMIDISTN

The VMIDISTN group specifies the parameters (mean and standard deviation) of the probability distribution function for annual mileage per vehicle in each class. The probability distribution function itself is assumed to be lognormal. The calculation and use of this function is discussed in Weaver (1985), Section 4.2. The VMIDISTN group takes a number of parameters equal to $2 \times NCLASS$, in addition to the group identifier.

VMIDISTN <vmtmean1>, <vmtstd1>, ... <vmtmeanN>, <vmtstdN>

The first parameter is the group identifier, VMIDISTN, which may be either lower or upper case. The other parameters must be supplied in groups of two each, where the number of groups is equal to NCLASS.

PARAMETER DEFINITIONS FOR GROUP: VMIDISTN

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMTMEAN</td>
<td>real</td>
<td>Mean annual mileage per year for vehicles in this class. This is taken to be invariant with time.</td>
</tr>
<tr>
<td>VMTSTD</td>
<td>real</td>
<td>Standard deviation of mileage per year for vehicles in this class.</td>
</tr>
</tbody>
</table>
The FLEET group specifies part of the initial fleet structure (the number of vehicles in use from each previous model year). This is used as the point of departure for the fleet simulation in the model. Each FLEET group specifies the fleet structure for one technology — thus, if FLEET is used, as many FLEET groups should appear in the input as there are vehicle technology types in the initial fleet. The initial fleet structure can also be specified using SALES, but the two types are not compatible. If any FLEET group is used, then no SALES group may be used, and vice versa.

The FLEET group takes a variable number of parameters, consisting of the technology name and the number of vehicles of that technology in the initial fleet for each model year from FIRSTYR to PRESENTYR - 1.

FLEET <techname>, <nveh1>, <nveh2> ... <nvehN>

The first parameter is the group identifier, FLEET, which may be either lower or upper case. The other parameters are described on the following page.
PARAMETER DEFINITIONS FOR GROUP: FLEET

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECHNAME</td>
<td>character</td>
<td>This is the twenty-character descriptive identifier for this technology. TECHNAME must match one of the technology names specified in the CLASSES group.</td>
</tr>
<tr>
<td>NVEH</td>
<td>real</td>
<td>The number of vehicles of model year M and using technology TECHNAME which are in the vehicle fleet as of the beginning of the present year. The total of NVEH for every model year and technology type in a given class should be equal to the total size of the vehicle fleet for that class.</td>
</tr>
</tbody>
</table>
4.9 FORMAT FOR GROUP: SALES

The SALES group specifies part of the historical sales record (the number of vehicles sold) for each previous model year. This is used to construct the initial fleet structure, which is used as the point of departure for the model. Each SALES group specifies the sales data for one technology — thus, if SALES is used, as many SALES groups should appear in the input as there are vehicle technology types in the initial fleet. The initial fleet structure can also be specified using FLEET, but the two types are not compatible. If any FLEET group is used, then no SALES group may be used, and vice versa.

The SALES group takes a variable number of parameters, consisting of the technology name and the number of vehicles sold of that technology for each year from FIRSTYR to PRESENTYR - 1.

SALES <techname>, <nveh1>, <nveh2> ... <nvehN>

The first parameter is the group identifier, SALES, which may be either lower or upper case. The other parameters are described on the following page.
PARAMETER DEFINITIONS FOR GROUP: SALES

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECHNAME</td>
<td>character</td>
<td>This is the twenty-character descriptive identifier for this technology. TECHNAME must match one of the technology names specified in the CLASSES group.</td>
</tr>
<tr>
<td>NVEH</td>
<td>real</td>
<td>The number of vehicles using technology TECHNAME which were sold (and entered the fleet) in year m.</td>
</tr>
</tbody>
</table>
4.10 FORMAT FOR GROUP: END

The **END** group signifies the end of the data input file. The program will not read beyond the **END** group — thus, for convenience, alternative or additional groups which are not desired in any given run can be "hidden" below the **END** group, and used in a later run by moving the **END** group downward. The **END** group takes no parameters except the group identifier. It has the form

```
END
```
5.0 FORMAT OF THE TECHNOLOGY DATA-BASE FILE

The technology data-base file is formatted and processed in the same way as the input data file described in the preceding chapter. All data are input in groups, where each group is set off from its neighbors by one or more blank lines. Each group consists of an ordered list of parameters, which are processed by the input parsing routines in exactly the same manner as parameters in the input data file. The nature of this processing is described in Section 4.1 above.

Unlike the input data file, the technology database file can have only two types of groups: technology description groups and the END group. The END group has the same function as in the input data file — it signals the end of the data in the file. Any group found in the technology data-base file is first checked to see if the first parameter is "END", and if so, reading stops. Otherwise, the group is assumed to be a technology description group, and the first parameter of the group is taken to be the name of the technology (this implies that no technology can be named END). The format of the technology specification group is shown below.

<technan TC>, <avgmiles>, <stdmiles>,
<yearl>, <cinitl>,<scinitl>,<cfixl>,<scfixl>,<caintl>,<scmaintl>,
<fuelecon1l> ... <fuelecon1M>
<year2>, <cinit2>,<scinit2>,<cfix2>,<scfix2>,<caint2>,<scmaint2>,
<fuelecon2l> ... <fuelecon2M>
  :  :  :  :  :
  :  :  :  :  :
<yearN>, <cinitN>,<scinitN>,<cfixN>,<scfixN>,<caintN>,<scmaintN>,
The first parameter is the technology name, which may be either lower or upper case. The second and third parameters describe the vehicle retirement function for the technology. These are followed by two or more groups specifying the costs and fuel consumption characteristics for vehicles of this technology type in each model year that this technology is available. As a convenience to the user, it is not necessary to specify data for all model years. Data for missing years will be filled in by linear interpolation from those years which are provided. However, data for both the first year and the last year in which this technology is available must be supplied. Specifically, the technology is assumed to be unavailable on the market before year1 or after yearN.

The meaning of each of the parameters for the technology description group is described on the following pages.
PARAMETER DEFINITIONS FOR THE TECHNOLOGY DESCRIPTION GROUP

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECHNAME</td>
<td>character</td>
<td>This is a twenty-character descriptive identifier for the technology. Before interpreting the rest of the group, the input routines look at TECHNAME and try to match it against the list of technologies specified with the CLASSES group in the input data file. If there is no match (i.e. this technology is not included in the present model) then the group is skipped.</td>
</tr>
<tr>
<td>AVGMILES</td>
<td>real</td>
<td>This is the average mileage at retirement for vehicles of this technology. It is used in constructing the probability distribution curve for retirement for the technology.</td>
</tr>
<tr>
<td>STDMILES</td>
<td>real</td>
<td>This is the standard deviation of mileage at retirement for this technology.</td>
</tr>
<tr>
<td>YEAR</td>
<td>integer</td>
<td>Year (date) to which the cost and fuel-consumption data which follow apply. It is not necessary to specify data for all years covered by the model. If data for some years are not specified, they will be filled in by linear interpolation, as discussed above. However, data for the first year and the last year that the technology is available must be included, since these dates are used to establish when the technology is available to the technology-choice model.</td>
</tr>
<tr>
<td>CINIT</td>
<td>real</td>
<td>The market price (i.e. the actual cost to the buyer) of a new vehicle of this technology in year YEAR. All purchasing decisions are assumed to be based on market prices.</td>
</tr>
<tr>
<td>SCINIT</td>
<td>real</td>
<td>The shadow price (the actual resource cost to society as a whole) for of a new vehicle of this technology of model year YEAR. This price may be greater or less than CINIT. Note that this price must be specified, whether or not the social-cost flag is set, since the technology database needs to be able to handle modeling with or without social costs.</td>
</tr>
</tbody>
</table>
PARAMETER DEFINITIONS FOR THE TECHNOLOGY DESCRIPTION GROUP (CONTINUED)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPIX</td>
<td>real</td>
<td>The fixed annual private cost (actual cost to the owner) of owning a vehicle of this technology bought in model year YEAR. This includes taxes, licence fees, insurance, etc.</td>
</tr>
<tr>
<td>SCFIX</td>
<td>real</td>
<td>The fixed annual cost to society of owning a vehicle of this technology in model year YEAR. This will usually include insurance and licenses (to the extent that these represent a recovery of costs) but not transfer payments such as taxes.</td>
</tr>
<tr>
<td>CMAINT</td>
<td>real</td>
<td>The average private cost for maintenance and related expenses per unit of distance travelled for a vehicle of this technology purchased in model year YEAR.</td>
</tr>
<tr>
<td>SCMAINT</td>
<td>real</td>
<td>The average social cost for maintenance and related expenses per unit of distance travelled for a vehicle of this technology purchased in model year YEAR.</td>
</tr>
<tr>
<td>FUELCON</td>
<td>real</td>
<td>The average fuel economy (in units of distance per unit of fuel volume) of vehicles of this technology purchased in model year YEAR, for each of the three types of fuel considered in the model (By default these are gasoline, diesel, and alcohol). Note that values must be specified for all possible types of fuel, not just the ones specified by NFUELS. If the vehicle does not use a particular kind of fuel, the corresponding parameter should be set to 0.0. Note that this facility allows the user to model vehicle technologies which use dual fuels, or fuel mixtures. A technology getting 30 miles per gallon of alcohol/gasoline mixture, for instance, might be modeled as getting 20 miles per gallon of gasoline, and 10 miles per gallon of alcohol.</td>
</tr>
</tbody>
</table>
Output from the program consists of a printed report and an optional series of graphic plots. The printed report consists of four components, of which three are optional. This report is produced on the output file specified in the command line, or on the default output file if none is specified. The three optional report components are a reproduction of the input data file (which is printed if /ECHO is specified in the command line), a reproduction of the technology data-base (printed if /TCECHO is specified), and a listing of the detailed structure of the fleet in selected years (printed if /FLEETPRINT is specified). The fourth component, a summary report of the results, is always produced.

The reproductions of the input data file and the technology data-base are self-explanatory. These options are useful primarily in checking a new data file for errors, or as a permanent record of the data and assumptions going into a particular run. The /FLEETPRINT option is less obvious. This option results in a listing of various intermediate variables for each class in selected years and (optionally) the detailed structure of the vehicle fleet. The fleet structure printout with this option is broken down by class, technology, model year, and mileage group. In addition, the new-vehicle price for each technology, the price adjustment factors, and the market price for each class and mileage group for the given year are reported. This option can generate a great deal of output, and the data are frequently only marginally interesting. However, it can
be very useful for verifying the correct operation of the program, and for identifying the cause of possible anomalies in the output.

The summary report section contains the normal output data from the model. It includes tables of total fuel consumption for each type of fuel in each year, and total cost and total variable cost of ownership and operation in each year. If the social-cost flag is set in the input, the totals are reported for both private (market) costs and social cost, with the latter calculated using the shadow prices provided in the input. In addition to the global totals, the summary report also includes totals for fuel consumption, total cost, and total variable cost for each vehicle class. The program also reports the total sales of vehicles using each technology in each class for each year, and the number of vehicles in the fleet using each technology in each class for each year.

Graphic output from the program consists of a series of plots, showing the total fuel usage and total usage of each type of fuel as functions of time, both for the entire vehicle fleet and for each individual class. In addition, plots showing the size and composition of the fleet by technology type are produced for each class.
7.0 HINTS ON USING THE TRATEC MODEL

The work involved in applying the TRATEC model to a particular problem can be divided into three major segments: assembling and verifying the input data, running the model, and analyzing and applying the results. In practice, this sequence may be repeated several times, as analysis of the output may indicate problems with the input data, requiring them to be modified and new outputs to be produced.

The importance of critically analyzing the model results and their applicability to the problem at hand cannot be stressed too highly. The TRATEC program, in common with every other computer model, cannot produce "truth". At best, it can only work out in elaborate detail the implications of the input data and of the assumptions which went into its design. The task and art of the computer modeler is to develop input data which, when combined with the algorithms of the model, give results that correspond sufficiently well with future reality. Predicting and evaluating the results of alternative policies — in transportation or in any other field — is fundamentally a human task. Mathematical or computer models such as the TRATEC program can only supply a rigorous structure for thinking; they cannot substitute for thought.

As with any model, the reasonableness of the results is critically dependent on the accuracy (or at least reasonableness) of the input data. The TRATEC model has been designed to use data which are (for the most
part) readily available, or for which a reasonable approximation can readily be estimated. Chapter 6 of Weaver (1985) provides an example of the development of a set of model input data for the case of Egypt. This should be reviewed before proceeding with serious modeling efforts using the TRATEC model.

The input data to the model can be divided into several categories, of which the most important are the technology characteristics, the size and age structure of the vehicle fleet, vehicle usage characteristics, and economic parameters. Chapters 3 and 6 of Weaver (1985) discuss general technological characteristics and the development of a specific technology database for Egypt. Technology characteristics are generally very similar from country to country, so that the Egyptian database (with some modifications to the cost and price data to reflect local conditions) should generally be applicable to a wide range of problems. This is probably largely true of the economic parameters developed for Egypt as well. Ideally, these parameters should be estimated by econometric means, using data for the specific country to be modeled. The requisite data, however, are seldom available, and the labor involved in any econometric study is large. Since precise values for the economic parameters are not critical to the model results, it is probably best to use reasonable estimates, and to carry out sensitivity tests on the more critical parameters.

Data on the size and composition of the motor-vehicle fleet are generally among the few reliable statistics available in developing nations. Data
on the age structure of the fleet may be less accessible, although in many cases a good approximation may be obtainable from a review of vehicle import records or vehicle license data. Data on vehicle sales year-by-year are usually also obtainable from the same sources, or from production records in those nations which have a domestic automotive industry. Estimates of total VMT are less accessible — generally, they rely on estimating the average VMT per vehicle in each class, and then multiplying by the number of vehicles in the fleet. If reasonably accurate data on fuel economy are available, this procedure can be checked by comparing the total VMT so calculated with total fuel use (because fuel is primarily imported, aggregate fuel consumption data are available in most nations).

The operation of the TRATEC model can consume substantial amounts of computer time. To economize on time, it is best to keep the number of competing technologies in each class small. If cost is a critical issue, it may be most efficient to model each class of vehicles separately, in order to work out any problems in the input data before combining the data for an integrated run. This will avoid repeated calculation of results for classes in which the input data have already been validated. It may also be desireable, at first, to restrict the range of time covered by the model, in order to reduce the amount of calculation.
8.0 TECHNICAL NOTES

This section contains technical notes on the program and its implementation which will be of interest primarily to the programmer attempting to adapt the program to another computer. It is not necessary to read or master the information herein in order to use the program. The ordinary non-programming user is advised to skip this section.

The TRATEC model is implemented as a computer program written in ANSI 1977 Standard FORTRAN. The program is presently configured to run on a Digital Equipment Corporation VAX-series computer, and the graphics output routines use subroutine calls which are unique to MIT's PENPLOT graphics library. However, machine-dependent coding has been minimized, so that the program could readily be converted to run on any other computer which supports the ANSI 1977 FORTRAN standard. At present, the coding makes use of the full ANSI 1977 Standard — neither the earlier 1966 standard nor the ANSI 1977 Subset Standard was sufficient for an efficient implementation of the model and its input routines. Although the VAX FORTRAN provides a number of extensions, the program coding has followed the standard closely, in order to minimize compatibility problems.

The major deviations from standard usage in the programming all involve the interface between the program and the operating system (VAX/VMS). The operations of opening and closing the various files used include some non-standard parameters in order to make efficient use of the VMS file
system. In addition, calls to VAX/VMS system service routines to retrieve the command line parameters and for logical-name translation are highly non-standard, and would need to be changed to adapt the program to another operating system. These calls are found in only two places: the main program and subroutine LOGNAM.

The major requirement for the full ANSI 1977 standard, as opposed to the subset, is in the free-format input routines. The mathematical routines making up the model itself are straightforward, and could be adapted to the ANSI 1977 Subset with minimal problems. Adaptation to the older 1966 standard or any of its numerous derivatives and extensions would be far more difficult, as the logic makes extensive use of the block IF and zero-iteration do loop features of the 1977 standard.

A copy of the FORTRAN code for the program is given in Appendix C of Weaver (1985), and a machine-readable version of the code may be available from the author or from the Technology Adaptation Program at MIT. The code is extensively self-documenting — thus, only a brief overview of the program and some comments on special features are given here.

Table 8.1 is a list of the FORTRAN modules used in the program, with a summary of what each one does. The main program module, TRATEC, serves as the main driver for the model. TRATEC also contains copies of every common block declaration used in the model, together with a data dictionary for each common block, specifying the name and function of each variable in common. Common block structures are uniform throughout the
### TABLE 8.1: FORTRAN PROGRAM MODULES FOR THE TRATEC MODEL

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAIN PROGRAM</strong></td>
<td></td>
</tr>
<tr>
<td>TRATEC</td>
<td>Main program: program driver, COMMON declarations, and data dictionary for all COMMON variables.</td>
</tr>
<tr>
<td><strong>INPUT ROUTINES</strong></td>
<td></td>
</tr>
<tr>
<td>READIN</td>
<td>Main driver for reading data-input file.</td>
</tr>
<tr>
<td>READTC</td>
<td>Main driver for reading technology database.</td>
</tr>
<tr>
<td>GETINP</td>
<td>Read raw input for one group and concatenate.</td>
</tr>
<tr>
<td>PARSER</td>
<td>Parse the raw input from GETINP.</td>
</tr>
<tr>
<td>DECODE</td>
<td>Decode a real parameter and check for errors.</td>
</tr>
<tr>
<td>IDECOD</td>
<td>Decode an integer parameter and check for errors.</td>
</tr>
<tr>
<td>CDECOD</td>
<td>Decode a character parameter and check for errors.</td>
</tr>
<tr>
<td>YDECOD</td>
<td>Decode a logical flag and check for errors.</td>
</tr>
<tr>
<td><strong>CALCULATION ROUTINES</strong></td>
<td></td>
</tr>
<tr>
<td>CALCL8</td>
<td>Main driver for the model calculation process.</td>
</tr>
<tr>
<td>PDISTN</td>
<td>Calculate mileage distribution for vehicle class.</td>
</tr>
<tr>
<td>RETSET</td>
<td>Set lookup tables for RETIRE and XLIFE.</td>
</tr>
<tr>
<td>RETIRE</td>
<td>Retainment function — percent not retiring.</td>
</tr>
<tr>
<td>XLIFE</td>
<td>Expected remaining vehicle life (in miles).</td>
</tr>
<tr>
<td>CSTVAR</td>
<td>Calculate annual variable costs by group/year.</td>
</tr>
<tr>
<td>EQUIV</td>
<td>Calculate annual equivalent cost factor.</td>
</tr>
<tr>
<td>LOGIT</td>
<td>Logit model of consumer choice.</td>
</tr>
</tbody>
</table>
TABLE 8.1: FORTRAN PROGRAM MODULES FOR THE TRATEC MODEL (CONTINUED)

**OUTPUT ROUTINES**

| REPORT | Print a summary report of the model results. |
| GRAFIT | Plot costs, fuel consumption and fleet structure. |

**UTILITY ROUTINES**

| UPPER | Convert character string to upper case. |
| LOWER | Convert character string to lower case. |
| ICHLNB | Find last non-blank character in a string. |
| ICHFNB | Find first non-blank character in a string. |
| IVVALUE | Translate character string to integer. |
| LOGNAM | Translate logical names through VMS calls. |
| LOOKUP | Find character string in an array. |
| NTRSEC | Find intersection point of two lines. |
| READDT | Read a technology record from the database. |
| VALUE | Translate character string to real number. |
| WRITET | Save a technology record in the database. |
| ZINTRP | Linear interpolation/extrapolation from a table. |
Machine-dependent code for the program is localized in a few routines — primarily TRATEC and LOGNAM, which (as noted above) contain calls to the VAX/VMS operating system. TRATEC also contains the file opening statements, and the data statements presetting default file names and flags. In addition to TRATEC and LOGNAM, subroutine LOGIT contains machine-dependent data, specifying the logarithms of the largest and smallest floating-point numbers representable by the machine.

Due to the widespread use of exponential functions, there is considerable possibility of floating-point underflow or overflow occurring during the calculations. Assuming reasonable input data, overflow is only a possibility in LOGIT, where it has been carefully guarded against. Underflows are possible in several routines, however, including PDISTN, LOGIT, and RETSET. Since these occur in the tail-ends of probability distributions, they are not significant, and can simply be ignored. If the machine in use responds strongly to underflows, however (e.g. by issuing an error message) and if this response cannot be overridden, then it will be necessary to add code to protect against underflow in RETSET and PDISTN.

