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COMPUTER-BASED RESOURCE ACCOUNTING MODEL FOR GENERATING AGGREGATE RESOURCE IMPACTS OF ALTERNATIVE AUTOMOBILE TECHNOLOGIES

Volume I - Fleet Attributes Model

Bruce Rubinger
Simon Prensky

U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

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16. Abstract

Auto production and operation consume energy, material, capital, and labor resources. Numerous substitution possibilities exist within and between resource sectors, corresponding to the broad spectrum of potential design technologies. Alternative auto design concepts are examined in terms of their aggregate resource impacts.

A computer-based model has been developed for generating the resource requirements of alternative automobile technologies. The model goes beyond previous tools in its scope, level of impact disaggregation, and flexibility. It projects the annual energy, material, capital, and labor requirements of the passenger-automobile fleet through the year 2000. The methodology integrates a family-tree technique for material and energy accounting, with an input-output approach which generates the capital and labor information. Twenty-four major materials are tracked, with supply disaggregated among primary and recycled materials, imports, and domestic sources. Net energy consumption is derived, along with capital and labor impacts disaggregated by 90 industries.

The Resource Accounting methodology is described, with emphasis on the Fleet Attributes Model. Representative results are presented and discussed.

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PREFACE

In March 1975, a multidisciplinary team was assembled by the Transportation Systems Center to assess the resource impacts of alternative auto design scenarios. This work was performed as part of the TSC support effort for the "Federal Task Force on Motor Vehicle Goals Beyond 1980," and extended over a period of one and one-half years. It resulted in the development of a series of integrated computer-based models which generate the aggregate resource impacts of various auto design technologies and constraints imposed by safety and emissions requirements.

This report is the first in a series whose intent it is to describe the Resource Accounting Simulation. An overview of the entire methodology is presented, along with a detailed description of the Fleet Accounting Model. Subsequent reports will focus on the Energy and Materials Resource Accounting Model and the INFORUM Capital and Labor Resources Model.

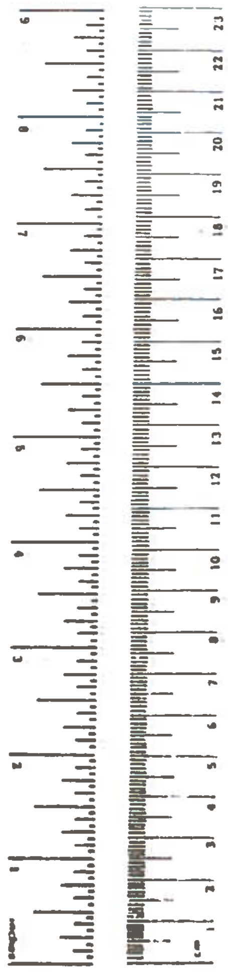
Auto technology data bases and macroeconomic forecasts are subject to change as more information becomes available. Although the estimates used in this report represent the best judgment at the time of the Interagency Task Force on Motor Vehicle Goals, it is anticipated that some refinement of these projections will occur with time. These changes will not affect the validity of the methodology since the data in question are exogenous inputs, but will require the rerunning of the models.

This work was carried out as part of the Automotive Energy Efficiency Project (AEEP) at the Transportation Systems Center and was sponsored by the Office of the Secretary of Transportation. The major contributors to the Project and their prime areas of responsibility were: Bruce Rubinger, Study Leader; Simon Prensky, Fleet Attributes; Phillip Coonley, Nonauto Petroleum Demand Requirements and Refinery Characteristics; Bart DeWolfe and Peter Heinemann, Aggregate Materials and Energy Requirements; Chris Davis, Bart DeWolfe, and Ron Mauri, Capital and Labor Impacts. Special recognition is due Alex Robb, Kentron Hawaii, Ltd., who structured and programmed the Fleet Model.

METRIC CONVERSION FACTORS

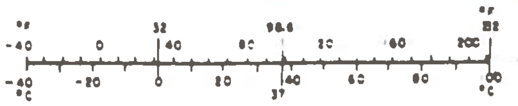
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

As a major consumer of petroleum, the automobile has been the subject of much recent attention. Various techniques have been proposed for improving auto fuel economy, ranging in complexity from simple retrofit devices to advanced engines and innovative structures. Unfortunately, the focus of this attention has been exclusively on petroleum consumption and has tended to ignore the other vital resources consumed by an automobile. Auto production and operation requires energy, materials, capital and labor resources in delivering a level of service which is usually measured in terms of fleet vehicle-miles-traveled (VMT). Aggregate demand for any of these four resources can be reduced through the substitution of the others. Thus, the selection of fuel-efficient auto designs should be viewed and evaluated in terms of the tradeoffs in aggregate resource requirements that they represent.

A good illustration of the above ideas is provided by the increased use of aluminum in autos, which would displace materials such as cast iron and sheet steel. Due to the light weight of aluminum, this substitution would lower the overall weight of the vehicle and improve fuel economy. However, manufacturing of aluminum is a very energy intensive process. Whether or not there is a net energy savings would, thus, depend on whether the reduction in propulsion fuel consumption exceeds the changes in auto fabrication and materials processing energy. Pursuing this example further, it can be shown that similar tradeoffs exist among the other resources: additional capital requirements are needed for motor vehicle and aluminum production, but they are offset by investment savings in such areas as refineries, petroleum distribution, and steel manufacturing.

The aluminum example suggests the broad range of options available in the selection of future auto design concepts and the large number of consequences. There are substitution possibilities within resource categories (e.g., between materials or between energy forms) and tradeoffs between resource sectors (e.g., capital-displacing energy). These tradeoffs raise several additional critical questions including:

a) In the process of lowering petroleum imports, are we creating a vulnerability in another area to a potential cartel?

b) Is the implementation of the design concepts feasible or constrained by supply bottlenecks?

c) To what extent do the direct energy savings exceed any increase in the indirect energy requirements?

In order to address the above questions, a computer-based accounting model was developed for generating the resource impacts of alternative automobile technologies and constraints imposed by safety and emissions regulations. The model derives the aggregate energy, materials, capital and labor requirements for auto production and usage over the time interval of 1976 through 2000. Functionally, the simulation is an accounting model and not a predictive model. In this respect, consumer behavior is exogenously specified, in terms of fleet size, new car sales, sales mix, and fleet VMT. Data on the attributes of alternative design concepts is another input required by the model.