As noted above, the graphics routines make use of the MIT/JCF PENPLOT function calls, and thus may not be compatible with other graphics libraries on other machines. In order to minimize the difficulties of adaptation, however, the use of PENPLOT's more sophisticated features has
been minimized. The routines which are used are basically lettering and line-drawing functions, which should be common to any graphics package.
APPENDIX B: TRATEC DATA FILES FOR THE EGYPT MODEL

B-1: Input Data File For The Base-Case Scenario

B-2: Automotive Technology Database
Appendix B: TRATEC Data Files For the Egypt Model

B-1: Input Data File for the Base-Case Scenario

MODEL 9, 1960, 1979, 2000, 2, YES
"EGYPT Transportation Model — Base-Case Scenario"
"Continue the Status Quo Through 2000"
"Units are kilometers/liters/1979 Egyptian pounds"

CLASSES
"Large Passenger Car", 2, "Std Large Gas Car", "Adv Large Gas Car"
"Taxicab", 2, "Std Gas Taxi", "Adv Gas Taxi"
"Light Truck", 2, "Std Gas Lt Truck", "Adv Gas Lt Truck"
"Large Bus", 2, "Std Heavy Bus", "Adv Heavy Bus"
"Small Truck", 3,"8-T Gas Truck","Std 8-T Diesel Truck","Adv 8-T Diesel Truck"
"Small Truck/Trailer", 2, "Std 20-T Truck/Trlr.", "Adv 20-T Truck/Trlr."
"Large Truck", 4, "Std 30-T Truck/Trlr.", "Std Semi-Trailer",
"Mod Semi-Trailer", "Adv Semi-Trailer"

ECON
0.25  0.30  0.00528  288  411
0.20  0.20  0.00206  909 1299
0.16  0.60  0.00256  682  487
0.25  0.20  0.00409  322  230
0.16  0.10  0.00112 1045 1045
0.12  0.10  0.00076 2065 2581
0.16  0.20  0.00191  790  790
0.16  0.20  0.00136 1053 1053
0.12  0.30  0.00088 1872 2340

FUELPRICE Gasoline, "Diesel Fuel"
1979  0.11,  0.198,  0.025,  0.198
1985  0.065,  0.115,  0.015,  0.122
1990  0.065,  0.133,  0.015,  0.141
2000  0.065,  0.179,  0.015,  0.190

TOTVMT
1979  2.061E9,  0.939E9,  4.950E9,  0.818E9,  0.388E9,  0.350E9,  1.325E9,
      0.265E9,  0.330E9
1983  3.298E9,  1.503E9,  7.850E9,  1.309E9,  0.549E9,  0.525E9,  1.728E9,
      0.346E9,  0.430E9
1987  5.015E9,  2.285E9, 11.975E9,  1.990E9,  0.711E9,  0.675E9,  2.131E9,
      0.426E9,  0.531E9
2000  10.718E9,  4.875E9,  25.475E9,  4.254E9,  1.357E9,  1.300E9,  3.664E9,
      0.733E9,  0.913E9

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Appendix B: TRATEC Data Files For the Egypt Model

B-I: Input Data File for the Base-Case Scenario

**VMIDISTN**
10277, 6680
10277, 6680
56420, 36673
24309, 15800
49846, 44861
49709, 44738
34777, 27821
50000, 43500
75000, 43500

**FLEET** "Std Small Gas Car" 10*4015 3865 5153 12884 24049 28559 28559
22117 17178 18037

**FLEET** "Std Large Gas Car" 10*1829 1761 2348 5870 10957 13011 13011
10076 7826 8218

**FLEET** "Std Gas Taxi" 10*1610 452 633 1447 10582 15014 17185 7507 9045 9768

**FLEET** "Std Gas Lt Truck" 10*75 248 124 248 373 1035 2566 3642 9271 15397

**FLEET** "Lgt. Gas Bus" 10*32 32 53 63 53 83 209 125 262 355

**FLEET** "Std Lgt. Diesel Bus" 10*130 126 211 253 211 330 835 498 1046 1418

**FLEET** "Std Heavy Bus" 10*141 316 476 476 476 489 970 970 970

**FLEET** "8-T Gas Truck" 10*320 376 204 376 327 294 702 784 564 792

**FLEET** "Std 8-T Diesel Truck" 10*1281 1503 817 1503 1307 1176 2810 3136 2254 3169

**FLEET** "Std 20-T Truck/Trlr." 10*171 294 203 283 305 345 825 441 362 537

**FLEET** "Std 30-T Truck/Trlr." 10*37 64 44 61 66 75 179 96 78 116

**FLEET** "Std Semi-Trailer" 10*10 481 153 23 74 153 408 611 459 787

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Appendix B: TRATEC Data Files For the Egypt Model
B-2: Automotive Technology Database

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## Appendix B: TRATEC Data Files For the Egypt Model
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### TRATEC Data Files For the Egypt Model

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<td>58162.00 46723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
</tr>
<tr>
<td>1985</td>
<td>20763.00 20275.00 3000.00 2755.00 0.0905 0.1226 0 1.78 0</td>
<td>46801.00 44633.00 4505.00 4105.00 0.1679 0.1913 0 1.45 0</td>
<td>58162.00 4505.00 4105.00 0.1679 0.1913 0 1.45 0</td>
<td>58162.00 46723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
</tr>
<tr>
<td>1990</td>
<td>20763.00 20275.00 3000.00 2755.00 0.0905 0.1226 0 1.78 0</td>
<td>46801.00 44633.00 4505.00 4105.00 0.1679 0.1913 0 1.45 0</td>
<td>58162.00 4505.00 4105.00 0.1679 0.1913 0 1.45 0</td>
<td>58162.00 46723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
</tr>
<tr>
<td>2000</td>
<td>20763.00 20275.00 3000.00 2755.00 0.0905 0.1226 0 1.78 0</td>
<td>46801.00 44633.00 4505.00 4105.00 0.1679 0.1913 0 1.45 0</td>
<td>58162.00 4505.00 4105.00 0.1679 0.1913 0 1.45 0</td>
<td>58162.00 46723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
<td>58162.00 4723.00 4505.00 4105.00 0.1679 0.1913 0 1.55 0</td>
</tr>
</tbody>
</table>

**END**
APPENDIX C: FORTRAN CODE FOR THE MODEL

Program TRATEC
Subroutine CALCL8
Function CDECOOD
Function CSTVAR
Function DECODE
Function EQUIV
Subroutine GETINP
Subroutine GRAFIT
Function ICHFINB
Function ICHLN
Function IDECOD
Subroutine LOGIT
Subroutine LOGNAM
Function LOOKUP
Function NTRSEC
Subroutine PARSER
Subroutine PDISTN
Subroutine READIN
Subroutine READT
Subroutine READTC
Function RETIRE
Subroutine RETSET
Function UPPER
Function VALUE
Function UPPER
Subroutine WRITET
Function XLIFE
Function YDECOOD
Function ZINSTRP
program tratec

*****************************************************************************

DEVELOPING COUNTRY TRANSPORTATION FUEL CONSUMPTION MODEL

Version 2.1

Version 1 Begun December 16, 1983
Version 2.0 Begun April 7, 1984
Completed January 8, 1985
Version 2.1 Modifications to cost calculation
February 9–18, 1985

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Phone: (303) 449-5515

*****************************************************************************

This version of the TRATEC model is documented in
"Automotive Technology Choice and Fuel Consumption in Egypt:
An Engineering-Economic Model"

Christopher S. Weaver
S.M. Thesis, Dept. of Mechanical Engineering
Massachusetts Institute of Technology, 1985

*****************************************************************************

***** SUMMARY OF THE ALGORITHM ****

The following is a brief summary of the algorithm. See the thesis
referred to above (especially chapters 4 and 5) for complete
documentation.

TRATEC is an engineering-economic model of automotive technology choice
and fuel consumption in developing countries. It is specifically
intended to be used in modelling the effects of possible price and
technology policy changes on fuel consumption — thus, it provides a
useful tool to developing-country policymakers in the transportation
type area. The model assumes that decision-makers choose technologies
"rationally", according to the technology which has the lowest
equivalent annual cost. The costs used are the "private" costs as seen
by the decision-maker. The model produces tables of vehicle purchases
by technology type by year, fuel consumption by fuel type and year, and
variable and total costs of operating the fleet, by user class and
class year. As an option, the model can also output the variable and total
c social costs as well, where these are different from the private costs, c but only private costs enter into the technology selection process.
c
The model takes two files as input: a data-base specifying the c characteristics of the available technologies, and an input file c describing the specific conditions to be modelled. The data-base is c provided with the program, and is not expected to be modified in most c applications (with the possible exception of price and social-cost c data, which may vary from country to country). The input data file c will normally be modified for each run of the model.
c
The model first obtains, parses, and decodes the parameters specified c on the command line, using VAX VMS utilities. These parameters c include the name of the input file, output file, graphics output file c (if any), and technology database file, as well as parameters c controlling whether intermediate results are printed and the c iteration limit on the market-simulation routine. The program c then reads and checks the input data file. If no errors were found c in the input, it then goes and reads the technology data-base file, c checking it for errors and copying it into a random-access data base c for use in the program. The program then calls subroutine CALCL8 to c carry out the actual modelling. Results from CALCL8 are printed by c subroutine REPORT, and may be displayed graphically as well (the c graphics option is not yet implemented).
c
CALCL8 is the main driver routine for the model itself. The vehicle c fleet is assumed to be divided into a number of generic "classes" of c vehicles, such as light-duty cars, heavy trucks, etc. Each class is c assumed to have relatively homogeneous economic characteristics, c available technologies, and so forth, as well as its own distribution c of annual VMT. The classes are further divided up in CALCL8 on the c basis of annual VMT, with the continuous VMT distribution being c discretized into a number of homogeneous mileage "groups". CALCL8 then c carries out a separate simulation of the market for new and used c vehicles in each mileage group in each year covered by the model. Used c vehicles are assumed to be traded within the class, but not outside it. c Vehicle owners at every point are assumed to make "rational" decisions c concerning which technology to buy, whether to keep their vehicle or c sell it to another group, and so forth. These decisions are modelled c by a logit function. The model keeps track of VMT accumulation, c retirements, sales, etc. Details of this process are discussed in the c thesis.
c
********** GLOBAL COMMON BLOCKS **********

compil-time parameters

These are used to set the dimensions of the data arrays.
Appendix C: FORTRAN Code For The Model
Program TRATEC

c IPNC — Maximum number of vehicle classes permitted in the model
c IPNF — Maximum number of fuel types permitted in the model
c IPNG — Maximum number of mileage groups permitted in the model
c IPNT — Maximum number of technology types in the database
C IPNTC — Maximum number of technology types per class
C IPNY — Maximum number of years covered by the simulation.
c IPNRT — Number of entries in the look-up table used in the
c vehicle retirement/expected life calculation.
c
parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
c
C C Common blocks /MODEL/ and /MODELc/ contain the basic model
c specifications, such as the title, the number of classes, and so on.
c
C NCLASS — Number of classes of vehicles to be considered
c NFUELS — Number of fuel types to be considered
c NSCOST — Number of cost types (social vs. private) to be
c considered. (Either 1 or 2).
c DSTART — Date of year 1 of the model
c DPRES — Date of the beginning year of the simulation (from DSTART
to DPRES, the model assumes it is working with user-supplied
c historical data.
c DEND — Date of ending year of the model
c NYSTRT — Number of the year in which simulation of retirement, used-
c vehicle sales, and so on is to begin.
c NYEND — Number of the year in which simulation is to end, equal to
total number of years included in the model.
c NYPRES — Number of the present year. The model assumes that we have
c vehicle sales data for all years earlier than this (if
SDFLAG = .TRUE.), or that we have the fleet_structure in
this year (SDFLAG = .FALSE.).
c NTCLAS — Number of technologies belonging to each class
c ITECH — Number of each technology for each class in the technology
data-base.
c TITLE — The name or title for this model, appears on reports, etc.
c CLSNAM — Descriptive name for each vehicle class, appears on reports
c FUELNM — Descriptive name for each type of fuel, appears on reports.
c
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend,
1 nypres, nfuels, nscost, ntclas(ipnc), itech(ipnt,ipnc)
character*ll title*80, clsnam*20, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
c
C C
C C Common blocks /SYSTEM/ and /SYSTEMc/ contain system data such as the
c names and unit number of the input and output files.
c
Appendix C: FORTRAN Code For The Model
Program TRATEC

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IUCMD</td>
<td>Unit number for interactive command I/O</td>
</tr>
<tr>
<td>IUIN</td>
<td>Unit number for batch input</td>
</tr>
<tr>
<td>IUDT</td>
<td>Unit number for printed output</td>
</tr>
<tr>
<td>IUOT</td>
<td>Unit number for the (formatted and sequential) technology data-base input file</td>
</tr>
<tr>
<td>IUDP</td>
<td>Unit number for the (unformatted and random I/O) technology data-base working file.</td>
</tr>
<tr>
<td>IUGR</td>
<td>Unit number for the graphics output file.</td>
</tr>
<tr>
<td>INFILE</td>
<td>File name for the batch input file (user supplied)</td>
</tr>
<tr>
<td>OUTFIL</td>
<td>File name for the printed output file (user supplied)</td>
</tr>
<tr>
<td>TCFILE</td>
<td>File name for the formatted technology data-base file (user supplied)</td>
</tr>
<tr>
<td>DBFILE</td>
<td>File name for the random-access technology file (system supplied).</td>
</tr>
<tr>
<td>GRFILE</td>
<td>File name for the graphics output file (user supplied).</td>
</tr>
</tbody>
</table>

parameter (iucmd=1, iuin=5, iuot=6, iuto=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /system/ infile, outfil, tcfile, dbfile, grfile

Common block /FLAGS/ contains system-wide event and status flags

<table>
<thead>
<tr>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDFLAG</td>
<td>Flag indicating that the initial fleet structure specified in XINIT is historical sales data, not base-year fleet.</td>
</tr>
<tr>
<td>GRAFIC</td>
<td>Flag indicating whether graphic output is desired.</td>
</tr>
<tr>
<td>CLSPRT</td>
<td>Flag indicating whether output is to be by classes or just grand totals.</td>
</tr>
<tr>
<td>SCFLAG</td>
<td>Flag indicating whether separate social-cost calculations are to be done and reported.</td>
</tr>
<tr>
<td>ECHO</td>
<td>Flag indicating whether the input data are to be echoed to the output file upon reading.</td>
</tr>
<tr>
<td>TCECHO</td>
<td>Flag indicating whether technology data-base is to be echoed to the output file upon reading</td>
</tr>
<tr>
<td>FLTPTRT</td>
<td>Flag indicating whether intermediate fleet structure data are to be printed in CALCL8.</td>
</tr>
<tr>
<td>INFLOPT</td>
<td>Interval (in years) between printings of the fleet structure if FLTPTRT is .TRUE.</td>
</tr>
<tr>
<td>NIMAX</td>
<td>Maximum number of iterations allowed in the used-vehicle market simulation in CALCL8.</td>
</tr>
</tbody>
</table>

logical sdflag, grafic, clsprt, scflag, echo, tcecho, fltptrt
common /flags/ sdflag, grafic, clsprt, scflag, echo, tcecho, fltptrt, inflopt, nimax

Common block /ECON/ contains data relevant to the economic calculations for each class.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| DISCNT   | The individual discount rates (in percent) used by
Appendix C: FORTRAN Code For The Model
Program TRATEC

purchasers of each class of vehicle. Corresponds to (rho)c in the model documentation

ELAST — Own-price elasticity of demand for transportation for each class of vehicles. Corresponds to (epsilon)c in model docs.

BETA — Beta parameter to the logit choice function for owners of each class of vehicle. Same as (Beta)c in model document.

CTRANS — Transaction costs for used-vehicle transactions in each class. Corresponds to (gamma)c in the model documentation.

PREMNV — New-vehicle premium for each class. Corresponds to (delta)c in the model documentation.

PFUEL — The fuel price for each class of fuel for each year. Corresponds to P(fuel)y,f,s in the model documentation. s = 1 for market price, s = 2 for shadow price.

common /econ/ discnt(ipnc), elast(ipnc), beta(ipnc), ctrans(ipnc), premnv(ipnc), pfuel(ipny,ipnf,2)

Common block /MILEAG/ contains user-input data on total VMT and VMT per vehicle for each class.

YRMBAS — Total nationwide VMT for each class of vehicles in each year at base-year prices. Corresponds to Q(tot) in model docs.

YRMILE — Total nationwide VMT demanded for each class of vehicles at actual prices, calculated from YRMBAS and elasticity. Equivalent to Q(tot') in the model documentation.

VMTAVG — Mean VMT per vehicle for each class, used for lognormal VMT distribution function. Corresponds to (mu)c in model docs.

VMTSTD — Standard deviation of VMT per vehicle for each class. corresponds to (sigma)c in the model documentation.

VMTGRP — Mean annual VMT per vehicle for each mileage group in the current class (calculated in PDISTN). common /mileag/ yrbas(ipny,ipnc), yrmile(ipny,ipnc),

vmtavg(ipnc), vmtstd(ipnc), vmtgrp(ipng)

Common blocks /TECH/ and /TECHC/ contain the data for all of the technologies which apply to a given class (covered by the subscript t' in the model documentation). There is one record for each vehicle technology type. These records are read in in the input data file, then stored in a random-access file, from which the records for a given class are retrieved when computation for that class begins.

NTECHN — Number of technologies defined (number of records in the technology data base)

NTECH — ID number for the technology (corresponds to subscript t in the model documentation).

NYTFST — Index number of year in which technology is first available

NTLST — Index number of last year in which technology is available
Appendix C: FORTRAN Code For The Model
Program TRATEC

FORTRAN Code For The Model
Program TRATEC

`CFIRST` — The initial capital cost for the technology for each year
`CFIXED` — Fixed cost per year for this technology, for each year.
`CMINT` — Maintenance cost per mile for the technology in each year
`FUCONS` — Fuel consumption per mile for the technology, for each type of fuel. Corresponds to F(spec)t,y,f in the model docs.
`RETAVG` — Average mileage at retirement for vehicles of this technology, used in calculating the retirement rate and expected life
`RESTD` — Standard deviation of mileage at retirement for this tech.
`TECHNM` — List of names of each technology, for use in looking it up.

```
common /tech/ ntechn, ntech(ipntc), nytst(ipntc),
1 nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)
```

Common block /FLEET/ contains the temporary results from simulating the composition of the vehicle fleet. (Mostly from CALCL8).

`ELX` — Number of vehicles in each element of the fleet for the current class and model year. Elements are divided by model year, mileage group, and technology (corresponds to X in model documentation)
`ELX2` — Alternate temporary array for X.
`XINIT` — Array to hold the initial fleet structure specified by the user. This may be either as historical sales or structure in the base year, depending on SDFLAG.
`ELT` — Average accumulated mileage per vehicle for the vehicles in each element of the fleet (corresponds to T in model docs)
`ELT2` — Alternate temporary array for T.
`PVNEW` — Array containing the "price" (annual cost per year in year of purchase) for new vehicles of each technology in each mileage group. Corresponds to P(vnew) in the model docs.
`PMKT` — Array containing the current guesses at the "market" price for transportation in each mileage group.
`XVOLD` — Array containing the number of vehicles in each mileage group in the quasi-equilibrium fleet calculated from the set of prices in PMKT.
`XVNEW` — Number of new vehicles required in each mileage group for the current values of PMKT and XVOLD.
`ZRFLAG` — Array of flags indicating whether the market price in this mileage group has had to be reduced below the new-vehicle price. If so, then the iteration must make the number of new vehicles required equal to zero, rather than just non-negative.

```
logical zrflag
common /fleet/ elx(ipntc,ipng,ipny), elx2(ipntc,ipng,ipny),
1 elt(ipntc,ipng,ipny), elt2(ipntc,ipng,ipny), pvnew(ipntc,ipng),
2 pmkt(ipng), xvold(ipng), xvnew(ipng), xinit(ipny,ipnt),
```

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Program TRATEC

zrflag(ipng)

Common block /RFUNCT/ contains tables of the cumulative probability distribution for retirement (as a function of mileage) and of the integral of \( P(x) \times x \, dx \), which is used in calculating the expected life. These are set in RETSET and used in RETIRE and XLIFE.

QRSTEP — Mileage increment between values in RETCP and RETCPQ (mileages start at zero and work up to 49 * QRSTEP)

RETCP — Values of the cumulative probability function for vehicle retirement as a function of mileage

RETCPO — Values of the integral of \( X \times Pr(X) \, dx \) from 0 to Q for each increment of Q

Common block /RESULTS/ contains the model results from CALCL8

FUEL — Total fuel consumption by year, fuel type, and class of vehicle. (Extra class contains total for all classes.)

OMCOST — Total fixed, operating, and maintenance costs for vehicles in each class in each year. Extra class contains total for all classes.

CPCOST — Total capital cost of new vehicles purchased in each class in each year. Extra class contains total for all classes.

FLEETV — Total (depreciated) value of vehicles in each class in each year. Extra class contains total for all classes.

TCOSTC — Total cash cost of vehicular transportation in each class in each year. Sum of OMCOST plus CPCOST.

DEPREC — Total depreciation in the vehicle fleet for each class and year. Calculated from difference of fleet value plus capital cost.

TCOSTA — Total cost of vehicular transportation in each class in each year, calculated on an accrual basis. Includes OMCOST plus depreciation.

FLEET — Total number of vehicles by year, vehicle class, and technology type as predicted by the model

SALES — Total sales of each technology type in each class in each year. (corresponds to \( S_{c,t,y} \) in model documentation).

Common /results/ fuel(ipnf,ipnc+1,ipny), omcost(ipnc+1,ipny,2),
1 cpcost(ipnc+1,ipny,2), fleetv(ipnc+1,ipny,2),
2 depreci(ipnc+1,ipny,2), tcostc(ipnc+1,ipny,2),
3 tcosta(ipnc+1,ipny,2), fleet(ipntc+1,ipnc,ipny),
4 sales(ipntc+1,ipnc,ipny)
Appendix C: FORTRAN Code For The Model
Program TRATEC

C ***** GLOBAL SYMBOL DEFINITIONS FOR SYSTEM SERVICES
C
include '($SSDEF)/NOLIST'
C ***** LOCAL VARIABLES
C
logical errflg, cmderr, qualif, qvalue
character cmdstr*256, char*l, cmdqul(10)*12, cmdval(10)*63
character temp*63
C ***** PRESET FLGS AND LIMITS **************************************************************************
C
data echo /.true./, tcecho / .true./, sdflag / .false./,
1 clsprt / .true./, grafic / .false./, fltprt / .false./,
2 infltp / 10 /, nimax / 50 /
data infile / ' ' /, outfil / ' ' /, tcfile / ' ' /, grfile / ' '/
C **********************************************************************
C BEGIN EXECUTION
C **********************************************************************
C
Open interactive input file and display banner
C
open (iucmd, file='SYS$OUTPUT', status='OLD', access='SEQUENTIAL',
1 form='FORMATTED')
write (iucmd,9000)
9000 format ('0 ***** TRATEC Transportation Fuel Consumption ',
1 'Model V2.1 *****')
C
Call system service to get the command line, and check the result
C
code to make sure its normal.
C
ireslt = lib$getforeign (cmdstr)
if (ireslt.ne. ss$normal) then
   write (iucmd,9010)
9010 format ('0***** ERROR RETRIEVING COMMAND PARAMETERS ****')
   stop 'COMMAND LINE ERROR'
endif
nchcmd = len (cmdstr)
if (nchcmd .eq. 0) then
cmdstr = ' '
nchcmd = 1
endif
C
*** Parse the command string into qualifiers and qualifier values
C (qualifiers are denoted by slashes, values by equal signs)
C
qualif = .false.
qvalue = .false.
qual = 0
nchv = 0
do 50 nch = 1, nchcmd
   char = cmdstr(nch:nch)
   ...
if (char .eq. '/') then
  qualif = .true.
  qvalue = .false.
  nqual = nqual + 1
  nchv = 0
  cmdqul(nqual) = ' ' 
  cmdval(nqual) = ' '
elseif (char .eq. '=') then
  if (qualif) then
    qualif = .false.
    qvalue = .true.
    nchv = 0
  endif
elseif (char .eq. ' ') then
  endif
else
  if (qualif) then
    nchv = nchv + 1
    if (nchv .le. 12) cmdqul(nqual)(nchv:nchv) = char
  elseif (qvalue) then
    nchv = nchv + 1
    if (nchv .le. 80) cmdval(nqual)(nchv:nchv) = char
  endif
endif
50 continue

Loop over the Command-Line Qualifiers, Taking Appropriate Action for Each

do 100 nq = 1, nqual
  if (cmdqul(nq)(1:4) .eq. 'INPU') then
    if (cmdval(nq) .ne. ' ') infile = cmdval(nq)
  elseif (cmdqul(nq)(1:4) .eq. 'OUTP') then
    if (cmdval(nq) .ne. ' ') outfile = cmdval(nq)
  elseif (cmdqul(nq)(1:4) .eq. 'DATA') then
    if (cmdval(nq) .ne. ' ') tcfile = cmdval(nq)
  elseif (cmdqul(nq)(1:4) .eq. 'GRAP') then
    if (cmdval(nq) .ne. ' ') grfile = cmdval(nq)
    grafic = .true.
  elseif (cmdqul(nq)(1:4) .eq. 'NOGR') then
    grafic = .false.
  elseif (cmdqul(nq)(1:4) .eq. 'ECHO') then
    echo = .true.
  elseif (cmdqul(nq)(1:4) .eq. 'NOBC') then
    echo = .false.
  elseif (cmdqul(nq)(1:4) .eq. 'TCEC') then
    tcecho = .true.
  elseif (cmdqul(nq)(1:4) .eq. 'NOTC') then
    tcecho = .false.
  elseif (cmdqul(nq)(1:4) .eq. 'FLEE') then
    fltprt = .true.
    if (cmdval(nq) .ne. ' ') infltp = ivalue(cmdval(nq),errflg)
  endif
if (errflg) then
Program TRATEC

write (iucmd,9100) cmdval(nq)(l:40)
format ('0 ***** ERROR — Bad integer value: ',a)
cmderr = .true.
endif
elseif (cmdqul(nq)(l:4) .eq. 'NOFL') then
fltprt = .false.
elseif (cmdqul(nq)(l:4) .eq. 'MAXI') then
  if (cmdval(nq) .ne. ' ') nimax = ivalue(cmdval(nq),errflg)
  if (errflg) then
    write (iucmd,9100) cmdval(nq)(l:40)
cmderr = .true.
  endif
else
  write (iucmd,9110) cmdqul(nq)
9110 format('0 ***** ERROR — Unrecognized command qualifier: ',a)
cmderr = .true.
endif
100 continue
if (cmderr) stop 'BAD COMMAND LINE'

*** Open all the files

Input file
if (infile .eq. ' ') then
  infile = 'TRATEC.INP'
else
  call lognam (infile,temp,errflg)
  if (errflg) stop 'ERROR TRANSLATING INPUT FILE'
  np = index (temp,'.') - 1
  if (np .le. 0) then
    np = ichlnb (temp)
    infile = temp(l:np) // '.INP'
  else
    infile = temp
  endif
endif
open (iuin,file=infile,status='OLD',access='SEQUENTIAL',
form='FORMATTED',readonly)

Output file
if (outfile .eq. ' ') then
  np = index (infile,'.') - 1
  if (np .le. 0) np = ichlnb (infile)
  outfile = infile(l:np) // '.OUT'
else
  call lognam (outfile,temp,errflg)
  if (errflg) stop 'ERROR TRANSLATING OUTPUT FILE'
  np = index (temp,'.') - 1
  if (np .le. 0) then
    np = ichlnb (temp)
    outfile = temp(l:np) // '.OUT'
else
outfil = temp
endif
endif
open (iuot, file=outfil, status='UNKNOWN', access='SEQUENTIAL',
1 form='FORMATTED')

c

c Graphic output file

c
if (grafic) then
if (grfile .eq. '') then
np = index (infile,'.' ) - 1
if (np .le. 0) np = ichlnb (infile)
grfile = infile(l:np) // '.PLT'
else
call lognam (grfile,temp,errflg)
if (errflg) stop 'ERROR TRANSLATING GRAPHIC FILE'
np = index (temp,'.' ) - 1
if (np .le. 0) then
np = ichlnb (temp)
grfile = temp(l:np) // '.PLT'
else
grfile = temp
endif
endif
open (iugr, file=grfile, status='UNKNOWN', access='SEQUENTIAL',
1 form='FORMATTED', carriagecontrol='LIST')
endif

c

c Technology data-base file

c
if (tcfile .eq. '') then
tcfile = 'TEKBASE.INP'
else
call lognam (tcfile,temp,errflg)
if (errflg) stop 'ERROR TRANSLATING TECHNOLOGY FILENAME'
np = index (temp,'.' ) - 1
if (np .le. 0) then
np = ichlnb (temp)
tcfile = temp(l:np) // '.INP'
else
tcfile = temp
endif
endif
open (iutc, file=tcfile, status='OLD', access='SEQUENTIAL',
1 form='FORMATTED', readonly)

c

c Random-access file for storing technology data.

c
dbfile = 'XTRATEC.TDB'
irecl = 5 + ipny * (6 + ipnf)
open (iudb, file=dbfile, form='UNFORMATTED', recl=irecl,
1 access='DIRECT', status='NEW')
c *** Go and read the input data file from the disk.
c
    write (iucmd,9690)
9690 format ('0 ***** BEGIN READING INPUT DATA FILE')
call readin (errflg)
if (errflg) then
    write (iucmd,9700)
9700 format ('0 ***** ERROR READING INPUT DATA FILE /
1 '***** PROGRAM ABORTED *****')
    stop 'TRATEC ABORT 1'
endif

c *** Go and read the technology data base.
c
    write (iucmd,9790)
9790 format ('0 ***** BEGIN READING TECHNOLOGY DATABASE')
call readtc (errflg)
if (errflg) then
    write (iucmd,9800)
9800 format ('0 ***** ERROR(S) READING TECHNOLOGY DATA-BASE /
1 '***** PROGRAM ABORTED *****')
    stop 'TRATEC ABORT 2'
endif

c *** Call CALCL8 to carry out the actual calculations.
c
    write (iucmd,9850)
9850 format ('0 ***** BEGIN CALCULATING THE MODEL')
call calc18

c *** Call REPORT to print the results
c
    write (iucmd,9860)
9860 format ('0 ***** PRINTING REPORT')
call report

c *** Call GRAFIT to plot the results
c
    if (grafic) call grafit

End of program — close files and quit

close (iudb,status='DELETE')
stop 'TRATEC V2.1 — Normal Termination.'
end
subroutine calcl8

C **********************************************************************
C This is the master driver subroutine for the combined fleet
C composition and fuel consumption models. It is called from the
C main program after all model parameters and input data have been
C set (model specifications, vehicle technical data, economic data,
C starting fleet composition, etc. etc.) This subroutine calculates
C the total number of vehicles, the age distribution, and the fraction
C using each type of technology for each class of vehicles in each
C year, then calculates total fuel consumption in each class.
C **********************************************************************

C COMPUTATIONAL ALGORITHM

C The algorithm is fully described and discussed in C.S. Weaver (1985)
C (Masters thesis in Mechanical Engineering, M.I.T.) A condensed
C summary is also given in the comments to the main program.

C **********************************************************************

C ***** Global Common Blocks

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend,
nypres, nfuels, nscost, ntclas(ipnc), itech(ipnt,ipnc)
character*11 title*80, clsnam*28, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
parameter (iucnd=l, iuin=5, iuot=6, iutc=1, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systarc/ infile, outfil, tcfile, dbfile, grfile
logical sdflag, grafic, clsprt, scflag, echo, tcecho, fltprt
common /flags/ sdflag, grafic, clsprt, scflag, echo, tcecho,
fltprt, infiltp, nmax
common /econ/ discnt(ipnc), elast(ipnc), beta(ipnc),
ctrans(ipnc), premnv(ipnc), pfuel(ipny,ipnf,2)
common /mileag/ yrmbas(ipny,ipnc), yrmile(ipny,ipnc),
vmtavg(ipnc), vmtstd(ipnc), vmtgrp(ipng)
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc),
nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
retstd(ipntc)
character technm*20
common /techc/ technm(ipnt)
logical zrflag
common /fleet/ elx(ipntc,ipng,ipny), elx2(ipntc,ipng,ipny),
elt(ipntc,ipng,ipny), elt2(ipntc,ipng,ipny), pvnew(ipntc,ipng),
pnkt(ipng), xvold(ipng), xvnew(ipng), xinit(ipny,ipnt),
zrflag(ipng)
common /rfunct/ qrstep(ipntc), retcp(ipnrt,ipntc),
retcpq(ipnrt,ipntc)
common /reslts/ fuel(ipnf,ipnc+1,ipny), omcost(ipnc+1,ipny,2),
Subroutine CALCL8

1 cpcost(ipnc+1,ipny,2), fleetv(ipnc+1,ipny,2),
2 deprec(ipnc+1,ipny,2), tcostc(ipnc+1,ipny,2),
3 tcosta(ipnc+1,ipny,2), fleet(ipntc+1,ipnc,ipny),
4 sales(ipntc+1,ipnc,ipny)

c ***** Function Declarations

c logical ntrsec

c ***** Local Variables and Arrays

c logical flag, convrg, print
dimension cftenp(2), cmtemp(2), u(ipng+1), v(ipng+1),
vtemp(ipnf), adjust(ipntc), adjf(ipntc), delta(ipng),
2 pmfrst(ipng), oldfac(ipng), elxtot(ipng), elttot(ipng)

c **************************************************

Begin Execution

C**************************************************

C **** INITIALIZE VARIABLES AND ARRAYS BEFORE ENTERING LOOP *****

C Zero out fuel consumption, fleet size, cost, and sales totals  

do 90  ny = 1, ipny
   do 20  nc = 1, ipnc + 1
      do 10  nf = 1, ipnf
         fuel(nf,nc,ny) = 0.0
      10 continue
   do 15  ns = 1, 2
      omcost(nc,ny,ns) = 0.0
      cpcost(nc,ny,ns) = 0.0
      fleetv(nc,ny,ns) = 0.0
   15 continue
20 continue
   do 40  nc = 1, ipnc
      do 30  nt = 1, ipntc + 1
         fleet(nt,nc,ny) = 0.0
         sales(nt,nc,ny) = 0.0
      30 continue
40 continue
   do 60  ng = 1, ipng
      do 50  nt = 1, ipntc
         elx(nt,ng,ny) = 0.0
         elx2(nt,ng,ny) = 0.0
         elt(nt,ng,ny) = 0.0
         elt2(nt,ng,ny) = 0.0
      50 continue
60 continue
90 continue

C Calculate fraction of total population falling into each mileage group

gfrac = 1.0 / float (ipng)
Subroutine CALCL8

C Set starting year depending on the value of SDFLAG. If
C SDFLAG is .TRUE., data in XINIT are annual sales, and we must calculate
C fleet structure at the beginning, thus start the simulation at DSTART.
C Otherwise, the data in XINIT give the fleet structure as of DPRES - 1,
C so start the simulation at DPRES.
C
     if (sdflag) then
       nystrt = 1
     else
       nystrt = nypres
     endif

C******************************************************************************
C Loop Over Each Class, Setting Up, Then Calculating Fleet
C Composition, VMT, and Fuel Consumption in Each Year
C******************************************************************************
C
     do 1000 ncls = 1, nclass

C Set up characteristics for the technologies applicable to this class
C
     ntc = ntclas(ncls)
     do 100 nt = 1, ntc
       call readt (itech(nt,ncls), nt)
     100 continue

C Display progress to command file
C
     write (iucmd,1010) ncls, clsnam(ncls)
     1010 format ('8',5x,'*** BEGIN SIMULATION FOR CLASS ',i2,' : ',a)

C Call PDISTN to calculate mean annual VMT per vehicle for each mileage
C group from VMTAVG and VMTSTD values for this class.
C
     call pdistn(ncls)

C Call RETSET to construct tables of the cumulative probability function
C for retirement for each vehicle technology. These are used by RETIRE
C and XLIFE inside the loop.
C
     call retset(ncls)

C Zero out the fleet structure arrays.
C
     do 150 ny = 1, nyend
       do 140 ng = 1, ipng
         do 130 nt = 1, ntc
           elx(nt,ng,ny) = 0.0
           elt(nt,ng,ny) = 0.0
         130 continue
       140 continue
     150 continue
c If SDFLAG is false, the data in XINIT for this class give the fleet
structure in the initial year of the model. Set these up.
c
if (.not. sdflag) then
  nyr = nystrt - 1
  do 180 ny = 1, nyr
    age = float(nystrt - ny) - 0.5
    do 170 nt = 1, ntc
      ntr = itech(nt, ncls)
      temp = xinit(ny, ntr) * gfrac
      do 160 ng = 1, ipng
        elx(nt, ng, ny) = temp
        elt(nt, ng, ny) = age * vmtgrp(ng)
        xmi = xlife (nt, elt(nt, ng, ny))
        do 155 ns = 1, nscost
          fleetv(ncls, nyr, ns) = fleetv(ncls, nyr, ns) +
          xmi * cfirst(ny, nt, ns) / retavg(nt) *
          elx(nt, ng, ny)
        155 continue
      160 continue
    170 continue
  180 continue
endif

c Initialize OLDFACT, the array of adjustment factors to use for the
market price, to 1.0 as the initial guess.
c
do 190 ng = 1, ipng
  oldfac(ng) = 1.0
190 continue

-----------------------------------------------

Loop Over Each Year, Simulating Mileage Accumulation, Vehicle
Retirement, Used-Vehicle Sales, And New-Vehicle Purchases

nyold = 1
do 950 nyr = nystrt, nyend

*** Calculate retirements, then add one year's mileage to each element
of the current fleet. Keep track of the oldest year for
which there are any surviving vehicles in the fleet.

do 220 ny = nyr - 1, nyold, -1
  do 210 nt = 1, ntc
    do 200 ng = 1, ipng
      if (elx(nt, ng, ny) .ne. 0.0) then
        temp = retire (nt, elt(nt, ng, ny), vmtgrp(ng))
        elx(nt, ng, ny) = elx(nt, ng, ny) * temp
      endif
    200 continue
  210 continue
Subroutine CALCL8

220 continue
nyold = nyoldx

*** Calculate the total annual cost of new vehicles of each technology
when purchased in the current year. Set this in PVNEW.

do 350 nt = 1, ntc
  if (nyr >= nytfst(nt) .and. nyr <= nytlst(nt)) then
    do 320 ng = 1, ipng
      xy = xlife (nt, 0.0) / vmtgrp(ng)
      df = equiv (discnt(ncls), xy)
      pvnew(nt,ng) = (cfirst(nyr,nt,l)-preann(ncls)) * df
      temp = cstvar (nt,nyr,nyr,ng)
      pvnew(nt,ng) = pvnew(nt,ng)+cfixed(nyr,nt,l) + temp
    320 continue
  else
    do 340 ng = 1, ipng
      pvnew(nt,ng) = 1.e6
    340 continue
  endif
350 continue

*** Used-Vehicle Market Simulation ***

Set up to enter the iterative simulation: set initial values for PMKT
for each mileage group to the minimum value of PVNEW for that group.
Save the original value of the market price in PMFRST, then adjust
the guess at the original market price by the adjustment factors that
worked for last year.

nlast = 0
niter = 1
do 410 ng = 1, ipng
  zrflag(ng) = .false.
  pmkt(ng) = 1.e6
  do 400 nt = 1, ntc
    if (pvnew(nt,ng) < pmkt(ng)) pmkt(ng)=pvnew(nt,ng)
  400 continue
if (pmkt(ng) < 0.99e6) pause 'CALCL8 ERROR 1'
  pmfrst(ng) = pmkt(ng)
  pmkt(ng) = pmkt(ng) * oldfac(ng)
410 continue

Begin the iterative portion of the used-vehicle market simulation

do 510 nt = ntc
  do 520 ng = 1, ipng
    pvkt(ng) = pvnew(nt,ng)
  520 continue
  do 530 ny = nyold, nyr - 1
    do 520 ng = 1, ipng
      pvkt(ng) = pvkt(ng) * oldfac(ng)
    520 continue
  530 continue

Zero out the alternate fleet array

do 550 ny = nyold, nyr - 1
do 520 ng = 1, ipng
  do 510 nt = 1, ntc

Subroutine CALCL8

elx2(nt,ng,ny) = 0.0
elt2(nt,ng,ny) = 0.0

510 continue
520 continue
530 continue

*** Begin looping over each model year for each mileage group, calculating
the utility to the owner of keeping the vehicle, scrapping it, and
selling it to each of the other mileage groups.

do 590 nt = 1, ntc
  iyl = max (nyold, nytfst(nt))
  iy2 = min (nyr-l, nytlst(nt))
  do 580 ny = iyl, iy2
     do 570 ngown = 1, ipng
        if (elx(nt,ngown,ny) .le. 0.0) go to 570
     enddo
     tmi = elt(nt,ngown,ny)
     xmi = xlife(nt, tmi)
     xyown = xmi / vmtgrp(ngown)
     eqown = equiv (discnt(ncls), xyown)
     do 540 ng = 1, ipng
        if (ng .eq. ngown) then
          u(ng) = cstvar(nt,nyr,ny,ng)+cfixed(ny,nt,l)
        else
          xy = xmi / vmtgrp(ng)
          eqf = equiv (discnt(ncls), xy)
          price = (pmkt(ng) - cstvar(nt,nyr,ny,ng)
                   - cfixed(ny,nt,l)) / eqf - ctrans(ncls)
          u(ng) = pmkt(ngown) - price * eqown
        endif
     enddo
     u(ipng+l) = pmkt(ngown)
     call logit (u,v,ipng+l,ncls)
   enddo
570 continue
580 continue
590 continue

*** Begin looping over each model year for each mileage group, calculating
the utility to the owner of keeping the vehicle, scrapping it, and
selling it to each of the other mileage groups.

do 590 nt = 1, ntc
  iyl = max (nyold, nytfst(nt))
  iy2 = min (nyr-l, nytlst(nt))
  do 580 ny = iyl, iy2
     do 570 ngown = 1, ipng
        if (elx(nt,ngown,ny) .le. 0.0) go to 570
     enddo
     tmi = elt(nt,ngown,ny)
     xmi = xlife(nt, tmi)
     xyown = xmi / vmtgrp(ngown)
     eqown = equiv (discnt(ncls), xyown)
     do 540 ng = 1, ipng
        if (ng .eq. ngown) then
          u(ng) = cstvar(nt,nyr,ny,ng)+cfixed(ny,nt,1l)
        else
          xy = xmi / vmtgrp(ng)
          eqf = equiv (discnt(ncls), xy)
          price = (pmkt(ng) - cstvar(nt,nyr,ny,ng)
                   - cfixed(ny,nt,1l)) / eqf - ctrans(ncls)
          u(ng) = pmkt(ngown) - price * eqown
        endif
     enddo
     u(ipng+l) = pmkt(ngown)
     call logit (u,v,ipng+l,ncls)
   enddo
570 continue
580 continue
590 continue
**Appendix C: FORTRAN Code For The Model**

**Subroutine CALCL8**

```fortran
    c
    c *** Add up total vehicles in each group
    c
    xvtotl = 0.0
    do 610 ng = 1, ipng
        xvold(ng) = 0.0
        do 605 ny = nyold, nyr - 1
            do 600 nt = 1, ntc
                xvold(ng) = xvold(ng) + elx2(nt,ng,ny)
            600 continue
            605 continue
            xvtotl = xvtotl + xvold(ng)
    610 continue

    c *** Calculate average price of transportation and transportation demand
    c using elasticity data. (If NYR is before the present year,
    c YRMBAS contains historical data, which are not adjusted. If it is
equal to present year, we must save the average price/mile for
c elasticity calculations, and elasticity adjustment is 1). Then
calculate number of vehicles needed to fill that demand. If NYR
is before NYPRES, jimmy the number of vehicles to make the sales
c figure come out right.

    pavg = 0.0
    do 620 ng = 1, ipng
        pavg = pavg + pmkt(ng)
    620 continue
        pavg = pavg * gfrac / vmtavg(ncls)
    if (sdflag .and. nyr .lt. nypres) then
        yrmile(nyr,ncls) = yrmbas(nyr,ncls)
        xvneed = xvtotl
        do 625 nt = 1, ntc
            ntr = itech(nt,ncls)
            xvneed = xvneed + xinit(nyr,ntr)
        625 continue
        xvneed = xvneed * gfrac
    elseif (nyr .eq. nypres) then
        pbase = pavg
        yrmile(nyr,ncls) = yrmbas(nyr,ncls)
        xvneed = yrmile(nyr,ncls) / vmtavg(ncls) * gfrac
    else
        elast = (pbase / pavg) ** elast(ncls)
        yrmile(nyr,ncls) = yrmbas(nyr,ncls) * elast
        xvneed = yrmile(nyr,ncls) / vmtavg(ncls) * gfrac
    endif

    c *** XVNEED is the total number of vehicles needed in each group to meet
    c demand. Compare with number of used vehicles in each group and
calculate number of new vehicles needed in each group. If
all values are positive at new-vehicles prices, we have converged,
otherwise, we must iterate, forcing the purchases in those groups
where market price is below new-vehicle price to zero (within a
tolerance of 3%).
```
Subroutine CALCL8

tol = max (xvneed * .03, 1.0)
convrg = .true.
do 630 ng = 1, ipng
   xvnew(ng) = xvneed - xvold(ng)
zrflag(ng) = (xvnew(ng) .le. 0.0) .or. 
     (pmkt(ng) .lt. pmfrst(ng))
1   if (zrflag(ng)) then
      if (abs(xvnew(ng)) .gt. tol) then
         convrg = .false.
      else
         xvnew(ng) = 0.0
      endif
   endif
630  continue

c *** If we have converged, calculate new values of OLDFAC for use next, 
c year, then copy ELX2 and ELT2 to ELX and ELT, and escape from 
c the used-vehicle market simulation loop. (Note that ELT2 contains 
c the weighted sum of vehicle mileages, which must be divided 
c by ELX2 to give the average mileage per vehicle for ELT).
c
   if (.not. convrg) go to 660
   do 635 ng = i, ipng
      oldfac(ng) = pmkt(ng) / pmfrst(ng)
   635  continue
   do 650 ny = 1, nyr - 1
      do 645 ng = 1, ipng
         do 640 nt = 1, ntc
            elx(nt,ng,ny) = elx2(nt,ng,ny)
            if (elx2(nt,ng,ny) .eq. 0.0) then
               elt(nt,ng,ny) = 0.0
            else
               elt(nt,ng,ny) = 
               elt2(nt,ng,ny) / elx2(nt,ng,ny)
            endif
      640 continue
   645 continue
   650 continue
   go to 700

c *** Otherwise, adjust the market prices and try again. Prices are 
c adjusted one group at a time, taking the group with the largest 
c deviation from zero each time, and guessing at the correct 
c market price using the secant rule.
c
   660 continue
   niter = niter + 1
   if (niter .gt. nimax) then
      write (iucmd,6600) nyr + dstart - 1, niter - 1
      write (iuot,6600) nyr + dstart - 1, niter - 1
      format (10x,'CALCULATION FOR YEAR ','i4, 
      6600 ' FAILED TO CONVERGE AFTER ','i4,' ITERATIONS.'/
      1 ' ***** PROGRAM ABORTED *****')
      pause 'CALCL8 ERROR 2'

Appendix C: FORTRAN Code For The Model

Subroutine CALL8

endif

xvmax = 0.0

do 670 ng = 1, ipng

if (zrflag/ng) .and. abs(xvnew/ng)) .gt. xvmax) then
  xvmax = abs(xvnew/ng)
  nmax = ng
endif

do 670 continue

if (nmax .ne. nlast) then

  nlast = nmax
  plast = pmkt(nmax) - 1.0 / beta(ncls)
  xvlast = xvold/nmax * 0.63
endif

flag = ntrsec (pmkt/nmax), xvnew/nmax), plast, xvlast,

plast = pmkt/nmax)

pmkt/nmax) = min (pint, pmfirst/max))
xlast = xvnew/nmax

go to 500

*** End of Used-Vehicle Market Simulation ***

*** Assign new-vehicle purchases in each mileage group to technologies
and add the appropriate number of vehicles of each type to the
ELX and ELT arrays.