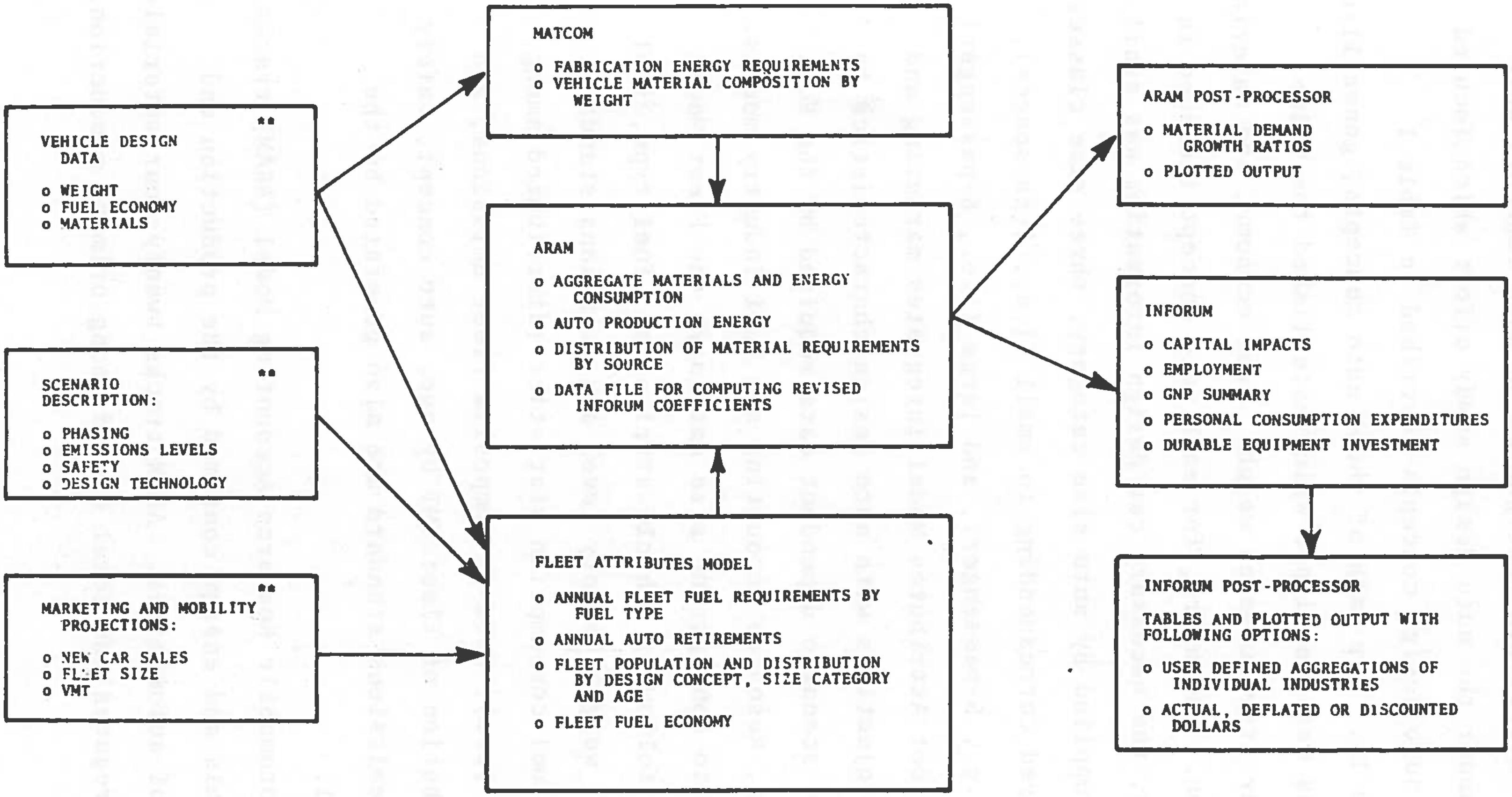
The objectives here are to describe the Resource Accounting Model, and to present some representative results. The report is organized in the following manner: first, an overview of the methodology is presented, including a description of the various component submodels, the manner in which they are tied together, and the system boundary. Next, a detailed description is given of the Fleet Model, including the data sources used and the procedure employed for model calibration. Finally, representative results are presented and discussed.

2. MODEL OVERVIEW

In order to estimate automobile resource requirements, a set of integrated computer models was created which generate data on aggregate fuel use, aggregate material and energy consumption, and capital and labor. These models were used to project over the time interval of 1976 through 2000 for selected auto technologies and constraints regarding fuel economy, safety, and emissions. Examination of the data generated for any case allowed the feasibility and desirability of that "scenario" to be assessed. Furthermore, by comparing different cases, the sensitivity of the results to changes in technology, and/or constraints was established providing information necessary for subsequent tradeoff studies.

An overview of the analysis process is depicted in Figure 1, where the dashed lines enclose those submodels which are within the simulation. Figure 1 also identifies exogeneous information supplied to the Fleet Model; this data falls into two general categories: (i) auto design attributes [References 1, 2 and 3], and (ii) marketing and mobility projections [References 4,5, and 6].

The analysis process is initiated by the specification of a scenario. Each scenario involves the selection of a series of auto technologies which are to be phased into production, along with schedules for implementing safety and environmental goals. Various combinations of structure,



**EXOGENOUS SCENARIO RELATED DATA REQUIRED BY THE MODEL

— — Boundary of the Model

**Non TSC Models external to the simulation which supplied input data.

FIGURE 1. OVERVIEW OF THE RESOURCE ACCOUNTING MODEL

engine and drivetrain (designated an auto concept) were examined under the auto design study effort which focused on the 10 auto design concepts described in Table 1 [Reference 1]. For each of these auto concepts, generalized car designs were developed which established the value of such key attributes as weight, fuel economy, and material composition. Therefore, for each auto concept included in a scenario, the necessary car design information was available and supplied by auto size category; three size classes were employed corresponding to small (i.e., 4-passenger), midsize (i.e., 5-passenger), and large (i.e., 6-passenger).