700 continue

do 720 ng = 1, ipng

if (xvnew/ng) .ne. 0.0) then

  call logit (pvnew/1/ng), v, ntc, ncls)
do 710 nt = 1, ntc

  elx(nt,ng,nyr) = xvnew/nt) * v(nt)
  if (v(nt) .ne. 0.0)

    elt(nt,ng,nyr) = 0.5 * vmtgrp/ng)

    sales(nt,ncls,nyr) = sales(nt,ncls,nyr) +

    elx(nt,ng,nyr)

710 continue

endif

720 continue

*** If SDFLAG is .TRUE. and the model year is before the present, the
data in XINIT are historical sales by technology type. We must
adjust model sales to make them come out the same as historical
sales.

if (sdflag .and. nyr .lt. nypres) then

Calculate the amounts by which we need to change sales for each
technology, and zero out temporaries.

do 730 nt = 1, ntc

    ntr = itech(nt,ncls)
Appendix C: FORTRAN Code For The Model
Subroutine CALCL8

adjust(nt) = (xinit(nyr,ntr) - sales(nt,ncls,nyr))

continue
do 732 ng = 1, ipng
    delta(ng) = 0.0
continue

C First pass — adjust all the technologies which must be reduced,
C reducing the numbers in each cell by the same proportion.

C dtotal = 0.0
do 750 nt = 1, ntc
    if (adjust(nt) .ge. 0.0) go to 750
    adjf(nt) = -adjust(nt) / sales(nt,ncls,nyr)
    do 740 ng = 1, ipng
        temp = elx(nt,ng,nyr) * adjf(nt)
        elx(nt,ng,nyr) = elx(nt,ng,nyr) - temp
    if (elx(nt,ng,nyr).eq. 0.0) elt(nt,ng,nyr) = 0.0
    delta(ng) = delta(ng) + temp
    dtotal = dtotal + temp
    sales(nt,ncls,nyr) = sales(nt,ncls,nyr) - temp
continue

C Second pass — calculate the proportion of total increase belonging
C to each technology, then go through increasing each cell which was
C previously decreased.

C if (dtotal .eq. 0.0) go to 790
do 760 nt = 1, ntc
    if (adjust(nt) .gt. 0.0) then
        adjf(nt) = adjust(nt) / dtotal
    else
        adjf(nt) = 0.0
    endif
continue

do 770 ng = 1, ipng
    do 760 nt = 1, ntc
        temp = delta(ng) * adjf(nt)
        elx(nt,ng,nyr) = elx(nt,ng,nyr) + temp
        elt(nt,ng,nyr) = vmtgrp(ng) * 0.5
        sales(nt,ncls,nyr) = sales(nt,ncls,nyr) + temp
continue

C *** Calculate totals for mileage in each technology, fuel consumption,
C total variable cost, total fixed cost, total sales, etc.
C
do 850 ng = 1, ipng
    do 805 nf = 1, nfuels
        vtemp(nf) = 0.0
continue

do 810 ns = 1, nscost

-356-
Subroutine CALCL8

```fortran
cmtemp(ns) = 0.0
ctemp(ns) = 0.0
810 continue
   do 830 nt = 1, ntc
      iyl = max (nytfst(nt), nyold)
      iy2 = min (nytlst(nt), nyr)
   do 825 ny = iyl, iy2
      fleet(nt,ncls,nyr) = fleet(nt,ncls,nyr) +
         elx(nt,ng,ny)
      xmi = xlife (nt, elt(nt,ng,ny))
   do 815 ns = 1, nscost
      cmtemp(ns) = cmtemp(ns) +
         elx(nt,ng,ny) * cmaint(ny,nt,ns)
      ctemp(ns) = ctemp(ns) +
         elx(nt,ng,ny) * cfixed(ny,nt,ns)
   fleetv(ncls,nyr,ns) = fleetv(ncls,nyr,ns) +
      xmi * cfirst(ny,nt,ns) / retavg(nt) *
         elx(nt,ng,ny)
815 continue
   do 820 nf = 1, nfuels
      if (fucons(nf,ny,nt) .ne. 0.0) vtemp(nf) =
         vtemp(nf) + elx(nt,ng,ny) / fucons(nf,ny,nt)
820 continue
825 continue
830 continue
   do 835 nf = 1, nfuels
      fuel(nf,ncls,nyr) = fuel(nf,ncls,nyr) +
         vmtgrp(ng) * vtemp(nf)
835 continue
   do 845 ns = 1, nscost
      omcost(ncls,nyr,ns) = omcost(ncls,nyr,ns) +
         vmtgrp(ng) * cmtemp(ns)
845 continue
850 continue
   do 860 ns = 1, nscost
      omcost(ncls,nyr,ns) = omcost(ncls,nyr,ns) + ctemp(ns)
   do 855 nf = 1, nfuels
      omcost(ncls,nyr,ns) = omcost(ncls,nyr,ns) +
         fuel(nf,ncls,nyr) * pfuel(nyr,nf,ns)
855 continue
860 continue
   do 870 nt = 1, ntc
      sales(ipntc+l,ncls,nyr) = sales(ipntc+l,ncls,nyr) +
         sales(nt,ncls,nyr)
   do 865 ns = 1, nscost
      cpcost(ncls,nyr,ns) = cpcost(ncls,nyr,ns) +
         sales(nt,ncls,nyr) * cfirst(ny,nt,ns)
865 continue
870 continue
```

If the print flag is turned on, and this year falls into the interval, then print the results. If INFLTP is positive, print out prices and
c detailed fleet structure, otherwise print only prices and totals.
c
if (fltprt) then
    print = (mod (nyr - nystrt, infltp) .eq. 0)
else
    print = .false.
endif
if (print) then
    iyear = nyr + dstart - 1
    write (iuot,9900) clsnam(ncls), iyear
9900
    format ('1',l30('**')/0 *** FLEET STRUCTURE FOR CLASS: ',
            a,' IN YEAR ',i4,' *****)
    write (iuot,9905) (pmfrst(ng), ng = 1, ipng),
            (pmkt(ng), ng = 1, ipng), (oldfac(ng), ng = 1, ipng),
            (technm(itech(nt,ncls)),(pvnew(nt,ng), ng = 1, ipng),
            nt = 1, ntc)
9905
    format ('0 *** PRICE DATA FOR THIS YEAR'/,
            '0',t5,'LOWEST NEW-VEH PRICE',t30,l0f10.0/,
            '0',t5,'MARKET PRICE',t30,l0f10.0/,
            '0',t5,'RATIO MKT/NEW-VEH',t30,l0f10.5/,
            '0 ** PRICES FOR INDIVIDUAL TECHNOLOGIES'/,
            ('0',t5,a20,l0f10.0/))
do 940 nt = 1, ntc
    write(iuot,9910) (technm(itech(nt,ncls))),
7
            (ng, ng = 1, ipng)
9910
    format ('0',l30('=')/
            '0 *** FLEET COMPOSITION DATA FOR TECHNOLOGY: ',a//
            2x,'M YEAR',t10,l0(' GROUP ',i2)/)
do 915 ng = 1, ipng
    elxtot(ng) = 0.0
    elttot(ng) = 0.0
915
    continue
do 930 ny = nystrt, nyr
    do 920 ng = 1, ipng
        elxtot(ng) = elxtot(ng) + elx(nt,ng,ny)
        elttot(ng) = elttot(ng) + elt(nt,ng,ny) *
            elx(nt,ng,ny)
920
    continue
    if (infltp .lt. 0) go to 930
    iyear = ny + dstart - 1
    write (iuot,9920) iyear, (elx(nt,ng,ny), ng=1,ipng)
9920
    format (4x,i4,t10,l0f10.0,' Vehicles')
    write (iuot,9930) (elt(nt,ng,ny), ng = 1, ipng)
9930
    format (t10,l0f10.0,' Miles/ Vehicle')
do 930 continue
write (iuot,9935) (elxtot(ng), ng = 1, ipng)
9935
    format (4x,'TOTAL',t10,l0f10.0,' Vehicles')
do 937 ng = 1, ipng
    if (elxtot(ng) .ge. 0.5) then
        elttot(ng) = elttot(ng) / elxtot(ng)
    else
        elttot(ng) = 0.0
    endif
937
    continue
Appendix C: FORTRAN Code For The Model

Subroutine CALCL8

```
write (iuot,9937) (elttot(ng), ng = 1, ipng)
9937      format (4x,'AVERG',tl0,10fl0.0, 'Miles/Vehicle')
940      continue
      write (iuot,9940)
9940      format (lx,130('*'))
      endif
      c
      c End of loop — report convergence
      c
      write (iucmd,9945) nyr + dstart - 1, niter
9945      format (10x,'CALCULATION FOR YEAR ','i4,' CONVERGED AFTER ',
1      i4,' ITERATIONS.')
950      continue
      c
      c End of Loop Over Each Year

1000      continue
      c
      c End of Loop Over Each Class

      c Sum costs and fuel consumption over each class to get grand totals
      c
      do 1100 ncls = 1, nclass
          do 1090 nyr = nystrt, nyend
              do 1050 ns = 1, nscost
                  omcost(ipnc+l,nyr,ns) = omcost(ipnc+l,nyr,ns) + 1
                  omcost(ncls,nyr,ns)
                  cpcost(ipnc+l,nyr,ns) = cpcost(ipnc+l,nyr,ns) + 1
                  cpcost(ncls,nyr,ns)
                  fleetv(ipnc+l,nyr,ns) = fleetv(ipnc+l,nyr,ns) + 1
                  fleetv(ncls,nyr,ns)
                  tcostc(ncls,nyr,ns) = omcost(ncls,nyr,ns) + 1
                  cpcost(ncls,nyr,ns)
                  tcostc(ipnc+l,nyr,ns) = tcostc(ipnc+l,nyr,ns) + 1
                  tcostc(ncls,nyr,ns)
                  deprec(ncls,nyr,ns) = fleetv(ncls,nyr-1,ns) + 1
                  cpcost(ncls,nyr,ns) - fleetv(ncls,nyr,ns)
                  deprec(ipnc+l,nyr,ns) = deprec(ipnc+l,nyr,ns) + 1
                  deprec(ncls,nyr,ns)
                  tcosa(ncls,nyr,ns) = omcost(ncls,nyr,ns) + 1
                  deprec(ncls,nyr,ns)
                  tcosa(ipnc+l,nyr,ns) = tcosa(ipnc+l,nyr,ns) + 1
                  tcosa(ncls,nyr,ns)
1050      continue
          do 1080 nf = 1, 3
              fuel(nf,ipnc+l,nyr) = fuel(nf,ipnc+l,nyr) + 1
              fuel(nf,ncls,nyr)
1080      continue
1090      continue
1100      continue
```
Appendix C: FORTRAN Code For The Model
Subroutine CALCL8

  c
  c Return
  c
  return
  end
character*20 function cdecod (text,ndx,nparam,index,nerrs)

C*****************************************
C This function breaks out parameter number NDX from the list of
C parser-processed parameters in TEXT. It then converts the parameter
C to upper-case and returns the first 20 characters as the value of
C the function. If the parameter does not exist, or if it is all
C blank, then the routine prints an error message and returns blanks.
C*****************************************

C Actual Parameters

character text(*)
dimension index(2,nparam)

C Global Common Blocks

parameter (iucmd=1, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile

C External function

character*80 upper

C*****************************************
C Begin Execution
C*****************************************

C If there is no such parameter, print an error message and return zero

if (nparam .lt. ndx) then
write (iuot,9000) ndx

9000 format (' ***** ERROR — TOO FEW PARAMETERS IN GROUP. ',
1 ' MISSING PARAMETER ',i3,' (CHARACTER CONSTANT) '/
2 ' ***** SETTING PARAMETER TO BLANK')
nerrs = errs + 1
    cdecod = ' '
endif

C Otherwise, break out the parameter, check if its all blank, and return
C it as CDECOD. If its all blank, display error message.

else
    cdecod = upper (text(index(1,ndx):index(2,ndx)))
    if (cdecod .eq. ' ') then
        write (iuot,9500) ndx

9500 format (' ***** ERROR — PARAMETER ',i3,' (CHARACTER ',
1 'CONSTANT) IS ALL BLANK.')
        errs = errs + 1
    endif
endif
return
end
function cstvar (ntechx, nyear, nymodl, ngroup)

******************************************
This function calculates and returns the annual variable cost of
operation (cost of fuel and maintenance) for a vehicle of technology
NTECH of the current class, which is of model year NYMOLDL, and
which is operated in mileage group NGROUP. Costs are calculated
using fuel prices for the current year, which is NYEAR.
******************************************

*** GLOBAL COMMON BLOCKS

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend,
l nypres, nfuels, nscost, ntclas(ipnc), itech(ipnt,ipnc)
character*1l title*80, clsnam*28, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
common /econ/ discnt(ipnc), elast(ipnc), beta(ipnc),
l ctrans(ipnc), premv(ipnc), pfuel(ipny,ipnf,2)
common /mileag/ yrmbas(ipny,ipnc), yrmile(ipny,ipnc),
l vmtavg(ipnc), vmtstd(ipnc), vmtgrp(ipnc)
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc),
l nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)

******************************************
Begin Execution
******************************************

Calculate cost per mile, the sum of maintenance and fuel costs.

cost = cmaint(nymodl,ntechx,1)
do 10 nf = 1, nfuels
   if (fucons(nf,nymodl,ntechx) .ne. 0.0)
      1 cost = cost + pfuel(nyear,nf,l) / fucons(nf,nymodl,ntechx)
10 continue
c Multiply by miles per year for this group to get total cost, then return.
c cstvar = cost * vmtgrp(ngroup)
return
end
function decode (text, ndx, nparam, index, nerrs)

*** This function breaks out parameter number NDX from the list of parser-processed parameters in TEXT. It then attempts to decode the parameter into a real number. If the decode is successful, the number is returned as the value of the function. Otherwise, if the parameter is not a legal real number, or if there is no such parameter, the routine prints an error message and returns a value of 0.0

***

Actual Parameters

character*(*) text
dimension index(2,nparam)

Global Common Blocks

parameter (iucmd=1, iuin=5, iuot=6, iutc=10, iub=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile

Local variables

character*7 format

Begin Execution

If there is no such parameter, print an error message and return zero

if (nparam .lt. ndx) then
  write (iout,9000) ndx
  9000 format (' ***** ERROR -- TOO FEW PARAMETERS IN GROUP. ', 1 ' MISSING PARAMETER ', 13, 1 ' (REAL NUMBER) '/
  nerrs = nerrs + 1
  decode = 0.0
else
  length = index(2,ndx) - index(1,ndx) + 1
  write (format,1000) length
  1000 format ('(F',i2.2,'.0)')
  il = index(1,ndx)
  i2 = index(2,ndx)
  read (text(index(1,ndx):index(2,ndx)),format,err=500) val
  decode = val
  return

If an error was detected, print error message and return 0
Function DECODE

500   continue
     write (iuot,9500) ndx, text(index(1,ndx):index(2,ndx))
9500  format (' ***** ERROR — PARAMETER ',i3,' = ',a,' IS NOT ',
   1 'A LEGAL NUMBER.'/' ***** SETTING PARAMETER = 0.0')
     decode = 0.0
     endif
     return
end
function equiv (r, t)

C***********************************************************************
C This function returns the discounted present value of a uniform
C cash flow of 1 unit per period for T periods, discounted at interest
C rate R (which must be a decimal, not percent). The formula used
C is the standard one,
C
C E = R * (1+R)**T / ((1+R)**T - 1)
C
C The actual form of the computation is modified slightly in order
C to reduce the amount of exponential and logarithmic calculations
C required, taking advantage of the fact that many evaluations at
C the same interest rates but different T will usually be done together.
C**********************************************************************

C *** Save the last interest rate and calculated intermediate value
C to save having to recalculate each time.
C
C save rlast, rplusl

C***********************************************************************
C Begin Execution
C***********************************************************************

C If current interest rate is same as last time, we can use the
C pre-calculated value for ln(1/(1+R)). Otherwise, we must recalculate.
C
if (r .ne. rlast) then
  rplusl = alog (1.0 + r) * -1.0
  rlast = r
endif

C Now do the calculation
C
C equiv = r / (1.0 - exp (rplusl * t))

C Return
C
return
end
subroutine getinp (iunit,nwant,text,nparam,index,errflg,ecoflg)

******************************************************************************
This subroutine is called to read and parse a single set of cards in
the input file specified by IUNIT. The subroutine skips over blank
lines until it finds a non-blank line, then reads and concatenates
all physical lines until it finds another blank one. It then
passes the concatenated text to the parser, and returns the results
in TEXT, NPARAM, INDEX, and ERRFLG. TEXT contains the parser-
processed text, NPARAM is the number of parameters found by the
parser, and INDEX(1,N) and INDEX(2,N) are the character locations in
TEXT of the beginning and ending of the Nth parameter, respectively.
ERRFLG is returned .FALSE. unless an error is detected in the
reading or parsing process, in which case it is returned .TRUE.
On entry, NWANT must contain the dimensionality of INDEX. ECOFLG
is a logical flag which — if .TRUE. — indicates that the input is
to be echoed to the output.

******************************************************************************

Dummy Arguments

character(*) text
logical errflg, ecoflg
dimension index(2,nwant)

Global Common

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
parameter (iucmd=1, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile

External Function

character upper*80

Local Variables

character linein*80, textin*2000, file*30
logical nonblk

******************************************************************************
Begin Execution
******************************************************************************

Set flags and counters

ll = 1
textin = ' '
errflg = .false.
nonblk = .false.
Subroutine GETINP

c Read the input file, looking for the first non-blank line, then
  c storing it and any succeeding lines in TEXTIN until we see another
  c blank.

  100 continue
    read (iunit,1010,end=500,err=600) linein
  1010 format (a)
    if (linein .eq. ' ' .and. .not. nonblk) go to 100
    if (ecoflg) write (iout,1015) linein
  1015 format (10x,a)
    if (linein .eq. ' ') go to 200
      nonblk = .true.
      n2 = ichlnb (linein) + 1
      12 = 11 + n2 - 1
      if (12 .le. 2000) then
        textin(11:12) = linein(1:n2)
        11 = 12 + 1
      else
        write (iout,1020) linein
  1020 format ('/***** ERROR — LINE(S) TOO LONG ON INPUT.'
  1 ' ABORTING READ.'/ Excess line was: ',a80)
      errflg = .true.
  endif
    go to 100

C
  C Come here to parse the text that has been read in.

  200 continue
    if (.not. errflg)
      1 call parser (textin,nwant,text,npargm,index,errflg)
  c
  c Return
  c
  return

C
  C Come here on end-of-file

  500 continue
    if (nonblk) then
      linein = upper(textin(1:3))
    else
      linein = ' '
  endif
    if (linein .eq. 'END') go to 200
    linein = 'UNEXPECTED END-OF-FILE'
    11 = 22
    go to 700

C
  C Come here on read error

  600 continue
    linein = 'INPUT/OUTPUT ERROR'
  700 continue
    if (iunit .eq. iuin) then
Subroutine GETINP

    file = infile
    elseif (iunit .eq. iutc) then
        file = tcfile
    else
        file = 'UNKNOWN FILE'
    endif
    write (iuot,1500) linein, file
1500 format (i30, '****', a22, ' WHILE READING FILE: ', a30)
    errflg = .true.
    return
end
subroutine grafit

C This subroutine produces graphic output for the program. The output
consists of a series of plots showing total fuel consumption (with
breakdown by type), fuel consumption by class (again by type), and
fleet composition by technology type by class. The program uses
subroutine calls to the MIT/JCF PENPLOT facility to produce a device
independent graphics output file, which can subsequently be plotted
via the PLOT command. See the PENPLOT system documentation for the
details of the commands.

C Global Common Blocks

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend,
1 nyres, nfuels, nscost, nclas(ipnc), itech(ipnt,ipnc)
character*ll title*88, clsnam*28,
fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnc)
parameter (iucmd=1, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile
logical sdflag, grafic, clsprt, scflag, echo,
1 tcecho, fltprt
common /flags/ sdflag, grafic, clsprt, scflag, echo, tcecho,
1 fltprt, infltp, nimax
common /tech/ ntecn, ntecn(ipntc), nyfst(ipntc),
1 nytst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)
common /reslts/ fuel(ipnc+1,ipny), omcost(ipnc+1,ipny,2),
1 cpcost(ipnc+1,ipny,2), fleetv(ipnc+1,ipny,2),
2 deprec(ipnc+1,ipny,2), tcostc(ipnc+1,ipny,2),
3 tcosa(ipnc+1,ipny,2), fleet(ipntc+1,ipnc,ipny),
4 sales(ipntc+1,ipnc,ipny)

character*68 labtex
dimension ydplot (ipny), xnplot (ipny)

c Set positions of plot and labels in normalized device
c coordinates
data
1 xnmin /20.0/ xmnax /110.0/, ynmmin /30.0/, ynmmax /100.00/,
1 xntic /20.8/ yntic /30.8/, xnlab /19.2/, ynlab /29.3/,
2 xncnt /1.0/ yntit /1.5/, xntitl /20.0/, yntitl /17.0/,
3 xntit /111.0/, yntit /30.0/, xntlt /3.0/

c Statement functions to convert from data-space coordinates to
Appendix C: FORTRAN Code For The Model

Subroutine GRAFIT

C normalized device coordinates and vice-versa.
C
C
Cxdn(a) = xslope * a + xoffs
Cxnd(a) = (a - xoffs) / xslope
Cydn(a) = yslope * a + yoffs
Cynd(a) = (a - yoffs) / yslope
C
C******************************************************************************
C Begin Execution
C******************************************************************************
C
C Initialize the plotting system for hardcopy graphics only and
C set the letter size to match the values in the data statements.
C
Ccall pltsel (32768)
call locate (0.0,138.0,0.0,100.0)
aspect = xnchar / ynchar
call letter (ynchar,aspect,0.0,0.0)
call lorg (0)
C
C Set minimum and maximum X values and tic distance
C
ii = dstart + nystrt - 1
xmin = float(ii)
xmax = float(dend)
temp = xmax - xmin
if (temp .ge. 30)
  xticd = 5.0
elseif (temp .ge. 10)
  xticd = 2.0
else
  xticd = 1.0
endif
C
C******************************************************************************
C Plot Private and Social Costs
C******************************************************************************
C
C Find the maximum Y value and calculate a pleasing Y increment
C (Scale for all cost plots is the same).
C
yfmax = 0.0
do 110 ny = nystrt, nyend
do 105 ns = 1, nscoast
  if (tcostc(ipnc+l,ny,ns) .gt. yfmax)
    yfmax = tcostc(ipnc+l,ny,ns)
  if (tcosta(ipnc+l,ny,ns) .gt. yfmax)
    yfmax = tcosta(ipnc+l,ny,ns)
105  continue
110 continue
ipowr = int (alol0 (yfmax))
yticd = float (lo**ipowr)
temp = yfmax / yticd
if (temp .le. 2.0) then
Appendix C: FORTRAN Code For The Model

Subroutine GRAFIT

```fortran
yticd = yticd / 5.0
elseif (temp .le. 5.0) then
  yticd = yticd / 2.0
endif
yfmax = float(int (yfmax / yticd + .001) + 1) * yticd

c Calculate slopes and offsets for the functions relating data-space coordinates to normalized device coordinates
xslope = (xnmx - xmnin) / (xmax - xmin)
oxoffs = xnmx - xmax * xslope
yslope = (ynmax - ymnin) / yfmax
yoffs = ynmn - yfmax * yslope

c Loop over each fuel type

do 190 ns = 1, nscost

c Draw in the outline of the plot frame

call move (xmnin,ymnin)
call draw (xnmnax,ymnin)
call draw (xnmnax,ymnmax)
call draw (xmnin,ymnmax)
call draw (xmnin,ymnin)

c Draw Tic Marks and Labels along the X axis

xl = xmin
115 continue
  xn = cxdn (xl)
call move (xn,ymnin)
call draw (xn,yn tic)
write (labtex,9000) xl
9000 format (f5.0)
  xn = xn - 2.0 * xnchar
  yn = ynlab - ynchar
call move (xn,yn)
call label (labtex(1:4))
xl = xl + xticd
  if (xl .lt. xmax + .1) go to 115

c Draw Tic Marks and Labels along the Y axis

cy = yticd
120 continue
  yn = cydn (yl)
call move (xmnin,yn)
call draw (xntic,yn)
write (labtex,9010) yl
9010 format (g8.2)
  xn = xnlab - 9.0 * xnchar
  yn = yn - 0.5 * ynchar
call move (xn,yn)
```

Page 3
Subroutine GRAFIT

call label (labtex(1:8))
yl = yl + yticd
if (yl .le. yfmax) go to 120

c c Put in the title for the Y axis and the graph title

temp = ynchar * 1.5
call letter (temp,aspect,90.0,0.0)
call move (xnytit,yntitl)
call label ('ANNUAL COST (EGYPTIAN POUNDS)')
temp = 2.0 * ynchar
call letter (temp,aspect,0.0,0.0)
call move (xntitl,yntitl)
np = ichlnb (fuelnm(nf))
if (ns .eq. 1) then
   labtex = ' PRIVATE COSTS OF TRANSPORTATION VS. TIME'
else
   labtex = ' SOCIAL COSTS OF TRANSPORTATION VS. TIME'
endif
call label (labtex)
call letter (ynchar,aspect,0.0,0.0)

c c Now plot the fuel consumption levels for each class in turn, labeling
 c each plot.

do 130 ny = nystrt, nyend
   xnpplot(ny) = cxdn(float(ny+dstart-1))
   ydplot(ny) = 0.0
130  continue

 c c Plot the CM Cost

yn = cydn (omcost(ipnc+l,nystrt,ns))
call move (xnplot(nystrt),yn)
do 140 ny = nystrt+l, nyend
   yn = cydn (omcost(ipnc+l,ny,ns))
call draw (xnpplot(ny),yn)
140  continue
yn = yn - 0.5 * ynchar
call move (xntitl,yn)
ylast = yn
call label ('CM COST')

 c c Plot the accrual-basis total cost

yn = cydn (tcosta(ipnc+l,nystrt,ns))
call move (xnplot(nystrt),yn)
do 150 ny = nystrt+l, nyend
   yn = cydn (tcosta(ipnc+l,ny,ns))
call draw (xnpplot(ny),yn)
150  continue
yn = yn - 0.5 * ynchar
if (yn .lt. ylast + ynchar) yn = ylast + ynchar
call move (xntitl,yn)
Subroutine GRAFIT

ylast = yn
call label ('TOTAL COST (ACCRUAL BASIS)')

c Plot the cash-basis total cost
c
yn = cydn (tcostc(ipnc+l,nystrt,ns))
call move (xplot(nystrt),yn)
do 160 ny = nystrt+1, nyend
   yn = cydn (tcostc(ipnc+l,ny,ns))
call draw (xplot(ny),yn)
160 continue
yn = yn - 0.5 * ynchar
if (yn .lt. ylast + ynchar) ylast = ylast + ynchar
call move (xncit,yt)
ylast = yn
call label ('TOTAL COST (CASH BASIS)')

c Put in the run titles
c
yn = 3 * ynchar
do 170 n = 1, 3
   yn = yn - ynchar
call move (xntitl,yn)
call label (title(n))
170 continue

c End of Loop to Plot Fuel Consumption by Class — Move to next plot.
c
call erase
190 continue

---------------------------------------------------------------------

c Plot Fuel Consumption By Class for Each Fuel

c Find the maximum Y value and calculate a pleasing Y increment
c (Scale for all fuel plots is the same).
c
yfmax = 0.0
do 210 ny = nystrt, nyend
do 205 nf = 1, nfuels
   if (fuel(nf,ipnc+l,ny) .gt. yfmax)
      yfmax = fuel(nf,ipnc+l,ny)
1
205 continue
210 continue
ipowr = int (alog10 (yfmax))
yticd = float (10**ipowr)
temp = yfmax / yticd
if (temp .le. 2.0) then
   yticd = yticd / 5.0
elseif (temp .le. 5.0) then
   yticd = yticd / 2.0
endif
yfmax = float(int (yfmax / yticd + .001) + 1) * yticd
Subroutine GRAFIT

Calculate slopes and offsets for the functions relating data-space coordinates to normalized device coordinates

\[
x_{\text{slope}} = \frac{(x_{\text{max}} - x_{\text{min}})}{(x_{\text{max}} - x_{\text{min}})}
\]
\[
x_{\text{offs}} = x_{\text{max}} - x_{\text{max}} \times x_{\text{slope}}
\]
\[
y_{\text{slope}} = \frac{(y_{\text{max}} - y_{\text{min}})}{y_{\text{max}}}
\]
\[
y_{\text{offs}} = y_{\text{max}} - y_{\text{max}} \times y_{\text{slope}}
\]

Loop over each fuel type

Loop over each fuel type

do 290 \( n_f = 1, n_{\text{fuels}} \)

Draw in the outline of the plot frame

Draw in the outline of the plot frame

Draw Tic Marks and Labels along the X axis

Draw Tic Marks and Labels along the X axis

\( x_{\text{l}} = x_{\text{min}} \)

\( x_{\text{n}} = \text{cxdn} (x_{\text{l}}) \)

\( x_{\text{n}} = x_{\text{n}} - 2.0 \times x_{\text{nchar}} \)

\( y_{\text{n}} = y_{\text{lab}} - y_{\text{nchar}} \)

\( x_{\text{l}} = x_{\text{l}} + x_{\text{ticd}} \)

if (\( x_{\text{l}} \lt \text{.lt.} x_{\text{max}} + .1 \)) go to 215

Draw Tic Marks and Labels along the Y axis

Draw Tic Marks and Labels along the Y axis

\( y_{\text{l}} = \text{cydn} (y_{\text{l}}) \)

\( y_{\text{n}} = y_{\text{n}} - 0.5 \times y_{\text{nchar}} \)

\( y_{\text{l}} = y_{\text{l}} + y_{\text{ticd}} \)

if (\( y_{\text{l}} \le \text{.le.} y_{\text{max}} \)) go to 220

Put in the title for the Y axis and the graph title

\( \text{temp} = y_{\text{nchar}} \times 1.5 \)
Subroutine GRAFIT

call letter (temp,aspect,90.0,0.0)
call move (xnytit,ynytit)
call label ('ANNUAL FUEL CONSUMPTION (LITERS)')
temp = 2.0 * ynchar
call letter (temp,aspect,0.0,0.0)
call move (xntitl,yntitl)
np = ichlnb (fuelnm(nf))
labtex = fuelnm(nf)(1:np) // 'CONSUMPTION VS. TIME'
call label (labtex(1:np+21))
call letter (ynchar,aspect,0.0,0.0)

C Now plot the fuel consumption levels for each class in turn, labeling each plot.

yn = cydn (ydplot(nystrt))
call move (xnplot(nystrt),yn)
do 250 ny = nystrt+1, nyend
yn = cydn (ydplot(ny))
call draw (xnplot(ny),yn)
250 continue

if (yn .lt. ylast + ynchar) ylast = ylast + ynchar
call move (xntitl,yn)
ylast = yn
call label (clsnam(nc))

C Put in the run titles

yn = 3 * ynchar
do 270 n = 1, 3
yn = yn - ynchar
call move (xntitl,yn)
call label (title(n))
270 continue

C End of Loop to Plot Fuel Consumption by Class — Move to next plot.
call erase

C
Subroutine GRAFIT

Plot Vehicle Fleet Composition By Technology Type

Loop over each class, plotting fleet composition by type.

do 390 nc = 1, nclass

Find the maximum Y value and calculate a pleasing Y increment

yfmax = 0.0

do 305 ny = nystrt, nyend
   if (fleet(ipntc+1,nc,ny) .gt. yfmax)
      yfmax = fleet(ipntc+1,nc,ny)
   continue
ipowr = int (alogn (yfmax))
yticd = float (10**ipowr)
temp = yfmax / yticd
   if (temp .le. 2.0) then
      yticd = yticd / 5.0
   elseif (temp .le. 5.0) then
      yticd = yticd / 2.0
   endif
   yfmax = float(int (yfmax / yticd + .001) + 1) * yticd

Calculate slopes and offsets for the functions relating data-space coordinates to normalized device coordinates

xslope = (xnmmax - xrnmin) / (xmax - xmin)
xoffs = xnmmax - xmax * xslope
yslope = (ynnmmax - ynmmin) / yfmax
yoffs = ynmmax - yfmax * yslope

Draw in the outline of the plot frame

call move (xrnmin,ynmin)
call draw (xnmmax,ynmin)
call draw (xnmmax,ynmax)
call draw (xnmmin,ynmax)
call draw (xnmmin,ynmin)

c Draw Tic Marks and Labels along the X axis

xl = xmin
310 continue
   xn = cdx (xl)
call move (xn,ynmin)
call draw (xn,yntic)
write (labtex,9000) xl
   xn = xn - 2.0 * xncr
   yn = yncr - ynchar
call move (xn,yn)
call label (labtex(1:4))
xl = xl + xticd
   if (xl .lt. xmax + .1) go to 310
Subroutine GRAFIT

c

c Draw Tic Marks and Labels along the Y axis

c
   yl = yticd
   continue

320   yn = cydn (yl)
call move (xmin,yn)
call draw (xntic,yn)
write (labtex,9010) yl
xn = xnlab - 9.0 * xnchar
yn = yn - 0.5 * ynchar
call move (xn,yn)
call label (labtex(1:8))
   yl = yl + yticd
if (yl .le. yfmax) go to 320

c

Put in the title for the Y axis and the graph title

c
temp = ynchar * 1.5
call letter (temp,aspect,90.0,0.0)
call move (xnytit,ynytit)
call label ('NUMBER OF VEHICLES IN THE FLEET')
temp = 2.0 * ynchar
call letter (temp,aspect,0.0,0.0)
call move (xntitl,yntitl)
np = ichlnb (clsnam(nc))
labtex = 'VEHICLE FLEET FOR CLASS: ' // clsnam(nc)
call label (labtex(l:np+37))
call letter (ynchar,aspect,0.0,8.8)

c

Now plot the number of vehicles for each technology in turn, labeling
each plot.
c
   ylast = - ynchar
do 330 ny = nystrt, nyend
      
      xnplot(ny) = cxdn(float(ny+dstart-l))
ydplot(ny) = 0.0

330   continue
do 360 nt = 1, ntclas(nc)
totf = 0.0
   do 340 ny = nystrt, nyend
      
      ydplot(ny) = ydplot(ny) + fleet(nt,nc,ny)
totf = totf + fleet(nt,nc,ny)
340   continue
if (totf .lt. 0.01 * yfmax) go to 360
yn = cydn (ydplot(nystrt))
call move (xnplot(nystrt),yn)
do 350 ny = nystrt+1, nyend
   
   yn = cydn (ydplot(ny))
call draw (xnplot(ny),yn)
350   continue
yn = yn - 0.5 * ynchar
if (yn .lt. ylast + ynchar) yn = ylast + ynchar
call move (xnctit,yn)
Subroutine GRAFIT

\[
\text{ylast} = \text{yn} \\
\text{ii} = \text{itech(nt,nc)} \\
c\text{call label (techm(ii))}
\]

\[
360 \quad \text{continue}
\]

\[
c\quad \text{Put in the run titles}
\]

\[
\text{yn} = 3 * \text{ynchar} \\
do 370 \text{n = 1, 3} \\
\text{yn} = \text{yn} - \text{ynchar} \\
c\text{call move (xntitl,yn)} \\
c\text{call label (title(n))}
\]

\[
370 \quad \text{continue}
\]

\[
c\quad \text{End of Loop to Plot Fuel Consumption by Class — Move to next plot}
\]

\[
c\quad \text{unless this is the last plot.}
\]

\[
\text{if (nc ne. nclass) call erase}
\]

\[
390 \quad \text{continue}
\]

\[
c\quad \text{End of plotting routine. Call plot cleanup routine and return.}
\]

\[
c\quad \text{call endplt}
\]

\[
\text{return}
\]

\[
\text{end}
\]
function ichfnb (string)
c
This function returns the index of the first character in
STRING which is not a blank. If STRING is all blank it returns 0.
c
character string(*)

c Look through STRING until a non-blank is found, then return.
c
length = len (string)
do 100 n = 1, length
    if (string(n:n) .ne. ' ') go to 150
100 continue
n = 0
150 continue
ichfnb = n
return
end
function ichlnb (string)
c  This function returns the index of the last character in
  STRING which is not a blank. If STRING is all blank it returns 0.
c  character string(*)
c
  Look backwards through STRING until a non-blank character is found,
  then set ICHLNB to its index and return.
  
  length = len(string)
do 100 n = length, 1, -1
    if (string(n:n) .ne. ' ') go to 150
100 continue
  n = 0
150 continue
  ichlnb = n
  return
c
end
function idecod (text, ndx, nparm, index, nerrs)

This function breaks out parameter number NDX from the list of parser-processed parameters in TEXT. It then attempts to decode the parameter into an integer. If the decode is successful, the number is returned as the value of the function. Otherwise, if the parameter is not a legal integer, or if there is no such parameter, the routine prints an error message and returns a value of 0.

Actual Parameters

character*(*) text
dimension index(2, nparm)

Global Common Blocks

parameter (iucmd=1, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile

Local variables

character*5 format

Begin Execution

If there is no such parameter, print an error message and return zero

if (nparm .lt. ndx) then
  write (iuot,9000) ndx
9000 format ('**** ERROR -- TOO FEW PARAMETERS IN GROUP. ',
1     'MISSING PARAMETER ',i3,' (INTEGER) '/
2     '**** SETTING PARAMETER = 0')
  nerrs = nerrs + 1
  idecod = 0
else
  length = index(2,ndx) - index(1,ndx) + 1
  write (format,1000) length
1000 format ('(I',i2.2,')'), il = index(1,ndx)
i2 = index(2,ndx)
  read (text(il:i2),format,err=500) ival
  idecod = ival
  return

If an error was detected, print error message and return 0
Function IDECOD

500  continue
write (iuot,9500) ndx, text(index(1,ndx):index(2,ndx))
9500  format (' ***** ERROR -- PARAMETER ',i3,' = ',a,' IS NOT ',
1   'A LEGAL INTEGER.'/ ' ***** SETTING PARAMETER = 0')
      idecod = 0
   endif
return
end
subroutine logit (u, v, nchose, nclass)

This subroutine implements the logit choice function. U is assumed to contain a vector of NCHOSE costs for alternative courses of action available to members of user class NCLASS. V is returned as the value given by the logit function

\[ v(i) = \frac{\exp(-B*U(i))}{\sum \exp(-B*U(j))} \] over all j

In order to reduce the work of computation in future steps, V is set equal to zero if its calculated value would be less than 0.005. (determined by comparing U to the largest U in the array)

*** DUMMY ARGUMENTS

dimension u(nchose), v(nchose)

*** GLOBAL COMMON

parameter (ipcn = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
common /econ/ discnt(ipnc), elast(ipnc), beta(ipnc),
1 ctrans(ipnc), premnv(ipnc), pfuel(ipny,ipnf,2)

*** Local Variables

dimension x(ipng+l)

*** Logarithms of largest and smallest numbers representable in VAX Single-Precision Floating Point, and of the cutoff ratio. Cutoff ratio is ratio (exp(-B*U(i) / exp(-B*Umax)) below which V(i) is simply set to zero. Presently, cutoff ratio = .005

data big /85.19/, small /-85.19/, cutoff /-5.3/

Begin Execution

Multiply by BETA for this class, then find the largest and smallest values to see if we need to adjust ranges to avoid overflow/underflow.

\[ \text{bigx} = -1.e37 \]
\[ \text{smallx} = 1.e37 \]
do 10 n = 1, nchose
\[ x(n) = u(n) * \text{beta}(nclass) * -1.0 \]
if (x(n) .gt. bigx) bigx = x(n)
if (x(n) .lt. smallx) smallx = x(n)
10 continue
Appendix C: FORTRAN Code For The Model

Subroutine LOGIT

c Establish correction factors if any numbers are too large or small
c (Note that X(i) is the logarithm of V(i), so that adding/subtracting
c correction factors to X is equivalent to multiplying/dividing V)
c
if (bigx .gt. big) then
  factor = big - bigx
elseif (smallx .lt. small) then
  factor = small - smallx
  bigx2 = bigx + factor
  if (bigx2 .gt. big) factor = factor + big - bigx2
else
  factor = 0.0
endif

c Establish the cutoff point, below which the exponential calculation
need not be done, because the value will not contribute measurably
in any case.
c
  xcut = bigx + factor + cutoff
c
Now go through and calculate exponentials, keeping track of the sum.
c If any X is below the cutoff point, it won't contribute noticeably to
c the sum, so just leave it out and set corresponding V to zero.
c
  sum = 0.0
  do 20 n = 1, nchoose
     xx = x(n) + factor
     if (xx .gt. xcut) then
       v(n) = exp(xx)
       sum = sum + v(n)
     else
       v(n) = 0.0
     endif
  20 continue

c Now invert the sum and calculate the final values for V.
c
  sum = 1.0 / sum
  do 30 n = 1, nchoose
    v(n) = v(n) * sum
  30 continue

c Return

c
return
end
subroutine lognam (namstr, trnstr, errflg)

******************************************************************************
This subroutine performs logical-name translation by means of
repeated calls to the VAX/VMS system services. NAMSTR is the
input string containing the logical name. The routine calls
system services to obtain a translation of this name, and
again to translate the translation, etc. until no translation is
done (i.e. the ultimate name translates as itself), or until
we go through 20 iterations (probably implying an infinite loop).
TRNSTR is used to return the translated string. ERRFLG is returned
FALSE. unless an error occurs in the translation.
******************************************************************************

c Dummy Arguments

c character(*) namstr, trnstr
character*63 name
logical errflg
integer sys$trnlog*4


c Include the system parameter settings

c include '($SSDEF)/NLIST'

******************************************************************************

Begin Execution

******************************************************************************

Begin looping

niter = 0
errflg = .false.
name = namstr
10 continue
   niter = niter + 1
   icode = sys$trnlog (name,,trnstr,,)
   if (icode .eq. ss$notran) return
   name = trnstr
   if (icode .eq. ss$normal .and. niter .lt. 20) go to 10

Come here on error

c errflg = .true.
return
end
function lookup (cval, carr, ndim)

**********************************************************************
This function returns the index of the cell in array CARR which
contains value CVAL, or zero if no cell in CARR contains CVAL.
Both CVAL and CARR should be of type character. NDIM is the
dimension of IARR. The value is found by exhaustive search.
*********************************************************************

Dummy Arguments

character(*) carr, cval
dimension carr(*)

Begin Execution

Loop over CARR, looking for CVAL

do 10 n = 1, ndim
   if (carr(n) .eq. cval) go to 20
10 continue

Come here if no matching value found

lookup = 0
return

Come here if a matching value was found

20 continue
   lookup = n
return
end
logical function ntrsec (xl,yl,x2,y2,x3,y3,x4,y4,xi,yi)

******************************************************************************
This function is used to find the point of intersection of the two
line segments (XL,Y1) - (X2,Y2) and (X3,Y3) - (X4,Y4). The function
returns .TRUE. if the two segments intersect. XI,YI are returned as
the point of intersection of the segments if they intersect, and as
the point of intersection of the lines that the segments lie on if
they don't intersect. If the two lines are parallel, XI,YI is
are returned as -1.0E10 (intersection very far away in the direction
of the lines.