The Fleet Attributes Model integrates marketing and mobility projections with auto design characteristics to produce the scenario dependent data required by the Fuel Consumption, Resource Accounting and Fuel Industry models. For each auto concept and size category, the Fleet Model tracks the following vehicle attributes: fuel type, fuel efficiency, weight, safety level and emissions standard. Aggregate fuel consumption statistics (distributed among four fuel types), data on composite fleet emissions, and the distribution of fleet VMT by age, auto concept, safety level and emissions standard are also generated by the Fleet Model.

The Automobile Resource Accounting Model (ARAM) tracks the materials and energy consumed by the production and operation of automobiles. ARAM tracks twenty-four materials and disaggregates the total demand among primary production,

TABLE 1. AUTO DESIGN CONCEPTS EXAMINED

		Technology		
Configuration Number	Performance Hp/Wt	Weight Configura.	Engine	Drivetrain
1a	0.03	Current	Current	Current
1b	0.02	Current	Current	Current
2a	0.03	Wt. Cons.	Current	Current
2b	0.02	Wt. Cons.	Current	Current
3a	0.03	Wt. Cons.	Top '75	Current
3b	0.02	Wt. Cons.	Top '75	Current
4a	0.03	Wt. Cons.	Top '75	Upgraded
4b	0.02	Wt. Cons.	Top '75	Upgraded
5a	0.03	Innov.	Top '75	Upgraded
5b	0.02	Innov.	Top '75	Upgraded
6a	0.03	Wt. Cons.	Diesel	Current
6b	0.02	Wt. Cons.	Diesel	Current
7a	0.03	Wt. Cons.	Diesel	Upgraded
7b	0.02	Wt. Cons.	Diesel	Upgraded
8a	0.03	Innov.	Diesel	Upgraded
8b	0.02	Innov.	Diesel	Upgraded
9a	0.03	Wt. Cons.	Adv.	Current
9b	0.02	Wt. Cons.	Adv.	Current
10a	0.03	Innov.	Adv.	Upgraded
10b	0.02	Innov.	Adv.	Upgraded

secondary production, and imports; this allocation is based on projections for future shipments and reflects a changing import ratio plus increased use of recycled materials [Reference 7]. The output data from ARAM is used to modify the final demand vector in the INFORUM input-output model, as well as certain technical coefficients.

Aggregate capital and labor requirements for the scenarios are generated by INFORUM, a dynamic model of the interindustry flows with the U.S. economy developed by the Interindustry Economic Research Project of the University of Maryland [Reference 8]. The INFORUM model was modified so that each scenario is translated into a new set of demands upon the motor vehicles, materials, producers durables, construction, and fuel supply sectors [References 7 and 9]. For example, increased auto industry investment requirements are converted into purchases from the Producers' Durables and Construction Industries. In addition, corresponding to the auto design requirements, technical coefficients are modified to reflect the new pattern of purchases by the Motor Vehicles sector from supplier industries such as steel, aluminum, and plastics. Under these scenario imposed constraints, INFORUM determines the gross national product (GNP) summary, personal consumption expenditures for the products of 185 industries, employment (disaggregated by 90 industries), durable equipment investment, and structures investment.

It should be emphasized that in computing the capital and labor resources no distinction was made between auto design concepts in estimating the man-hours of labor per car. As a result, direct labor requirements for auto production are assumed proportional to total domestic unit sales.

Finally, the INFORUM model requires as input information the fuel industry impacts associated with the scenarios. Specifically, annual investment in new refinery capacity and fuel distribution facilities is needed. These data were extrapolated from a series of computer runs made by Bonner and Moore Associates [Reference 10].

3. FLEET ACCOUNTING MODEL

3.1 GENERAL

The Fleet Accounting Model stores and processes data on a discrete number of auto designs which represent existing vehicles and those which might be produced in future years under a variety of conditions. Each of these designs encompasses a different combination of attributes (type of fuel, mpg, etc.) and is introduced into production at different times and rates. It is assumed that the attributes of each technology design remain unchanged, while the production rate, usage, and scrappage of that particular vehicle will necessarily vary with time.

For each year of analysis, new cars are introduced into the fleet in accordance with new car sales and market share projections. Within each size category, the breakdown of sales by technological design configuration is based upon the production phase-in schedule (see Figure 8). Concurrent with the introduction of new cars, the existing fleet is aged, and older cars are retired at a rate determined by the scrappage algorithm. The structure of the model is shown in Figure 2.

3.2 MODEL STRUCTURE

In the Fleet Accounting Model, automobiles are characterized along three discrete dimensions: design concept, size