The algorithm is to find the intersection point of the two lines
the segments lie on, then to see if that point lies on both
segments. If so, then they intersect, if not, they don't. We need
to test for a number of special cases (vertical lines, parallelism,
etc.) which break the algorithm.
******************************************************************************

Local variables

logical vertl, vert2, onl, on2

Small number (indistinguishable from zero)

data small /=1.0E-6/

******************************************************************************
Begin Execution
******************************************************************************

Calculate distances between points and determine whether either line
c is vertical. If not, calculate slopes and intercepts.

dyl = y2 - y1
dx1 = x2 - x1
vertl = (abs(xl) lt. small)
if (.not. vertl) then
  a = dyl / dx1
  b = yl - a * xl
endif

dy2 = y3 - y4
dx2 = x3 - x4
vert2 = (abs(dx2) lt. small)
if (.not. vert2) then
  c = dy2 / dx2
  d = y3 - c * x3
endif

*** Check for special cases that break the algorithm. If none are found,
c calculate the intersection point.

c If both lines are vertical
if (vert1 .and. vert2) then
    ntrsec = .false.
    xi = xl
    yi = -1.0E10
    return

  c If first line is vertical
  c
  elseif (vert1) then
    xi = xl
    yi = c * xl + d

  c If second line is vertical
  c
  elseif (vert2) then
    xi = x3
    yi = a * x3 + b

  c If the two lines are parallel
  c
  elseif (abs (c - a) .lt. small) then
    ntrsec = .false.
    xi = -1.0E10
    yi = a * xi + b
    return

  c Normal case
  c
  else
    xi = (d - b) / (a - c)
    yi = a * xi + b
  endif

  c Now determine whether the intersection point lies on each line segment
  c
  if (vert1) then
    onl = ((abs(yi-y1) .le. abs(dy1)) .and. (abs(yi-y2) .le. abs(dy1)))
  else
    onl = ((abs(xi-xl) .le. abs(dx1)) .and. (abs(xi-x2) .le. abs(dx1)))
  endif

  if (vert2) then
    on2 = ((abs(yi-y3) .le. abs(dy2)) .and. (abs(yi-y4) .le. abs(dy2)))
  else
    on2 = ((abs(xi-x3) .le. abs(dx2)) .and. (abs(xi-x4) .le. abs(dx2)))
  endif

  ntrsec = onl .and. on2

  c Return
  c
  return
end
subroutine parser (linein,nwant,lineot,nparam,index,errflg)

This subroutine parses the line of input passed to it in LINEIN
and outputs the parsed line in LINEOT. NWANT contains the number
of parameters desired by the program; NPARAM is returned with the
number actually found by the parser. INDEX is returned containing
character positions of each parameter in LINEOT. INDEX(1,np)
contains the location of the first character of the NPth parameter,
INDEX(2,np) contains the location of the last character. INDEX
must be dimensioned at least INDEX(2,NWANT). ERRFIG is a logical
flag which is returned .FALSE. unless an error has been detected in
c parsing the line.

Parameters are defined as strings of arbitrary length, containing
any characters except comma, space, asterisk, or the double quote.
Parameters containing commas, spaces, or asterisks may be input
by enclosing them between two double quotes: for instance
"this string is all one parameter **".

Parameters are delimited by one comma, one or more spaces, one
asterisk, or the beginning or ending of a line. Two successive
commas constitute a null parameter, which is returned as a single
space. The first space character at the end of a parameter acts
as a delimiter, any subsequent space characters are ignored, as
are any spaces after a comma, between a parameter and an asterisk,
etc. An asterisk acts as a multiplier count. The parameter
immediately preceding the asterisk MUST be a legal positive number
1 < n < 100. The parameter immediately following the asterisk
is then repeated N times. For instance,
0.0, 4*1.0
parses as
0.0 1.0 1.0 1.0 1.0

Dummy Arguments

logical errflg
character(*) linein, lineot
dimension index(2,nwant)

Global Common Blocks

parameter (iucmd=1, iuin=5, iout=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile

Local Variables

logical open, quote, comma
character char*1, string*80

******************************************************************************
Subroutine PARSER

C Begin Execution

C *********************************************************************

C Preset indices and limits before entering the parsing loop.

maxout = len (lineot)
ichlst = ichlnb (linein)
nparam = 0
nchout = 0
nch = 0
nchp = 0
nmult = 1
string = '
open = .false.
quote = .false.
comma = .true.
errflg = .false.

C Preset all the pointers in INDEX to point to a blank at the end of the
C output line.

lineot = '
   do 10 n = 1, nwant
      index(1,n) = maxout
      index(2,n) = maxout
   10 continue
   maxout = maxout - 1

C Now enter the main parsing loop. Loop over each character, examining
C it and taking appropriate action.

1000 continue
   nch = nch + 1

C Check whether we have gotten to the end of the line; if so,
C finish the last parameter (if any) and return

if (nch .gt. ichlst) then
   if (open .or. comma) then
      nmult = min (nmult, (nwant - nparam))
      nchp = max (nchp,1)
      do 100 n = 1, nmult
         nparam = nparam + 1
         index(1,nparam) = nchout + 1
         index(2,nparam) = index(1,nparam) + nchp - 1
         if (index(2,nparam) .gt. maxout) go to 2100
         lineot(index(1,nparam):index(2,nparam)) =
            string(l:nchp)
         nchout = index(2,nparam)
      100 continue
   endif
   return
Subroutine PARSER

If we are not at the end of the line yet, strip the current character off and process it.

else
char = linein(nch:nch)

If the character is a double quote ("), then toggle the QUOTE flag

if (char .eq. "") then
    quote = .not. quote
    open = .true.
    comma = .false.

If the quote flag is in effect, then don't look at the character, just add it to the string.

elseif (quote) then
    nchp = nchp + 1
    if (nchp .gt. 80) go to 2200
    string(nchp:nchp) = char
    open = .true.
    comma = .false.

If the character is a comma, then it delimits the end of a parameter, (if a parameter is presently in progress). Likewise, a comma following another comma with no intervening parameters is a null parameter. In either case, set the pointers to the parameter in INDEX and reset the parameter string.

elseif (char .eq. ',') then
    if (open .or. comma) then
        nmult = min (nmult, (nwant - nparam))
        nchp = max (nchp,1)
        do 200 n = 1, nmult
            nparam = nparam + 1
            index(1,nparam) = nchout + 1
            index(2,nparam) = index(1,nparam) + nchp - 1
            if (index(2,nparam).gt.maxout) go to 2100
            lineout(index(1,nparam):index(2,nparam)) =
                string(1:nchp)
            nchout = index(2,nparam)
        200 continue
        if (nparam .eq. nwant) return
        nmult = 1
        open = .false.
        string = ' '
        nchp = 0
    endif
    comma = .true.

If the character is an asterisk, it delimits a parameter which is a multiplier count for the next parameter in the series. If a parameter is presently open, then close it and decode it. If there
c is no parameter open, then strip the last previous parameter off
c of the output and use it for the multiplier count.
c
elseif (char .eq. '*') then
  if (.not. open) then
    if (nparam .gt. 0) then
      string =
      lineot(index(1,nparam):index(2,nparam))
      index(1,nparam) = maxout + 1
      index(2,nparam) = maxout + 1
      nparam = nparam - 1
    endif
  endif
  endif
  nmult = ivalue (string,errflg)
  if (errflg) go to 2000
  nrult = max (nmult,1)
  nchp = 0
  string = ' '
  comma = .true.
  open = .false.

elseif (char .eq. ' ') then
  if (open) then
    nmult = min (nmult, (nwant - nparam))
    nchp = max (nchp,1)
    do 300 n = 1, nmult
       nparam = nparam + 1
       index(1,nparam) = nchout + 1
       index(2,nparam) = index(1,nparam)+nchp-1
       if (index(2,nparam).gt.maxout) go to 2100
       lineot(index(1,nparam):index(2,nparam)) =

       string (1:nchp)
       nchout = index(2,nparam)
 300     continue
  endif
  if (nparam .eq. nwant) return
  nmult = 1
  open = .false.
  string = ' '
  nchp = 0
endif

else
  nchp = nchp + 1
  if (nchp .gt. 80) go to 2200
  string(nchp:nchp) = char
  open = .true.
  comma = .false.
endif
endif

go to 1000

c
End of the Main Parsing Loop

c

**** ERROR PROCESSING

c
Come here if an error is detected in a multiplier count

c
2000 continue
  ns = max (nch - 60, 1)
  nf = min (ns + 79, ichlst)
  write (iuot,2010) linein(ns:nf), ('.', n = ns, nch - 1), ''
2010 format ('***** ERROR: Illegal multiplier count.'/lx,a/lx,80al)
  errflg = .true.
  return

c
Come here if the output line overflows

c
2100 continue
  ns = max (nch - 60, 1)
  nf = min (ns + 79, ichlst)
  write (iuot,2110) linein(ns:nf), ('.', n = ns, nch - 1), ''
2110 format ('***** ERROR: Line Overflow in Parser '/lx,a/lx,80al)
  errflg = .true.
  return

c
Come here if a parameter is too long for STRING

c
2200 continue
  ns = max (nch - 60, 1)
  nf = min (ns + 79, ichlst)
  write (iuot,2210) linein(ns:nf), ('.', n = ns, nch - 1), ''
2210 format ('***** ERROR: Parameter Too Long in Parser '/
  1 lx,a/1x,80al)
  errflg = .true.
  return
end
subroutine pdistn (ncls)

*******************************************************************************
This subroutine calculates the Q (annual mileage) values corresponding to even values of CP for the cumulative lognormal distribution function CP(Q) whose parameters are given by VMTAVG(NCLS) and VMTSTD(NCLS). These Q values are the boundary points between cells in the discretized mileage distribution (each cell corresponds to one "mileage group"). The routine also calculates the weighted average annual mileage within each mileage group. These are saved in VMTGRP.

The Q calculation is done by numerically integrating the lognormal distribution function, using linear interpolation and the trapezoid rule for integration. Weighted average mileage for each group is calculated as the Q coordinate of the centroid of the area under the Q-P curve.

*******************************************************************************

*** GLOBAL COMMON BLOCKS

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
common /mileag/ yrmbas(ipny,ipnc), yrmile(ipny,ipnc),
1 vmtavg(ipnc), vmtstd(ipnc), vmtgrp(ipng)

*******************************************************************************

Begin Execution

*******************************************************************************

Set up before entering the numerical integration loop. Convert mean and standard deviation to sigma prime and mu prime for the lognormal function (see thesis Chapter 4 for this).

\[ xx = \frac{vmtstd(ncls)}{vmtavg(ncls)} \]
\[ \text{sigsq} = \text{alog} (xx^2 + 1.0) \]
\[ \text{sigma} = \sqrt{\text{sigsq}} \]
\[ \text{xmu} = vmtavg(ncls) \times \exp (-0.5 \times \text{sigsq}) \]
\[ \text{sqr2pi} = \sqrt{8.0 \times \text{atan}(1.0)} \]

Set counters and so forth to initial values before entering the loop.

\[ \text{dpccel} = 1.0 / \text{float}(ipng) \]
\[ \text{spcell} = \text{dpccel} \]
\[ \text{qinc} = \text{vmtavg(ncls)} \times 0.01 \]
\[ \text{qmax} = \text{vmtavg(ncls)} + 5.0 \times \text{vmtstd(ncls)} \]
\[ q = 0.0 \]
\[ \text{plast} = 0.0 \]
\[ \text{qlast} = 0.0 \]
\[ \text{spdq} = 0.0 \]
\[ \text{splast} = 0.0 \]
\[ \text{spqdq} = 0.0 \]
\[ \text{spqlst} = 0.0 \]
Appendix C: FORTRAN Code For The Model
Subroutine PDISTN

spgbl = 0.0
ngrp = 1

*** Enter The Numerical Integration Loop ***

100 continue

Increase mileage counter Q by one increment, then calculate the value
of P(Q) (the probability distribution function) for the endpoint of
the increment.

q = q + qinc
xx = alog (q / xmu) / sigma
p = exp (-0.5 * xx**2) / (q * sigma * sqr2pi)

Calculate (P * dq) and (P * Q * dq) using the trapezoid rule, and add
them to the integrals of P(Q) and Q * P(Q) respectively. These integrals
are the cumulative probability distribution function CP(Q) and the
probability-weighted average mileage, respectively.

pdq = (plast + p) * 0.5 * qinc
spdq = spdq + pdq
spqdq = spqdq + pdq * (q + qlast) * 0.5

If adding this increment to P * dq causes us to cross a cell boundary,
then we stop and calculate the weighted average mileage within the
cell, and reset the boundary and counters for next time. If we
have reached the last cell, escape from the loop.

if (spdq .ge. spcell) then
   frac = (spcell - splast) / (spdq - splast)
pb = (p - plast) * frac + plast
qb = qinc * frac + qlast
spqbl = spqlst +
   1          (pb + plast) * qinc * frac * (qb + qlast) * 0.25
vmtgrp(ngrp) = (spqbl - spgbl) / dpcell
ngrp = ngrp + 1
   if (ngrp .gt. ipng) go to 200
spcell = spcell + dpcell
spqbl = spqbl
elseif (q .gt. qmax) then
   spqbl = spqlst + plast * qinc * (qlast + q) * 0.25
vmtgrp(ngrp) = (spqbl - spgbl) / dpcell
   go to 200
endif

Transfer values for p and q to plast and qlast, to use in trapezoid
rule calculations for the next increment.

plast = p
qlast = q
splast = spdq
Subroutine PDISTN

    spqlst = spqdx
    c Go back for the next increment
    c   go to 100
    c
    c *** End of Numerical Integration Loop ***
    c
    c Come here after calculating average mileage for the last group.
    c 200 continue
    c c Return
    c      return
    end
subroutine readin (errflg)

This subroutine reads the data input file for the TRATEC model and
sets the data in common blocks /MODEL/, /FLAGS/, /ECON/, and /MILEAG/, and
sets the initial fleet composition in /FLEET/. ERRFLG is returned .FALSE. unless an error is detected or insufficient data are read, in which case it is returned .TRUE.

** INPUT FILE SPECIFICATION

SEE THE TRATEC USER'S MANUAL FOR A MORE COMPLETE DISCUSSION

The input file is a coded (card-image) file. It is divided into
"groups" of lines, which are separated by one or more blank lines.
The contents of each group of lines are concatenated before being passed to the parser, so the number of physical lines in each group doesn't matter, as long as all the required parameters are there. Parameters are separated by blank spaces, commas, or the end-of-line on a physical line, which functions as a blank space.

The first parameter in each group must be the group identifier, which is a on-word string identifying the contents of each group. The following groups MUST be included in the input file:

- MODEL — Specifies years, number of classes, and title
- CLASSES — Identifies classes and technologies for each class
- ECON — Specifies economic parameters — elasticity, etc.
- FUELPRICE — Specifies fuel prices for each fuel and year.
- TOTVMT — Specifies total base VMT for each class and year.
- VMIDISTN — Specifies VMT distribution for each class.
- END — Marks the end of the input deck.

The following groups MAY be included in the input file.

- SALES — Specify the initial fleet composition by sales data.
- FLEET — Specify the initial fleet composition directly.

MODEL must be the first group in the file, CLASSES must be the second, and END must be the last. The order of the other groups in the file is not important. Generally, only one of each group is entered, and the last one of each group overrides any previous groups of the same type. The exception is for FLEET and SALES. With these, one group is entered for each technology in the initial fleet. FLEET and SALES are mutually exclusive — if one is used for one technology, it must be used for each technology.

*****************************************************************************

Dummy Argument

logical errflg
Appendix C: FORTRAN Code For The Model

Subroutine READIN

Global Common

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend,
1 nypres, nfuels, nscost, ntclas(ipnc), itech(ipnt,ipnc)
character*11 title*80, clsnam*20, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
parameter (iucnd=1, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile
logical sdflag, grafic, clsprt, scflag, echo, tcecho, fltprt
common /flags/ sdflag, grafic, clsprt, scflag, echo, tcecho,
1 fltprt, infltp, nmax
common /econ/ discnt(ipnc), elast(ipnc), beta(ipnc),
1 ctrans(ipnc), premnv(ipnc), pfuel(ipny,ipnf,2)
common /mileag/ yrmbas(ipny,ipnc), yrmile(ipny,ipnc),
1 vmtavg(ipnc), vmtstd(ipnc), vmtgrp(ipng)
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc),
1 nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 restd(ipntc)
character technm*20
common/techc/ technm(ipnt)
logical zrflag
common /fleet/ elx(ipntc,ipng,ipny), elx2(ipntc,ipng,ipny),
1 elt(ipntc,ipng,ipny), elt2(ipntc,ipng,ipny), pnvnew(ipntc,ipng),
2 pmkt(ipng), xvold(ipng), xvnew(ipng), xinit(ipny,ipnt),
3 zrflag(ipng)

External Functions

character upper*80, cdecod*20
logical ydecod

Local Variables and Arrays

logical clflag, ecflag, fpflag, tvflag, vdflag, slflag, flflag
character*20 label, name
character*2000 text
dimension xdt(ipny), zd(t(ipny,ipnc)

Index array for parameters

dimension ix(2,200)

Equivalence first few cells of IX to small variables for easy reference

equivalence (il, ix(1,1)), (i2, ix(2,1))

Begin Execution
Subroutine READIN

C **********************************************************************
C c Preset flags and error counter
C clflag = .false.
ecflag = .false.
fpflag = .false.
tvflag = .false.
vdflag = .false.
slfag = .false.
fiflag = .false.
nerrs = 0
C Zero out the initial fleet
C do 30 nt = 1, ipnt
   do 20 ny = 1, ipny
     xinit(ny,nt) = 0.0
   20 continue
 30 continue
C If ECHO is set, print header for input data listing.
C if (echo) write (iuot,6000) infile
   6000 format ('1',130('*')//t10,'***** MK4EL INPUT DATA ***** '//'
         1 tl5,'Reading input from file: ',a/'0',130('=')/)
C Read The Model Specification Group and Set Appropriate Parameters
C Go read the first group in the input file, aborting if an error occurs
C call getinp (iuin,200,text,nparam,ix,errflg,echo)
if (errflg) return
C Check that the first group is the MODEL group, then decode model
C parameters.
C label = upper(text(il:i2))
if (label .eq. 'MODEL') then
   if (echo) write (iuot,6005) label
   6005 format ('0 ***** GROUP: ',a20)
     nclass = idecod (text,2,nparam,ix,nerrs)
     dstart = idecod (text,3,nparam,ix,nerrs)
     dpres = idecod (text,4,nparam,ix,nerrs)
     dend = idecod (text,5,nparam,ix,nerrs)
     nfuels = decode (text,6,nparam,ix,nerrs)
     scflag = ydecode (text,7,nparam,ix,nerrs)
     do 80 n = 1, 3
       ndx = n + 7
       title(n) = text(ix(1,ndx):ix(2,ndx))
 80 continue
Subroutine READIN

If any errors were found, abort with error message.

If (nerrs .gt. 0) then
    write (iuot, 6010)
    6010 format ('0***** ERRORS READING MODEL SPECIFICATION *****' /
          1    ' ***** PROGRAM ABORTED ***** ')
    errflg = .true.
    return
endif

c Check that NCLASS is not too large or too small
if (nclass .lt. 1 .or. nclass .gt. ipnc) then
    write (iuot,6020) nclass, ipnc
    6020 format ('0***** ERROR -- BAD VALUE FOR NUMBER OF CLASSES' /
             1 16x,'NCLASS was input as ',14,' but must be between 0 and ',
             2 i4)
    nerrs = nerrs + 1
endif

c Check that NFUELS is not too large or too small
if (nfuels .lt. 1 .or. nfuels .gt. ipnf) then
    write (iuot,6025) nfuels, ipnf
    6025 format ('0***** ERROR -- BAD VALUE FOR NUMBER OF FUELS' /
             1 16x,'NFUELS was input as ',14,' but must be between 1 and ',
             2 i4)
    nerrs = nerrs + 1
endif

c Calculate the number of years in the model, and the number of the
c present year, aborting with an error message if these are wrong.
nypres = dpres - dstart + 1
nyend = dend - dstart + 1
if (nyend .lt. 1 .or. nypres .lt. 1 .or. nyend .gt. ipny
  1 .or. nypres .gt. nyend) then
    nerrs = nerrs + 1
    write (iuot,6030) dstart, dpres, dend, ipny
    6030 format ('0***** ERROR -- BAD VALUE(S) FOR DATES' /
            1 16x,'DSTART = ',i4,' DPRES = ',14,' DEND = ',i4/
            2 16x,'DEND - DSTART must be less than ',i4,' and DEND =>',
            3 ' DPRES => DSTART')
endif

c Set the social-cost index to 1 (if social costs are not used) or 2
c (if they are).
if (scflag) then
    nscost = 2
else
    nscost = 1
endif
Appendix C: FORTRAN Code For The Model

Subroutine READIN

C If any errors were found, abort with error message.
C
C if (nerrs .gt. 0) then
  write (iout, 6040)
  6040 format ('0****** ERRORS IN MODEL SPECIFICATION *****'/
  1 ' ***** PROGRAM ABORTED ***** ')
  errflg = .true.
  return
endif
C
C If ECHO is set, print the model specifications to the output file.
C
if (echo) write (iout,6050) nclass, dstart, dpres, dend,
1 nfuels, scflag, title
6050 format ('1***** MODEL SPECIFICATIONS *****//'/
1 tl0,'NUMBER OF USER CLASSES = ',i2/
2 tl0,'FIRST YEAR = ',i4,t35,'PRESENT YEAR = ',i4,
3 t70,'LAST YEAR = ',i4/
4 tl0,'NUMBER OF FUELS = ',i2,t35,'SOCIAL-COST FLAG = ',//
5 tl0,'MODEL TITLE'/tl5, a/tl5, a/tl5,a)
if (echo) write (iout,6990)
C
C If the first group in the input file is not MODEL, abort with error
C message.
C
else
  write (iout,6060) infile
6060 format ('0****** ERROR — FIRST GROUP IN FILE: ',a,' IS NOT ',
1 'MODEL" GROUP *****'/0****** READING ABORTED')
  errflg = .true.
  return
endif
C
C Read The Class/Technology Specification Group and Set Parameters
C
C Read the next group in the input file, aborting if an error occurs
C
  call getinp (iuin,200,text,nparam,ix,errflg,echo)
if (errflg) return
C
C Check that this group is the CLASSES group, then start reading the
C name and list of technologies for each class.
C
  label = upper(text(il:i2))
  if (label .eq. 'CLASSES') then
    if (echo) write (iout,6005) label
    ntechn = 0
    ndx = 1
    do 150 nc = 1, nclass
      ndx = ndx + 1
      clsnam(nc) = cdecode(text,ndx,nparam,ix,nerrs)
      ndx = ndx + 1
  150  continue
  endif
Subroutine READIN

ntclas(nc) = idecod(text,ndx,nparam,ix,nerrs)
if (ntclas(nc) .gt. ipntc .or. ntclas(nc) .lt. 1) then
  write (iuot,6100) clsnam(ntc), ntclas(nc), ipntc
  6100 format ('0***** ERROR — BAD VALUE FOR NUMBER OF '  
  'TECHNOLOGIES FOR CLASS ',a20,' *****'/16x,  
  'Value entered was ',i4,'. Value must be between ',  
  '1 and ',i4/' ***** READING ABORTED *****')
  erfflg = .true.
  return
endif
do 140 nt = 1, ntclas(nc)
  ndx = ndx + 1
  name = cdecode (text,ndx,nparam,ix,nerrs)
  ntr = lookup (name,technm,ntechn)
  if (ntr .eq. 0) then
    ntechn = ntechn + 1
    if (ntechn .le. ipnt) then
      itech (nt,nc) = ntechn
      technm(ntechn) = name
    else
      write (iuot,6110) ntr
      6110 format ('0***** ERROR — TOO MANY TECHNOLOGIES',  
      'SPECIFIED IN "CLASSES". *****'/16x,  
      'MAXIMUM OF ',i2,'TECHNOLOGIES ARE ALLOWED FOR',  
      'ALL CLASSES — ADDITIONAL ONES IGNORED')
      nerrs = nerrs + 1
    endif
  else
    write (iuot,6120) nt, name, clsnam(nc)
    6120 format ('0***** ERROR -- TECHNOLOGY ',i4,  
    ',a20,' FOR CLASS ',a20,' HAS ALREADY BEEN SPECIFIED.'  
    '***** NO DUPLICATE TECHNOLOGIES ARE ALLOWED ')
    nerrs = nerrs + 1
  endif
140 continue
150 continue

c If ECHO is set, print the classes data on the output file
c
if (echo) then
  write (iuot,6140)
  6140 format ('0***** VEHICLE CLASSES AND TECHNOLOGIES *****'/  
  'CLASS ',t20,'VEHICLE CLASS',t40,' TECH.',  
  'AVAILABLE TECHNOLOGIES'/)
  do 160 nc = 1, nclass
    write (iuot,6150) nc, clsnam(nc), ntclas(nc),  
    (technm(itech(nt,nc)), nt = 1, ntclas(nc))
    6150 format (t10,t13,t20,a20,t40,i3,t50,4a20/(t50,4a20/))
  160 continue
  write (iuot,6990)
endif

c If the second group in the file is not CLASSES, print error message and
c abort the program.
Subroutine READIN

write (iuot,6190) infile
6190 format ('0 ***** ERROR — SECOND GROUP IN FILE: ',a,' IS NOT ',
1 "CLASSES" GROUP *****'/0 ***** READING ABORTED')
errflg = .true.
return
endif

c Loop, Reading In One Group At A Time. Look At The Group Specifier,
c Then Go To The Right Location To Decode That Group.
c
200 continue
    call getinp (iuin,200,text,nparam,ix,errflg,echo)
    if (errflg) return
    label = upper (text(il:i2))
    if (echo) write (iuot,6005) label
    c ECON — Set Discount Rates, Etc.
c
    if (label .eq. 'ECON') then
        ecflag = .true.
        ndx = 1
        do 250 nc = 1, nclass
            ndx = ndx + 1
            discnt(nc) = decode (text,ndx,nparam,ix,nerrs)
            ndx = ndx + 1
            elast(nc) = decode (text,ndx,nparam,ix,nerrs)
            ndx = ndx + 1
            beta(nc) = decode (text,ndx,nparam,ix,nerrs)
            ndx = ndx + 1
            ctrans(nc) = decode (text,ndx,nparam,ix,nerrs)
            ndx = ndx + 1
            premv(nc) = decode (text,ndx,nparam,ix,nerrs)
        250 continue
        if (echo) then
            write (iuot,6250)
3250 format ('0 ***** ECONOMIC PARAMETERS BY CLASS *****'//
1 t10,'CLASS ','t20','CLASS NAME','t40','DISCOUNT RATE','t55, 
2 'ELASTICITY','t70,' BETA','t85,'TRANS. COST','t10, 
3 'NEW-VEHICLE PREMIUM'/)
        do 270 nc = 1, nclass
            write (iuot,6270) nc, clsnam(nc), discnt(nc)
3270 format (t10,12,t20,a20,5(f11.4,4x))
        270 continue
    endif
    c FUELPRICE — Fuel Prices
    c
    elseif (label .eq. 'FUELPRICE') then
        fpflag = .true.
-403-
Subroutine READIN

ndx = 1
do 330 nf = 1, nfuels
   ndx = ndx + 1
   fuelnm(nf) = cdecode (text,ndx,nparam,ix,nerrs)
   continue

  330 do 350 ny = 1, ipny
    ndx = ndx + 1
    if (ndx .gt. nparam) go to 360
    xdt(ny) = float(idecode(text,ndx,nparam,ix,nerrs)-dstart) + 1.0
    do 340 nf = 1, nfuels
      ndx = ndx + 1
      zdt(ny,nf) = decode(text,ndx,nparam,ix,nerrs)
      if (scflag) then
         ndx = ndx + 1
         zdt(ny,nf+ipnf) = decode(text,ndx,nparam,ix,nerrs)
      endif
      continue
  340 continue
  350 continue
  ny = ipny
  continue
  360 ntable = ny - 1
  do 380 nf = 1, nfuels
    do 370 ny = 1, nyend
      xyr = float(ny)
      pfuel(ny,nf,1) = zintrp(xyr,xdt,zdt(1,nf),ntable)
      if (scflag) pfuel(ny,nf,2) =
         zintrp(xyr,xdt,zdt(1,nf+ipnf),ntable)
    370 continue
    continue
  380 continue
  if (echo .and. scflag) then
    write (iuot,6350) (fuelnm(nf), nf = 1, nfuels)
    6350 format ('0 ***** FUEL PRICES BY YEAR *****'/
     tl0,'YEAR',t32,3(a15,15x))
    write (iuot,6360) (' PRICE ',' SOCIAL COST ',
     nf = 1, nfuels)
    6360 format (t20,3(2a15))
    write (iuot,6380)
    6380 format (lx)
    do 390 ny = 1, nyend
      iyear = ny + dstart - 1
      write (iuot,6370) iyear,
       (pfuel(ny,nf,1), pfuel(ny,nf,2), nf=1,nfuels)
      6370 format (t10,i4,t20,6(f8.4,7x))
      continue
    elseif (echo) then
      write (iuot,6350) (fuelnm(nf), nf = 1, nfuels)
      write (iuot,6380)
      do 395 ny = 1, nyend
        iyear = ny + dstart - 1
        write (iuot,6390) iyear, (pfuel(ny,nf,1), nf=1,nfuels)
      6390 format (t10,i4,t20,3(f8.4,22x))
      continue
  395 endif
Subroutine READIN

**TOTVMT** — Mileage per year for each class in each year.

```fortran
   elseif (label .eq. 'TOTVMT') then
      tvflag = .true.
      ndx = 1
      do 450 ny = 1, ipny
         ndx = ndx + 1
         if (ndx .gt. nparam) go to 460
         xdt(ny) = float(idecod(text,ndx,nparam,ix,nerrs)-dstart) + 1.0
         do 440 nc = 1, nclass
            ndx = ndx + 1
            zdt(ny,nc) = decode(text,ndx,nparam,ix,nerrs)
            continue
            440 continue
            450 continue
      ny = ipny
      460 continue
      ntable = ny - 1
      do 480 ny = 1, nyend
         xyr = float(ny)
         do 470 nc = 1, nclass
            yrmbas(ny,nc) = zintrp(xyr,xdt,zdt(l,nc),ntable)
            continue
            470 continue
      if (echo) then
         write (iuot,6450) (clsnam(nc), nc = 1, nclass)
      6450 format ('0 ***** BASE TOTAL VMT BY CLASS AND YEAR *****' /
         /tl0,'YEAR',t20,5a20/(t20,5a20/))
      write (iuot,6380)
      do 490 ny = 1, nyend
         iyear = ny + dstart - 1
         write (iuot,6470) iyear, (yrmbas(ny,nc), nc = 1, nclass)
      6470 format (tl0,i4,t20,5(f15.0,5x)/(t20,5(f15.0,5x)/))
      490 continue
      endif
```

**VMTDISTN** — Mean and standard deviation of lognormal VMT distribution for each class.

```fortran
   elseif (label .eq. 'VMTDISTN') then
      vdflag = .true.
      ndx = 1
      do 550 nc = 1, nclass
         ndx = ndx + 1
         vmtavg(nc) = decode(text,ndx,nparam,ix,nerrs)
         ndx = ndx + 1
         vmtstd(nc) = decode(text,ndx,nparam,ix,nerrs)
         continue
      if (echo) then
         write (iuot,6550)
         6550 format ('0 ***** VMT DISTRIBUTION PARAMETERS BY CLASS ' , /
            ', ! *****/tl0,'CLASS ',t20,'CLASS NAME',t40, 
```
Subroutine READIN

2 'MEAN OF VMT',t55,'VMT STANDARD DEVIATION'/)
do 570 nc = 1, nclass
   write (iuot,6570) nc,clsnam(nc),vmtavg(nc),vmtstd(nc)
6570 format (tl0,i2,t20,a20,2(fl0.4,5x))
570 continue
endif

c SALES — Sales of each technology in each year
c
elseif (label .eq. 'SALES') then
   if (flflag) then
      write (iuot,6600)
6600 format ('8***** ERROR — "SALES" GROUP ENTERED WHEN ',
1 'THERE IS ALREADY A "FLEET" GROUP IN EFFECT *****'/,
2 '***** SKIPPING "SALES" GROUP *****')
      nerrs = nerrs + 1
   else
      slflag = .true.
sdflag = .true.
      ndx = 2
      name = cdecode (text,ndx,nparam,ix,nerrs)
      nt = lookup (name,technm,ntechn)
      if (nt .eq. 0) then
         write (iuot,6610) name
6610 format ('8***** ERROR — TECHNOLOGY ',a20,' WAS ',
1 'NOT SPECIFIED FOR ANY CLASS *****'/,
2 '***** SKIPPING GROUP *****')
         nerrs = nerrs + 1
      else
         do 650 ny = 1, nypres - 1
            ndx = ndx + 1
            xinit(ny,nt) = decode (text,ndx,nparam,ix,nerrs)
650 continue
         if (echo) then
            write (iuot,6650) name
6650 format ('0 ***** SALES DATA FOR TECHNOLOGY ',a,
1 ' *****'//tl0,'YEAR',t20,'ANNUAL SALES/')
         nl = (nypres - 2) / 5
         do 670 n = 0, nl
            iy = dstart + n * 5
            nyl = n * 5 + 1
            ny2 = min (nyl+4,nypres-1)
            write (iuot,6670) iy, (xinit(ny,nt), ny=nyl,ny2)
6670 format (tl0,i4,t20,5(fl0.0,5x))
670 continue
      endif
   endif
endif

c FLEET — Record specifying the composition of the existing fleet in the
c base year.
c
elseif (label .eq. 'FLEET') then
   if (slflag) then
Subroutine READIN

write (iuot,6700)

6700 format ('0***** ERROR — ’FLEET’ GROUP ENTERED WHEN ’1',
1 'THERE IS ALREADY A ’SALES’ GROUP IN EFFECT *****'/
2 '***** SKIPPING ’FLEET’ GROUP *****')
nerrs = errs + 1
else
filflag = .true.
sdflag = .false.
ndx = 2
name = cdecode (text,ndx,nparam,ix,nerrs)
nt = lookup (name,technm,ntechn)
if (nt .eq. 0) then
write (iuot,6610) name
nerrs = errs + 1
else
do 750 ny = 1, nypres - 1
ndx = ndx + 1
xinit(ny,nt) = decode (text,ndx,nparam,ix,nerrs)
750 continue
if (echo) then
write (iuot,6750) name, dpres
6750 format ('0***** INITIAL FLEET FOR TECHNOLOGY ’a, 
1 ' *****/t5,’MODEL YEAR’,t22,’NUMBER IN FLEET’
2 ' IN ’,i4/)
nl = (nypres - 2) / 5
do 770 n = 0, nl
iy = dstart + n * 5
ny1 = n * 5 + 1
ny2 = min (ny1+4,nypres-1)
write (iuot,6670) iy, (xinit(ny,nt), ny=ny1,ny2)
770 continue
endif
endif
endif
endif
endif

END — End of data file. Check to make sure we have all data and
print error message if not. Return ERRFLG as .FALSE. if we
have all data, .TRUE. if not.

elseif (label .eq. 'END') then
if (.not. ecflag) then
write (iuot,6920) 'ECON'
6920 format ('0***** ERROR — MISSING REQUIRED DATA GROUP: ’a,’
1 ' *****')
nerrs = errs + 1
endif
if (.not. fpflag) then
write (iuot,6920) 'FUELPRICE'
nerrs = errs + 1
endif
if (.not. tvflag) then
write (iuot,6920) 'TOTVMT'
nerrs = errs + 1
endif
Subroutine READIN

if (.not. vdflag) then
  write (iuot,6920) 'VMIDISTN'
  nerrs = nerrs + 1
endif
if (nerrs .gt. 0) then
  errflg = .true.
  write (iuot,6930) nerrs
  format(['0***** ',i4, ' FATAL INPUT ERRORS DETECTED *****'/1
    ' ***** PROGRAM ABORTED *****'])
else
  if (echo) write (iuot,6940)
  format('0***** INPUT DATA SUCCESSFULLY READ IN *****'/1
    '0',130('*'))
endif
return

c Unrecognized group label, print error message and go on.
c
else
  write (iuot,6950) label
  format('0***** ERROR — UNRECOGNIZED GROUP LABEL: ',a20/
    '0***** SKIPPING THIS GROUP *****')
  nerrs = nerrs + 1
endif

c End of loop, write a separator.
c
if (echo) write (iuot,6990)
format('0',130('=')/
go to 200

c
End of Loop To Read Groups Of Cards

end
subroutine readt (ntr, ntx)

THIS SUBROUTINE DOES A RANDOM READ OF TECHNOLOGY RECORD NUMBER NTR, 
PUTTING THE DATA INTO INDEX LOCATION NTX IN /TECH/.

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
character*63 infile, outfil, tefile, dbfile, grfile
common /systmc/ infile, outfil, tefile, dbfile, grfile
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc), 
nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2), 
cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc), 
retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)

read (iudb,rec=ntr) ntech(ntx), nytfst(ntx), nytlst(ntx), 
((cfirst(ny,ntx,ns),ny = 1, ipny), ns = 1, 2), 
((cfixed(ny,ntx,ns),ny = 1, ipny), ns = 1, 2), 
((cmaint(ny,ntx,ns),ny = 1, ipny), ns = 1, 2), 
((fucons(nf,ny,ntx),nf = 1, ipnf),ny = 1, ipny), 
retavg(ntx), retstd(ntx)
return
end
subroutine readtc (errflg)

*******************************************************************************
This subroutine reads the technology data-base file for the TRATEC model, checks it, the writes it out again to a random-access file.
The input file for the technology data-base is assumed already to be open on unit IUTC, and the random-access file is assumed to be open on unit IUDM. ERRFLG is returned .FALSE. unless an error is detected, in which case it is returned .TRUE.
*******************************************************************************

** TECHNOLOGY DATA-BASE FILE SPECIFICATION

SEE THE TRATEC USER'S MANUAL FOR A MORE COMPLETE DISCUSSION

The input technology data-base file is a coded (card-image) file. It is divided into "groups" of lines, separated by one or more blank lines. These are parsed, converting the group into a list of values. The contents of each group of lines are concatenated before being passed to the parser, so the number of physical lines in each group doesn't matter, as long as all the required parameters are there. Parameters are separated by blank spaces, commas, or the end-of-line on a physical line, which functions as a blank space.

The data for each technology are input as a separate group. The first parameter for each technology must be the technology name, which must be a unique string (note — all names are converted to upper-case, so that "GASOLINE CAR" and "Gasoline Car" are the same name. This is followed by the values for RETXVG, RETSTD, and then a series of (YEAR, CFIRST(YEAR), CFIXED(YEAR), CMAINT(YEAR), (FUCONS(NF,YEAR), NF = 1, IPNF)). The first year in the list is taken as the first year for which this technology is available, and the last year in the list is taken as the last year it is available.

*******************************************************************************

Dummy Argument

logical errflg

Global Common

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend, nypres, nfuels, nscost, ntcclas(ipnc), itech(ipnt,ipnc)
character*ll title, clsnam*20, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
parameter (iucmd=l, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile
logical sdflag, grafic, clsprt, scflag, echo, tcecho, fltprt
common /flags/ sdflag, grafic, clsprt, scflag, echo, tcecho,
Subroutine READTC

1 fltptr, infltp, nimax
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc),
1 nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)

Character Upper*80, cdecod*20

Local Variables and Arrays

character*20 name
character*2000 text
logical tflag
dimension xdt(ipny), zdt(ipny,ipnf+6), tflag(ipnt)

dimension ix(2,200)

Index array for parameters

equivalence (il, ix(1,1)), (i2, ix(2,1))
neprs = 0

Set flags for each technology in TECHNM to .FALSE.
do 30 nt = 1, ntechn
tflag(nt) = .false.
30 continue
c If TCECHO is set, print header for technology listings.
if (TCECHO) write (iuot,6000) tcfile
6000 format (l,130('*')//tl0,'***** TECHNOLOGY DATA-BASE ***** '//
1 tl5,'Reading from data-base file: ',a/'0',130('=')/

Loop, Reading In One Technology At A Time And Checking It.

100 continue
call getinp (iutc,200,text,nparam,ix,errflg,tcecho)
Subroutine READTC

if (errflg) return

C Convert technology name to uppercase and check whether it is "END".
C If not, check whether it is in the list of technologies for this model.
C
name = cdecod (text,1,nparam,ix,nerrs)
if (name .eq. 'END') go to 500
ntr = lookup (name,techn,ntechn)

C If this technology is in use, strip off and decode the average and
C standard deviation of mileage at retirement.
if (ntr .ne. 0) then
  tflag(ntr) = .true.
  retavg(l) = decode (text,2,nparam,ix,nerrs)
  retstd(l) = decode (text,3,nparam,ix,nerrs)
endsubroutine READTC

C Now read the table of data from which to construct the first-cost,
C fixed cost, maintenance cost, and fuel-consumption arrays
C
ndx = 3
do 350 ny = 1, ipny
  ndx = ndx + 1
  if (ndx .gt. nparam) go to 360
  xdt(ny) = float(idecod(text,ndx,nparam,ix,nerrs)-dstart)
    + 1.0
    do 340 nz = 1, ipnf + 6
    ndx = ndx + 1
    zdt(ny,nz) = decode(text,ndx,nparam,ix,nerrs)
    340    continue
    350    continue
  ny = ipny
  360    continue
ntable = ny - 1

C Set the first year and last year this technology is available.
C
nytfst(l) = nint (xdt(l))
nytlst(l) = nint (xdt(ntable))

C Now set the values for the costs and fuel consumption for each
C year the technology is available, zeroing out the years it isnt.
C
do 380 ny = 1, ipny
  if (ny .ge. nytfst(l) .and. ny .le. nytlst(l)) then
    xyr = float(ny)
    cfirst(ny,1,1) = zintrp (xyr,xdt,zdt(1,1),ntable)
    cfirst(ny,1,2) = zintrp (xyr,xdt,zdt(1,2),ntable)
    cfixed(ny,1,1) = zintrp (xyr,xdt,zdt(1,3),ntable)
    cfixed(ny,1,2) = zintrp (xyr,xdt,zdt(1,4),ntable)
    cmaint(ny,1,1) = zintrp (xyr,xdt,zdt(1,5),ntable)
    cmaint(ny,1,2) = zintrp (xyr,xdt,zdt(1,6),ntable)
    do 370 nf = 1, ipnf
      fucons(nf,ny,1)=zintrp(xyr,xdt,zdt(1,nf+6),ntable)
      370    continue
else
  cfirst(ny,1,1) = 0.0
  cfirst(ny,1,2) = 0.0
  cfixed(ny,1,1) = 0.0
  cfixed(ny,1,2) = 0.0
  cmaint(ny,1,1) = 0.0
  cmaint(ny,1,2) = 0.0
  do 375 nf = 1, ipnf
     fucons(nf,ny,1) = 0.0
  continue
375 continue
endif
380 continue

c Write this record to the technology data base

c call writet (ntr, 1)
c
If TCECHO is set, echo this group to the output file.
c
if (tcecho) then
  write (iuot,6400) name, retavg(l), retstd(l)
6400 format('0 ***** TECHNOLOGY DATA RECORD FOR TECHNOLOGY: ',
1 a,' *****'//tl0,'Average Mileage at Retirement = ',f10.0/
2 tl0,'Standard Deviation of Mileage at Retirement = ',
3 f10.0//tl0,'COSTS BY MODEL YEAR'//
4 t20,' FIRST COST',t50,'ANNUAL FIXED COST',t80,
5 'MAINTENANCE COST PER MILE OR KM'//
6 tl0,'YEAR',t20,'PRIVATE',t35,'SOCIAL',t50,'PRIVATE',t65,
7 'SOCIAL',t80,'PRIVATE',t95,'SOCIAL'/)
iy1 = max (nytfst(1), 1)
iy2 = min (nytlst(1), ipny)
do 400 ny = iy1, iy2
  iyear = ny + dstart - 1
  write (iuot,6410) iyear, cfirst(ny,1,1),
1 cfirst(ny,1,2), cfixed(ny,1,1), cfixed(ny,1,2),
2 cmaint(ny,1,1), cmaint(ny,1,2)
6410 format(tl0,i4,t20,4(f11.2,5x) ,2(f10.7,5x))
400 continue
write (iuot,6420) (fuelnm(nf), nf = 1, nfuels)
6420 format('/0',tl0,'FUEL CONSUMPTION (MPG OR KM/LITER) ',
1 'BY MODEL YEAR'//tl0,'YEAR',t20,5a20)
do 450 ny = iy1, iy2
  iyear = ny + dstart - 1
  write (iuot,6450) iyear, (fucons(nf,ny,1), nf = 1, nfuels)
6450 format (tl0,i4,t20,5(f12.2,8x))
450 continue
endif

c Otherwise, if this technology is not in use, note that fact on the
c output file
c
else
  if (tcecho) write (iuot,6490) name
6490 format('0 ***** NOTE — TECHNOLOGY ',a,' NOT SPECIFIED ',
1 ' '
Appendix C: FORTRAN Code For The Model
Subroutine READTC

1 'FOR ANY CLASS — GROUP IGNORED *****')
endif

c Print separator, then go back and read the next group
c
if (tcecho) write (iuot,6495)
6495 format ('0',130('1=')/)
go to 100
c
End of Loop To Read Technology Records
c
END — End of data file. Check whether we have found all the
technologies we need.
c
500 continue
do 520 nt = 1, ntechn
if (.not. tflag(nt)) then
 write (iuot,6500) techm(nt)
6500 format ('0'**** ERROR — NO TECHNOLOGY RECORD FOR TECH',
 1 'NOLOGY 'a',' *****')
nerrs = errs + 1
endif
520 continue
c
Check whether errors have been detected, and if so, print error message
c and abort. Otherwise, print successful-completion message.
c
if (nerrs .gt. 0) then
 errflg = .true.
 write (iuot,6930) nerrs
6930 format('0***** ',i4, 'FATAL INPUT ERRORS DETECTED *****/
 1 ' ***** PROGRAM ABORTED *****')
else
 if (tcecho) write (iuot,6940)
6940 format ('0'**** TECHNOLOGY DATA-BASE SUCCESSFULLY READ',
 1 ' IN *****/0',130(' '*))
 errflg = .false.
endif
return
end subroutine report
c
This subroutine prints the results of the model calculation on
c file OUTFIL. If CLSPRT is .TRUE., then results are printed out by
c classes as well as grand totals, otherwise, only totals are printed.
c
Global Common Blocks
c
parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
Subroutine READTC

integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nynd,
1 npres, nfuels, nscost, nclas(ipnc), itech(ipnt,ipnc)
character*11 title*80, clsnam*20, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
parameter (iucmd=1, iuin=5, iout=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile
logical sdflag, grafic, clsprt, scflag, echo, tcecho, fltprt
common /flags/ sdflag, grafic, clsprt, scflag, echo, tcecho,
1 fltprt, infltp, nimax
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc),
1 nycost(ipncy,ipntc,2), cmaint(ipny, ipntc, 2),
2 fucons(ipnf, ipny, ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)
common /reslts/ fuel(ipnf,ipnc+l,ipny), omcost(ipnc+l,ipny,2),
1 cpcost(ipnc+l,ipny,2), fleetv(ipnc+l,ipny,2),
2 deprec(ipnc+l,ipny,2), tcostc(ipnc+l,ipny,2),
3 tcosta(ipnc+l,ipny,2), fleet(ipntc+l,ipnc,ipny),
4 sales(ipntc+l,ipnc,ipny)