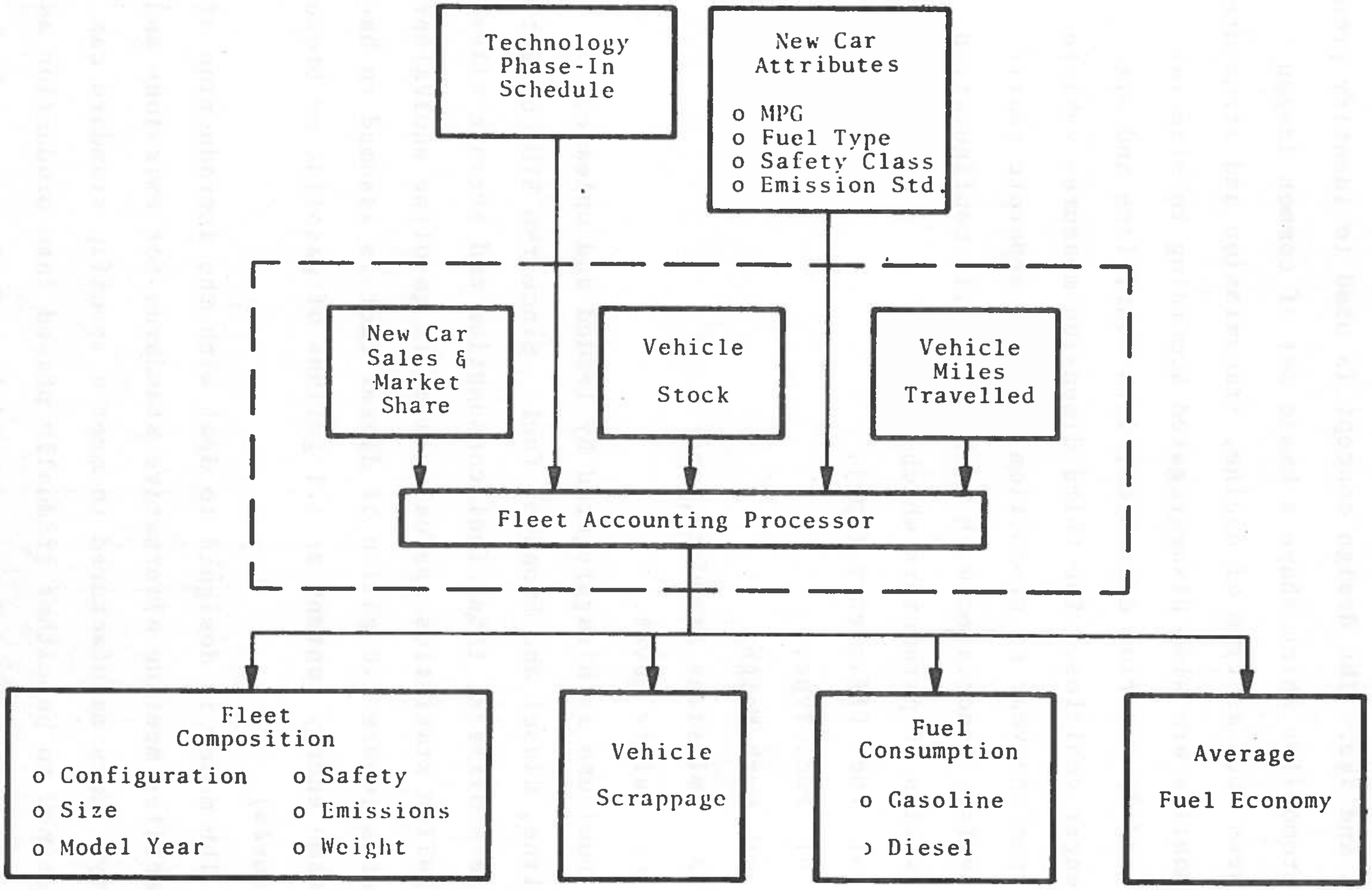


FIGURE 2. FLEET ACCOUNTING MODEL

class and age. The design concept is used to identify groups of automobiles which share a basic set of common design features such as type of engine, transmission and structure. Automobiles are also disaggregated according to size (as measured by interior dimension) into four, five and six-passenger vehicles. The third dimension measures vehicle age from the year of production using 16 separate yearly intervals. Associated with each automobile configuration is a series of parameters which include:

a) Fuel Efficiency (mpg),
b) Fuel Type,
c) Curb Weight,
d) Emissions Standard, and
e) Safety Level.

Fuel use is disaggregated by leaded and unleaded gasoline, diesel and broadcut fuel. Since the BTU content of fuels differs, total fuel consumption and average miles-per-gallon statistics are calculated in gasoline equivalent measures (where 1.0 gallon of diesel fuel is assumed to have the same energy content as 1.1 gallons of gasoline or broad-cut fuels).

The model is designed to deal with the introduction of automobiles meeting alternative standards for emissions and safety. Cars manufactured to meet a specific standard can be assumed to be either gradually phased into production as technology is upgraded, or stepped into full production as would occur in response to a change in Government regulations.

The Fleet Accounting Model tracks the population of each auto design configuration which existed in the base year, or is introduced into the fleet in subsequent years. In addition, the parameter list associated with each automobile configuration is updated over time as vehicles are aged. The following discussion attempts to clarify some of the procedures identified in the Fleet Accounting model flow chart (Figure 2); in particular, those relating to the calculations of vehicle miles traveled, vehicle scrappage and fuel consumption.

The automobile stock existing in any year, t, is the sum of the vehicle population subgroups processing each combination of attributes:

$$(1)\quad \mathrm{STOCK}_t = \sum_{i}^{N_t} \sum_{j=1}^{3} \sum_{k=1}^{16} \mathrm{AUTO}_{ijk}^{t}$$

where AUTO_{ijk}^{t} is the number of automobiles of design concept i, size class j, and age k in year t. N_t is the total number of design concepts in existence in year t.

The number of automobiles in the fleet in future years is a function of the existing stock, the number of automobiles retired, and the number of new cars corresponding to the identity:

$$(2)\quad \mathrm{STOCK}_t = \mathrm{STOCK}_{t-1} + \mathrm{SALES}_t - \mathrm{RET'R}_t$$

The Fleet Accounting Model is designed so that exogenous projections for the above variables can be employed, if desired. Alternatively, the model incorporates algorithms which predict new car sales, vehicle retirements and automobile fleet size. Thus, equation (2) is overspecified, and any one component may be derived as a function of the remaining variables. The model has the flexibility to operate with stock, sales, or scrappage as the dependent variable. However, in practice, projected sales and fleet size are usually specified, and the total number of cars scrapped annually is the dependent variable:

$$(2a) \quad RET'R_t = SALES_t - (STOCK_t - STOCK_{t-1})$$

The number of automobiles retired in each vehicle category is determined as a function of the vehicle scrappage curve. This curve, Figure 3, based on the age of the car, was derived from estimates compiled by Polk and Company, of the number of cars in operation in the years from 1957 to 1974 [Reference 11]. Specifically, in employing this information, total retirements are estimated, first using equation (2a). Then, the historic scrappage curve is modified by a scale factor to meet the following additional constraint on total retirements:

$$(3) \quad RET'R_t = \sum_i \sum_j \sum_k \left(R_k \cdot S_t\right) \cdot AUTO^t_{ijk}$$

where R_k is a vector of empirically derived historic scrappage rates which depend only on the age of the vehicle; S_t is a scale factor applied uniformly to all scrappage rates and is derived from:

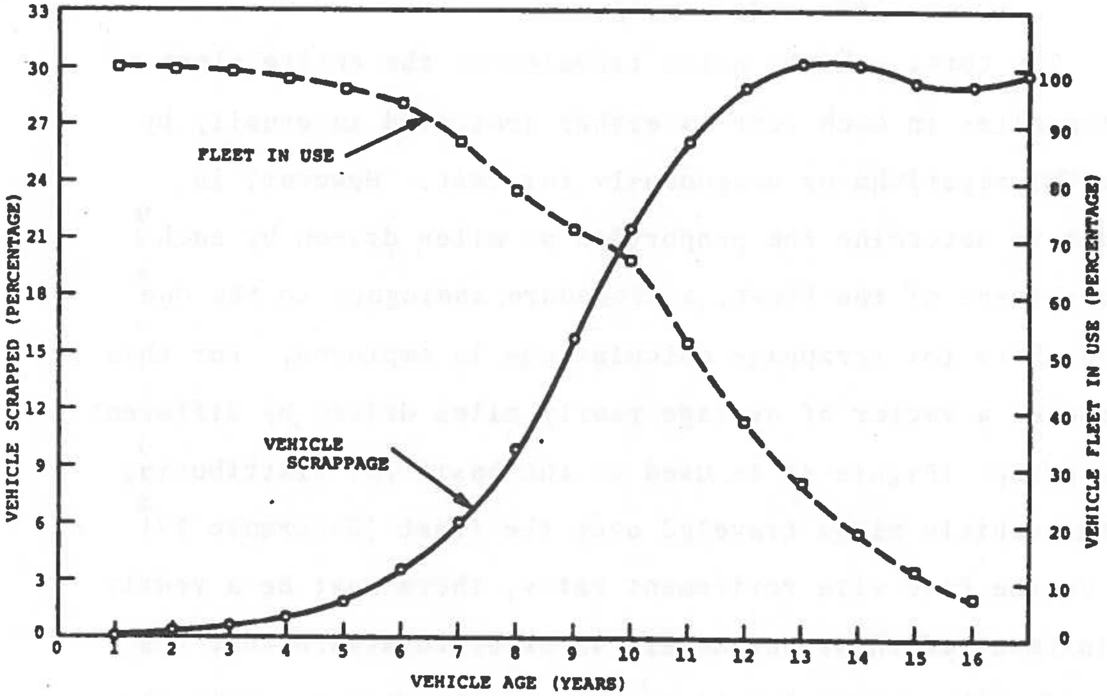


FIGURE 3. VEHICLE SCRAPPAGE AND VEHICLE SURVIVAL VS VEHICLE AGE

$$(4)\quad S_t = RET'R_t \Big/ \sum_i \sum_j \sum_k \left(R_k \cdot AUTO^t_{ijk}\right)$$

Thus, S_t represents the adjustment in scrappage conditions in year t.

Once the value of S_t is established, the retirement schedule for each vehicle category is determined as follows:

$$(5)\quad RET'R^t_{ijk} = \left(R_k \cdot S_t\right) \cdot AUTO^t_{ijk}$$

The total vehicle miles traveled by the entire fleet of automobiles in each year is either generated internally by the VMT algorithm or exogenously forecast. However, in order to determine the proportion of miles driven by each constituent of the fleet, a procedure analogous to the one used above for scrappage calculations is employed. For this purpose, a vector of average yearly miles driven by different age groups (Figure 4) is used as the basis for distributing total vehicle miles traveled over the fleet [Reference 12]. As in the case with retirement rates, there must be a yearly adjustment of these parameters in order to assure that the sum of miles driven by all passenger automobiles equals the specified VMT estimate. Total vehicle miles traveled is equal to the sum of each fleet constituent's VMT:

$$(6)\quad VMT_t = \sum_i \sum_j \sum_k VMT^t_{ijk} = \sum_i \sum_j \sum_k (M_k \cdot G_t) \cdot AUTO^t_{ijk}$$

where VMT^t_{ijk} is vehicle usage in year t for autos of design concept i, size class j and age k; M_k is a vector of miles

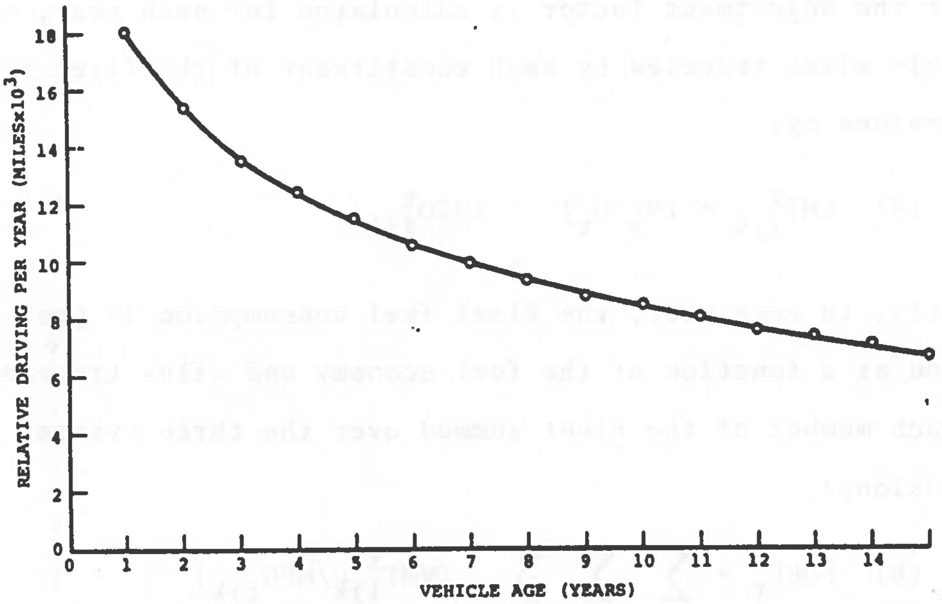


FIGURE 4. MILES DRIVEN AS A FUNCTION OF CAR AGE

driven as a function of vehicle age and reflects historic usage patterns; and G_t is an auto usage adjustment factor which is derived from:

$$(7) \quad G_t = VMT_t \Big/ \sum_i \sum_j \sum_k (M_k \cdot AUTO^t_{ijk})$$

After the adjustment factor is calculated for each year, the vehicle miles traveled by each constituent of the fleet is determined by:

$$(8) \quad VMT^t_{ijk} = (M_k \cdot G_t) \cdot AUTO^t_{ijk}$$

Finally, in each year, the fleet fuel consumption is projected as a function of the fuel economy and miles traveled of each member of the fleet summed over the three system dimensions:

$$(9) \quad FUEL_t = \sum_i \sum_j \sum_k (VMT^t_{ijk}/MPG_{ijk})$$

where MPG_{ijk} is the vehicle fuel efficiency for autos of design concept i, size class j and age k.
The average fuel efficiency of the fleet is then:

$$(10) \quad \overline{MPG}_t = VMT_t/FUEL_t$$

It should be noted from the above equations that average fleet fuel economy is the <u>harmonic</u> mean of the fuel economy of the auto design concepts weighted by relative usage.