Local Variables

character*20 tot, costyp(2)*7
data tot /' TOTAL'/, costyp /'PRIVATE','SOCIAL'/

**********************************************************************
Begin Execution
**********************************************************************

c Print title and model specifications

c write (iout,9000) title
9000 format ('1','130('=')/0***** Developing Country Transportation ',
1 'Fuel Use Model: Version 2.1 *****'/0',130('=')/3lx,a80/),
2 lx,130('=')
write (iout,9010) dstart, dpres, dend
9010 format ('0',5x,'Historical Data From: ',i4/
1 6x, 'Model Projections Beginning In: ',i4/
2 6x,'Ending Date For Projections: ',i4)
write (iout,9999)
9999 format ('0',130('='))
c Print total costs for all classes.

do 150 ns = 1, nscost
write (iout,9997)
9997 format ('1',130('='))
write (iout,9100) costyp(ns)
9100 format('0 ***** TOTAL ','a,' COST FOR ALL CLASSES *****')
write (iout,9999)
write (iout,9105)
Subroutine READTC

9105  format ('O',t15,'OM COST',t30,'CAPITAL COST',t45,
1 'FLEET VALUE',t60,'DEPRECIATION',t75,'TOTAL (CASH)',t90,
2 'TOTAL (ACCRUAL)')
write (iuot,9998)
9998  format (lx)
do 100 ny = nystrt, nyend
   iyr = ny + dstart - 1
   write (iuot,9120) iyr, omcost(ipnc+l,ny,ns),
1 cpcost(ipnc+l,ny,ns), fleetv(ipnc+l,ny,ns),
2 depreci(ipnc+l,ny,ns), tcostc(ipnc+l,ny,ns),
3 tcosta(ipnc+l,ny,ns)
9120  format (t4,i4,t12,7(gl5.4))
100  continue
write (iuot,9150)
9150  format ('8',130('='))
150  continue

c Print fuel consumption for all classes.
c
   write (iuot,9997)
   write (iuot,9200)
9200  format ('O ***** TOTAL FUEL CONSUMPTION FOR ALL CLASSES *****')
   write (iuot,9999)
   write (iuot,9205) (fuelnm(nf), nf = 1, nfuels), tot
9205  format ('O',t15,4a15)
   write (iuot,9998)
do 200 ny = nystrt, nyend
   totf = 0.0
   do 190 nf = 1, nfuels
      totf = totf + fuel(nf,ncls,ny)
190  continue
   iyr = ny + dstart - 1
   write (iuot,9120) iyr, (fuel(nf,ignc+l,ny),nf=l,nfuels), totf
200  continue
write (iuot,9150)
c
if (not. clsprt) go to 1000
do 500 ncls = 1, nclass
   ntc = ntclas(ncls)
c Print private and social costs for this class.
c
   do 350 ns = 1, nscost
      write (iuot,9300) costyp(ns), clsnam(ncls)
9300  format ('O',132('=')/
1 'O',20x,'***** ','a,' COSTS FOR CLASS: ',a20,' *****'/
2 'O',130('='))
   write (iuot,9105)
Subroutine READTC

write (iuot,9998)
do 300 ny = nystrt, nyend
  iyr = ny + dstart - 1
  write (iuot,9120) iyr, omcost(ncls,ny,ns), cpcost(ncls,ny,ns), fleetv(ncls,ny,ns),
                2  depreci(ncls,ny,ns), tcostc(ncls,ny,ns), tcosta(ncls,ny,ns)
300 continue

write (iuot,9150)
c
  c Print fuel consumption for this class.
c
  write (iuot,9997)
  write (iuot,9350) clsnam(ncls)
9350 format('0 ***** FUEL CONSUMPTION FOR CLASS: ',a, ' *****')
  write (iuot,9999)
  write (iuot,9205) (fuelnm(nf), nf = 1, nfuels), tot
  write (iuot,9998)
do 375 ny = nystrt, nyend
    totf = 0.0
    do 360 nf = 1, nfuels
      totf = totf + fuel(nf,ncls,ny)
360 continue
  iyr = ny + dstart - 1
  write (iuot,9120) iyr, (fuel(nf,ncls,ny),nf=l,nfuels), totf
375 continue
  write (iuot,9150)
c
  c Print New-Vehicle Sales for this class
  c
  write (iuot,9400) clsnam(ncls)
9400 format('l',130('=')/'0',20x,'***** NEW VEHICLE SALES ','
                1 'FOR CLASS: ',a20,' *****'/0,130('='))
  write (iuot,9410) (technm(itech(nt,ncls)), nt=1,ntc), tot
9410 format('0',tl0,'YEAR',t20,6a20)
  write (iuot,9415)
9415 format (lx)
do 420 ny = nystrt, nyend
  iyr = ny + dstart - 1
  write (iuot,9430) iyr, (sales(nt,ncls,ny), nt = 1, ntc),
                1  sales(ipntc+l,ncls,ny)
9430 format(tl0,i4,t20,5(f15.0,5x))
420 continue
  write (iuot,9150)
c
  c Print fleet composition for this class
  c
  write (iuot,9450) clsnam(ncls)
9450 format('l',130('=')/'0',20x,'***** FLEET COMPOSITION ','
                1 'FOR CLASS: ',a20,' *****'/0,130('='))
  write (iuot,9410) (technm(itech(nt,ncls)), nt=1,ntc), tot
  write (iuot,9415)
do 470 ny = nystrt, nyend
Subroutine READTC

\[
\text{iyr} = \text{ny} + \text{dstart} - 1
\]

\[
\text{write (iuot,9430) iyr, (fleet(nt,ncls,ny),nt=1,ntc),}
\]
\[
\text{fleet(ipntc+1,ncls,ny)}
\]

470 continue

\[
\text{write (iuot,9150)}
\]

500 continue

c

c Return

c
1000 continue

\[
\text{return}
\]

end
function retire (ntechx, accmi, annmi)

This function calculates the retention rate (fraction of vehicles in the fleet at the beginning of a given year which don't retire in that year) for the cohort of vehicles which use technology NTECHX, which have accumulated average mileage ACCMI, and which will travel an average distance ANNMI in this year. The calculation is done by assuming that vehicle retirement is a function of accumulated mileage only, and that it is lognormally distributed with respect to mileage. The parameters of the lognormal distribution are given in /TECH/, and a table of values of the cumulative probability distribution for retirement is stored in /RFUNCT/ by subroutine RETSET.

The probability that a given vehicle in existence this year will be retained in the next year is calculated as \( P(Q+dQ) / P(Q) \) where \( Q \) is the accumulated mileage to date and \( dQ \) is the mileage to be accumulated in the next year. (See Thesis Chapter 4 for details).

The subroutine finds \( P(Q+dQ) \) and \( P(Q) \) by linear interpolation from the data in /RFUNCT/.

*** Global Common

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
common /rfunct/ qrstep(ipntc), retcp(ipnrt, ipntc),
       retcpq(ipnrt, ipntc)

Begin Execution

Look up \( P(Q) \) (cumulative retirement rate corresponding to current mileage for these vehicles)

\[
q = \text{accmi} \\
\text{ndx} = \text{int} \left( q / \text{qrstep(ntechx)} \right) + 1 \\
\text{if (ndx .ge. ipnrt)} \text{then} \\
\quad pq = 0.99999 \\
\text{else} \\
\quad \text{frac} = \text{amod} \left( q, \text{qrstep(ntechx)} \right) / \text{qrstep(ntechx)} \\
\quad pq = (\text{retcp(ndx+1,ntechx)} - \text{retcp(ndx,ntechx)}) * \text{frac} + 1 \\
\quad \text{retcp(ndx,ntechx)}
\]

Look up \( P(Q+dQ) \) (= retirement rate corresponding to present mileage plus 1 year's annual mileage.)

\[
q = \text{accmi} + \text{annmi} \\
\text{ndx} = \text{int} \left( q / \text{qrstep(ntechx)} \right) + 1 \\
\text{if (ndx .ge. ipnrt)} \text{then}
\]
Appendix C: FORTRAN Code For The Model

Function RETIRE

pqdq = 1.0
else
    frac = amod (q,qrstep(nTechx)) / qrstep(nTechx)
    pqdq = (retcp(ndx+1,nTechx) - retcp(ndx,nTechx)) * frac +
           1
           retcp(ndx,nTechx)
endif

c Calculate the retainment rate next year for vehicles in existence
c this year.
c
    retire = (1.0 - pqdq) / (1.0 - pq)
c
RETURN

END
subroutine retset (ncls)

*******************************************************************************
This subroutine is called from CALCL8 to calculate and set the values in /RFUNCT/ for use by the RETIRE and XLIFE routines. The parameters of the lognormal probability distribution function for each technology are taken from /TECH/. The subroutine then performs a straightforward numerical integration, using the rectangle rule of \( P(X) \, \Pi \, X \, P(X) \, \Pi \), storing the values at every 10th iteration in /RFUNCT/.

NCLS is the number of the current class of vehicles.
*******************************************************************************

*** Global Common

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
integer dstart, dend, dpres
common /model/ nclass, dstart, dend, dpres, nystrt, nyend,
1 nypres, nfuels, nscost, ntclas(ipnc), itech(ipnt,ipnc)
character*1l title*80, clsnam*28, fuelnm*15
common /modelc/ title(3), clsnam(ipnc), fuelnm(ipnf)
common /tech/ ntechn, ntech(ipntc), nytfst(ipntc),
1 nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)
common /rfunct/ qrstep(ipntc), retcp(ipnrt,ipntc),
1 retcpq(ipnrt,ipntc)

*** Local Variables

*******************************************************************************
Begin Execution
*******************************************************************************

Set the square root of two pi.

sqr2pi = sqrt (8.0 * atan(1.0))

Loop over each technology in the current class of vehicles

do 1000 ntc = 1, ntclas(ncls)

Set up before entering the numerical integration loop. Convert mean and standard deviation to sigma prime and mu prime for the lognormal function.

\[
\begin{align*}
xx &= \frac{\text{retstd(ntc)}}{\text{retavg(ntc)}} \\
\text{sigsq} &= \text{a}o\text{g} (xx^2 + 1.0) \\
\text{sigma} &= \sqrt{\text{sigsq}} \\
\text{xmu} &= \text{retavg(ntc)} \times \exp (-0.5 \times \text{sigsq})
\end{align*}
\]
Subroutine RETSET

Calculate the upper limit for integration, and the integration step size \( (\mu + \sigma \times 5 = \text{upper limit}) \). Save the size of the increment between values in /RFUNCT/.

\[
\begin{align*}
q\text{limit} &= \text{retavg}(ntc) + 5.0 \times \text{retstd}(ntc) \\
q\text{step} &= q\text{limit} / \text{float}(10 \times (ipnrt - 1)) \\
q\text{half} &= q\text{step} \times 0.5 \\
q\text{rstep}(ntc) &= 10.0 \times q\text{step}
\end{align*}
\]

Zero out the accumulators, and set the first values in the arrays to zero as well. Initialize Q to \(-1/2\) step so it will wind up in the middle of each cell during integration.

\[
\begin{align*}
\text{retcp}(1,ntc) &= 0.0 \\
\text{retcpq}(1,ntc) &= 0.0 \\
sp &= 0.0 \\
spq &= 0.0 \\
q &= -q\text{half}
\end{align*}
\]

Begin numerical integration, saving each 10th value in /RFUNCT/. (Note that Q is actually calculated to fall in the midpoint of each cell in the integration, since we are using the rectangle rule).

\[
\begin{align*}
do 900 & \text{ nr } = 2, \text{ ipnrt } - 1 \\
do 800 & \text{ ns } = 1, 10 \\
q &= q + q\text{step} \\
xx &= \text{alog} \left( q / \text{xmu} \right) / \sigma \\
p &= \exp \left( -0.5 \times xx^2 \right) / \left( q \times \sigma \times \text{sqrt}(2\pi) \right) \\
sp &= sp + p \times q\text{step} \\
spq &= spq + p \times q\text{step} \times q
\end{align*}
\]

\[
\begin{align*}
800 & \text{ continue} \\
\text{retcp}(nr,ntc) &= sp \\
\text{retcpq}(nr,ntc) &= spq
\end{align*}
\]

900 continue

Set the last values in each array to the values in the limit where Q = infinity.

\[
\begin{align*}
\text{retcp}(ipnrt,ntc) &= 1.0 \\
\text{retcpq}(ipnrt,ntc) &= \text{retavg}(ntc)
\end{align*}
\]

End of loop over each technology

1000 continue

Return

```
return
```
function upper (string)

c This function returns a string having the same letters as the
c argument STRING, but with all lower-case letters converted to
c uppercase. Entry LOWER performs the reverse substitution, returning
c a string with all uppercase letters converted to lowercase

c character string*, upper*80, lower*80
character upcase*26, locase*26

data locase */'abcdefghijklmnopqrstuvwxyz'/
data upcase */'ABCDEFGHIJKLMNOPQRSTUVWXYZ'/*

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!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function value (string,errflg)

C
C *******************************************************************
C This subroutine decodes the character-coded real number passed
C to it in STRING and returns it as a floating point number.
C Entry IVALUE also decodes the number, but converts it to integer
C before returning it. For both subroutines, ERRFLG is returned
C .FALSE. if a legal number was found in string. If STRING does
C not contain a legal number VALUE (or IVALUE) is returned as zero,
C and ERRFLG is returned as .TRUE.
C *********************************************************************
C
C Actual Parameters
C
character*(*) string
logical errflg

C Local variables
C
character*7 format
logical floatv

C Maximum 4-Byte integer representable on the VAX 11/780
C
parameter (amaxi = 2147483648.e0)
C
C *******************************************************************
C Begin Execution
C *******************************************************************
C
C Begin here from entry VALUE
C
floatv = .true.
go to 100

C Begin here from entry IVALUE
C
entry ivalue (string,errflg)
floatv = .false.

C Come here from either VALUE or IVALUE to decode the number in STRING.
C First find out how long it is, then set up a format statement and
C read the string.
C
100 continue
length = ichlnb (string)
if (length .eq. 0) then
val = 0.0
else
write (format,1000) length
1000 format ('(F',i2,'.0)')
read (string,format,err=500) val
endif
Appendix C: FORTRAN Code For The Model
Function VALUE

c Normal Return—Send back either VALUE or IVALUE
c
   if (floatv) then
      value = val
   else
      if (abs(val) .gt. amaxi) go to 500
      ivalue = int (val)
   endif
   errflg = .false.
   return

500 continue
   if (floatv) then
      value = 0.0
   else
      ivalue = 0
   endif
   errflg = .true.
   return
end
subroutine writet (ntr, ntx)

******************************************************************************
This subroutine does a random write of technology record number NTR,
taking the data from index location NTX in /TECH/.
******************************************************************************

parameter (ipnc = 12, ipnf = 3, ipng = 10, ipnt = 30, ipntc = 4)
parameter (ipny = 51, ipnrt = 51)
parameter (iucmd=1, iuin=5, iuot=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile
common /tech/ ntechn, ntech(ipntc), ntyfst(ipntc),
1 nytlst(ipntc), cfirst(ipny,ipntc,2), cfixed(ipny,ipntc,2),
2 cmaint(ipny,ipntc,2), fucons(ipnf,ipny,ipntc), retavg(ipntc),
3 retstd(ipntc)
character technm*20
common/techc/ technm(ipnt)

write (iudb,rec=ntr) ntech(ntx), ntyfst(ntx), nytlst(ntx),
1 ((cfirst(ny,ntx,ns),ny = 1, ipny), ns = 1, 2),
2 ((cfixed(ny,ntx,ns),ny = 1, ipny), ns = 1, 2),
3 ((cmaint(ny,ntx,ns),ny = 1, ipny), ns = 1, 2),
4 ((fucons(nf,ny,ntx),nf = 1, ipnf), ny = 1, ipny),
5 retavg(ntx), retstd(ntx)
return
end
function xlife (ntechx, accmi)

C ***********************************************************************
C This function calculates the expected remaining life (in miles) for
C the cohort of vehicles which use technology NTECHX and which have
C accumulated average mileage ACCMI. The calculation is done by assu-
C ming that vehicle retirement is a function of mileage only, and that
C the retirement function is given by a lognormal distribution.
C The expected life in miles for the vehicle is calculated by
C integrating the product of the probability density function for
C retirement (P'(x)) and x from the current mileage Q to infinity, and
C dividing by the integral from Q to infinity of P'(x) to get the
C weighted average mileage at retirement.
C
C Tables of the values of the integrals for P(Q) and X * P(Q) are set
C in common /RFUNCT/ by subroutine RETSET. This routine looks up the
C values corresponding to ACCMI using linear interpolation.
C
C **********************************************************************
C Begin Execution
C**********************************************************************
C
C Find the index corresponding to this value for the mileage.
C
q = accmi
ndx = int (q / qrstep(ntechx)) + 1
C
C If mileage is greater than or equal to the largest in the table,
C vehicles retire this year. Set expected life to a nominal 1% of
C average lifetime mileage.
C
if (ndx .ge. ipnrt) then
  xlife = 0.01 * retcpq(ipnrt,ntechx)
endif
C
C Otherwise we must calculate the expected life as the centroid of the
C area above Q under the probability curve (See Thesis Chapter 4).
C
else
  frac = amod (q,qrstep(ntechx)) / qrstep(ntechx)
  pq = (retcp(ndx+1,ntechx) - retcp(ndx,ntechx)) * frac +
      retcp(ndx,ntechx)
  pqx = (retcpq(ndx+1,ntechx) - retcpq(ndx,ntechx)) * frac +
       retcpq(ndx,ntechx)
  xlife = ((retcpq(ipnrt,ntechx) - pqx) / (1.0 - pq)) - accmi
endif
Appendix C: FORTRAN Code For The Model
Function XLIFE

```
  c
  c Return
  c
   return
   end
```
logical function ydecod (text, ndx, nparam, index, nerrs)

******************************************************************************

This function breaks out parameter number NDX from the list of
parser-processed parameters in TEXT. It then converts the parameter
to upper-case and tries to interpret it as a logical flag. Legal
values for the flag are "Y", "YES", "T", "TRUE", " .T.", and " .TRUE."
all of which translate as .TRUE., and "N", "NO", "F", "FALSE", " .F.",
and " .FALSE.", which all translate as .FALSE. If the parameter is
one of these, ydecod is returned as the value of the parameter. If
the parameter does not exist, or if it is not one of the above, then
the routine prints an error message and returns .FALSE.

******************************************************************************

Actual Parameters

character text(*)
dimension index(2,nparam)

Global Common Blocks

parameter (iucmd=1, iuin=5, iuto=6, iutc=10, iudb=11, iugr=7)
character*63 infile, outfil, tcfile, dbfile, grfile
common /systmc/ infile, outfil, tcfile, dbfile, grfile

External function

character*80 upper

Local Variable

character*20 temp

******************************************************************************

Begin Execution

******************************************************************************

If there is no such parameter, print an error message and return zero

if (nparam .lt. ndx) then
  write (iuot,9000) ndx
9000   format (' ***** ERROR — TOO FEW PARAMETERS IN GROUP. ',
1   ' MISSING PARAMETER ',i3,' (LOGICAL FLAG) '/
2   ' ***** SETTING PARAMETER TO .FALSE. ')
  nerrs = nerrs + 1
  ydecod = .false.
else
  temp = upper (text(index(1,ndx):index(2,ndx)))
  if (temp .eq. 'Y' .or. temp .eq. 'YES' .or. temp .eq. 'T' .or.
1     temp .eq. 'TRUE' .or. temp .eq. ' .T.' .or.

2      temp .eq. '.TRUE.') then
       ydecod = .true.
   elseif (temp .eq. 'N' .or. temp .eq. 'NO' .or. temp .eq. 'F'
1      .or. temp .eq. 'FALSE' .or. temp .eq. '.F.' .or. 
2      temp .eq. '.FALSE.') then
       ydecod = .false.
   else
       write (iuot,9500) ndx, temp
9500    format ("**** ERROR — PARAMETER ",i3,’ = ’,a,
1      ’ IS NOT A LEGAL LOGICAL FLAG./
2      ’ **** SETTING PARAMETER TO .FALSE.’)
       nerrs = nerrs + 1
       ydecod = .false.
   endif
endif
return
end
FUNCTION ZINTRP

c
C
C**********************************************************************
c
This function does one-dimensional linear interpolation from the
table in XAR and ZAR. X is the value for which the interpolated
c Z-coordinate is desired. XAR contains the X-ordinates in the
table, while ZAR contains the Z-ordinates. XAR is assumed to be
sorted in increasing order. ND is the dimension of XAR.
c
The value of ZINERP returned is linearly interpolated from the
table if XAR(1) < X < XAR(ND). Z = ZAR(1) if X < XAR(1), and
Z = ZAR(ND) if X > XAR(ND)
c
C**********************************************************************
c
dummy arguments
c
dimension xar(nd), zar(nd)
c
check whether X is above or below the table. If not, make an initial
guess at the indices which bracket X, assuming that XAR is evenly
c spaced, then search from there using binary search.
c
if (x .ge. xar(nd)) then
zintrp = zar(nd)
elself (x .le. xar(l)) then
zintrp = zar(l)
else
itop = nd
ibot = 1
ix = int ((x - xar(1)) / (xar(nd) - xar(1)) * float(nd))
ix = max0 (ix, (ibot+1))
10 continue
if (x .le. xar(ix)) then
itop = ix
else
ibot = ix
endif
if ((itop - ibot) .eq. 1) go to 20
ix = int ((x - xar(ibot)) / (xar(itop) - xar(ibot))
* float(itop - ibot))
ix = max0 (ix, (ibot+1))
go to 10
20 continue
frac = (x - xar(ibot)) / (xar(itop) - xar(ibot))
zintrp = zar(ibot) + frac * (zar(itop) - zar(ibot))
endif
c
return
c
end