3.3 BASE-YEAR DATA

The purpose of this section is to present the data used to characterize the initial fleet and calibrate the model.

For the base year 1975, estimates of the existing vehicle population were developed and disaggregated into 16 model years and three size categories (see Table 2). This information was extrapolated from two sources: (a) data on the number of cars in each age group were based on a compliation by R. L. Polk [Reference 11], and (b) the distribution of autos by size class relied on information on the proportion of autos sold by weight [Reference 13].

The fuel efficiencies of existing autos for each model year were based upon measurements performed by the Environmental Protection Agency. These results are reported in Reference 14 and are summarized in Table 3.

Fuel consumption for the base year is generated by the model as the estimated vehicle miles traveled for 1975 divided by average fuel efficiency of the fleet. An independent derivation of 1975 automotive fuel consumption was developed from data in the Federal Energy Administration's Monthly Energy Review [Reference 15]. A comparison of the two estimates revealed that the Fleet Accounting Model's projection for national automotive fuel consumption was 13 percent lower than the FEA estimate. This discrepancy could be caused by a variety of factors, but it is likely that two dominate:

TABLE 2. 1975 STOCK OF AUTOMOBILES (millions)

MODEL YEAR	4-PAX	5-PAX	6-PAX	Total
1975	2.2	2.2	4.3	8.7
1974	2.8	1.3	4.8	8.9
1973	3.4	1.1	6.8	11.4
1972	3.3	0.8	6.3	10.4
1971	2.9	1.4	5.3	9.6
1970	2.1	1.7	4.0	7.8
1969	1.6	1.8	5.0	8.3
1968	1.3	2.0	4.1	7.4
1967	1.1	1.5	2.9	5.5
1966	1.1	1.1	2.5	4.6
1965	0.9	0.7	2.0	3.6
1964	0.7	0.4	1.2	2.2
1963	0.4	0.3	0.7	1.4
1962+	0.7	0.6	1.5	2.8
TOTAL *	24.4	17.0	51.3	92.7

*May not sum due to rounding error.

TABLE 3. FUEL ECONOMY OF BASE-YEAR AUTOMOBILE FLEET

MODEL YEAR	AVERAGE* MILES PER GALLON
1975	15.6
1974	13.9
1973	14.0
1972	14.5
1971	14.7
1970	15.1
1969	14.7
1968	15.0
1967	15.5
Fleet Average	14.9

*EPA Composite City/Highway Fuel Economy (Source: Reference 14).

a) The fuel economy estimates developed by dynamometer measurements over a simulated city/highway driving cycle are higher than those attained in actual vehicle operation [Reference 16].

b) The published estimates of vehicle miles traveled may be too high due to inaccuracies in the mechanism for collecting national data [Reference 17 and 18].

Because there is considerably more confidence in the accuracy of fuel consumption estimates than in either average fuel economy or fleet VMT statistics, the Fleet Accounting Model was calibrated to match exogenously reported base-year fuel use. This was accomplished by modifying the original fleet fuel consumption estimate, as calculated in equation (9), by an adjustment factor which is the ratio of the exogenous forecast to the initial internally generated estimate of 1975 fuel use:

$$(9) \quad \mathrm{FUEL}_t = \sum_i \sum_j \sum_k (\mathrm{VMT}^t_{ijk}/\mathrm{MPG}_{ijk}) \cdot K$$

where K is derived from:

$$K = \frac{\text{Exogenous Estimate of Base Year Fuel Consumption}}{\sum_i \sum_j \sum_k (\mathrm{VMT}^t_{ijk}/\mathrm{MPG}_{ijk})}$$

4. REPRESENTATIVE RESULTS

The Resource Accounting Model provides the framework for examining a broad range of scenarios. For each case, the results will of course reflect the input assumptions regarding the rate of technology implementation, the weight and fuel efficiency of the design configurations, new-car sales, and fleet VMT projections, etc. It is important to recognize that the validity of the methodology is independent of the choice of input data; were other input assumptions preferred, the simulation would be rerun with the alternative data. A useful application of the model is for examining the sensitivity of the results to the input assumptions; this knowledge puts into perspective the significance of changes in the input data.

In the remainder of this report, representative results are presented and discussed. The cases selected focus on the resource impacts of alternative auto design technologies and constraints related to national safety and emissions standards. To isolate these effects, the marketing and mobility projections (i.e., sales, market shares, and VMT) have been held invariant between scenarios. For this purpose, it was assumed that the future sales mix would remain comparable with that in 1975; i.e., 25 percent four-passenger cars, 25 percent five-passenger cars, and 50 percent six-passenger cars. Furthermore, the growth in new-car sales, fleet size, and VMT were extrapolated from projections made by the Data Resources, Inc. (DRI)

Long-Term Trend Model [References 19 and 20]; these estimates are only dependent upon the expected demographic and economic growth of the Nation and not on a scenario's fleet fuel economy or other vehicle characteristics. A recent study showed that the actual variations in sales and mobility expected between cases are quite small [Reference 21].

The central marketing and mobility projections are shown in Figures 5 through 7. New-car sales are assumed to grow from about 10-million in 1976 to 16-million units in the year 2000, an annual growth rate of about 2 percent. Simultaneously, total fleet size is expected to increase from 95.2-million vehicles (1976) to 161-million vehicles (2000). Over this period of time, the corresponding growth in VMT is from 1030-billion miles to 1760-billion miles. Finally, the source of the input data on the alternative auto design concepts is Reference 1, where the derivation of this information is also presented.

The scenarios are illustrated in Figure 8. In the initial case (Figure 8a), designated the reference case, 1975 begins with 100 percent production of auto design concept #1, the "average 1975" vehicle. (The auto design concepts are defined in Table 1.) Production of concept #1 is gradually reduced by the phase-in of auto concept #3, which is characterized by a weight-conscious structure and top '75 engine technology. Concept #3, which has a composite (i.e, averaged over sales mix) fuel economy of 24.2 mpg, is phased into production at the rate of 10 percent per year through

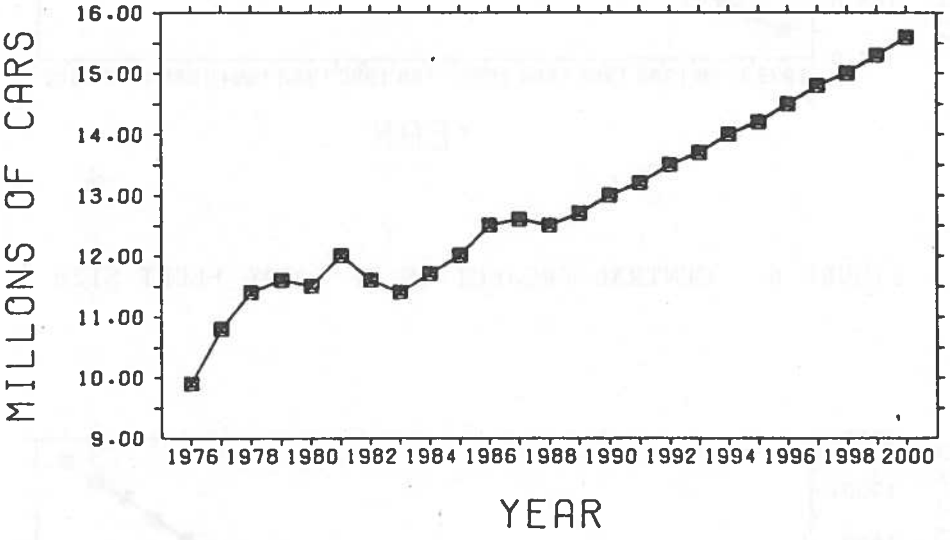


FIGURE 5. CENTRAL PROJECTION FOR NEW-CAR SALES

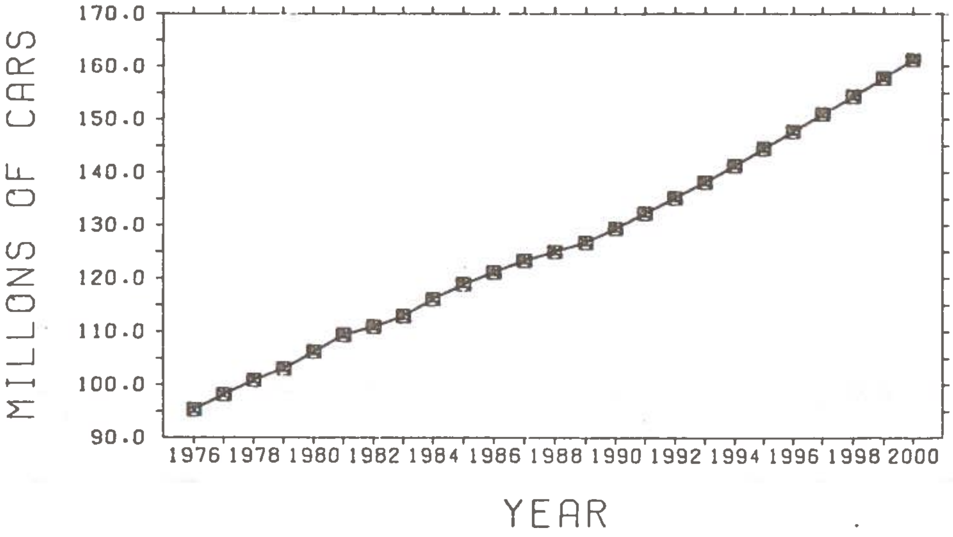


FIGURE 6. CENTRAL PROJECTION OF TOTAL FLEET SIZE

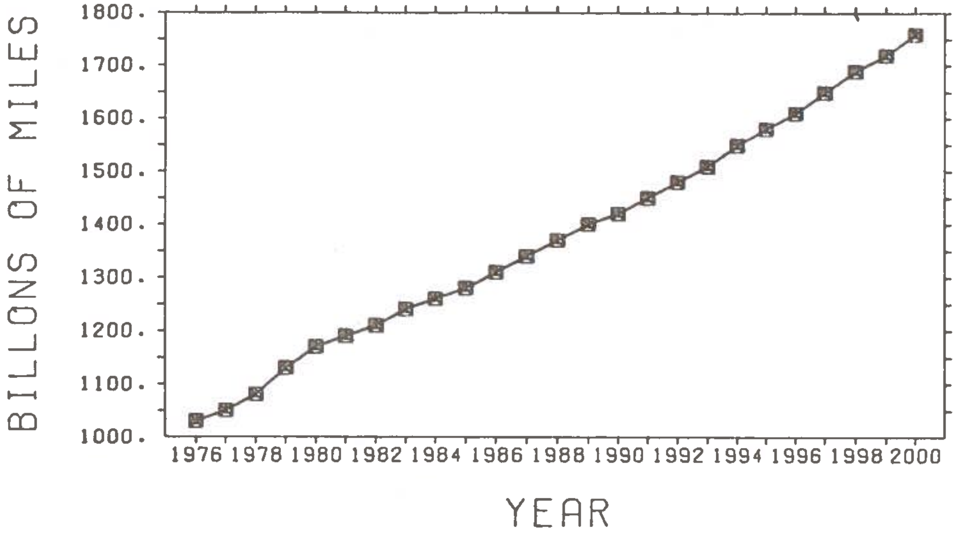


FIGURE 7. CENTRAL PROJECTION FOR TOTAL VEHICLE-MILES-TRAVELED

FIG. 8a
CASE A
THE REFERENCE CASE

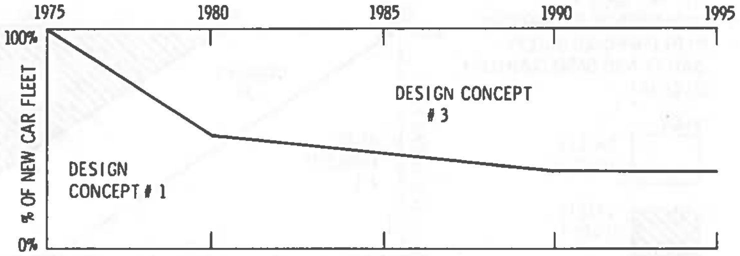


FIG. 8b
CASE B
1975 TECHNOLOGY
UPGRADED

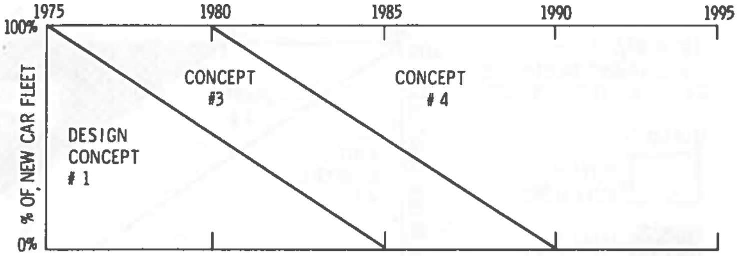


FIG 8c
CASE C
UPGRADED '75 TECHNOLOGY
WITH LEVEL II EMISSIONS

LEGEND

☐ LEVEL I EMISSIONS

▨ LEVEL II EMISSIONS

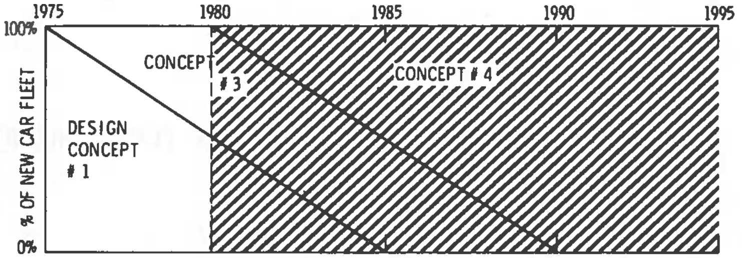


FIG 8d
CASE D
UPGRADED '75 TECHNOLOGY
WITH MAXIMUM EMISSIONS
CONTROL TO LEVEL III

LEGEND

☐ LEVEL I EMISSIONS

▨ LEVEL III EMISSIONS

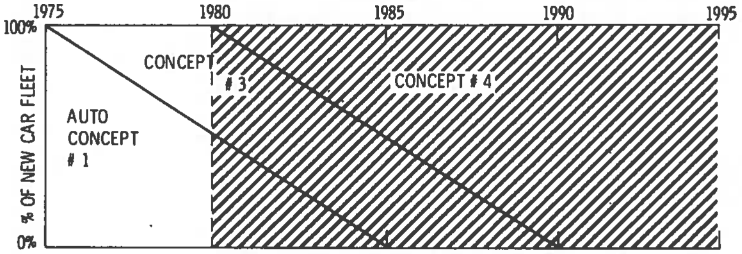


FIGURE 8. SCENARIOS

FIG. 8e - CASE E
UPGRADED '75 TECHNOLOGY
WITH IMPROVED SAFETY
(SAFETY AND DAMAGEABILITY
LEVEL II)

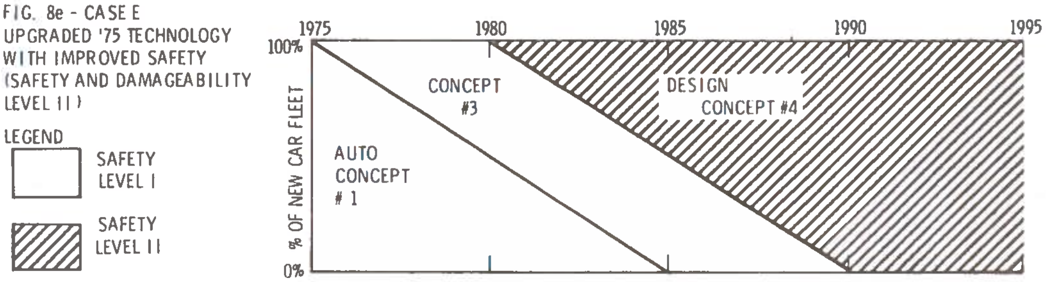


FIG. 8f CASE F
FUEL ECONOMY MAXIMIZED
WITH LEVEL II EMISSIONS

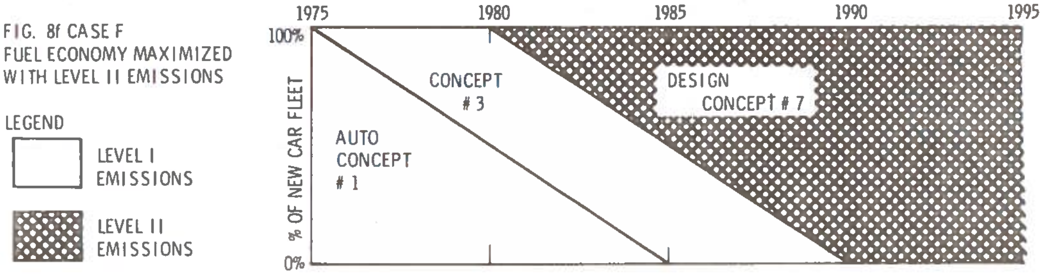


FIGURE 8. SCENARIOS (CONTINUED)

1980, and 2.2 percent per year between 1980 and 1990. This phasing assures that composite new-car fuel economy in 1980 will be 20 mpg, the goal of both the voluntary fuel efficiency improvement program and standard of the recent Act [Reference 22]. Between 1980 and 1990, new-car fuel economy improves an additional 10 percent and levels off thereafter at 22 mpg.

In the next scenario, designated "1975 Technology Upgraded," design concept #3 is introduced into production at the rate of 10 percent per year, as above, but in 1980, production of concept #4 is initiated (Figure 8b). This latter design concept is a weight-conscious vehicle like concept #3, but in addition includes an upgraded transmission; its composite fuel economy is 26.3 miles per gallon. Design concept #4 is introduced into production at the rate of 10 percent per year, and by 1990 represents 100% of new car production.

Scenario C, designated "Upgraded '75 Technology with Level II Emissions," is the first in a series designed to examine the impact of constraints associated with alternative emissions and safety standards (Figure 8c). The emissions standards considered, identified as Level I, Level II, and Level III, are defined in Table, 4 while the safety standards are defined in Table 5. For the purpose of comparison, recent levels of auto emissions are shown in Figure 9; over the past 10 years, improved designs have

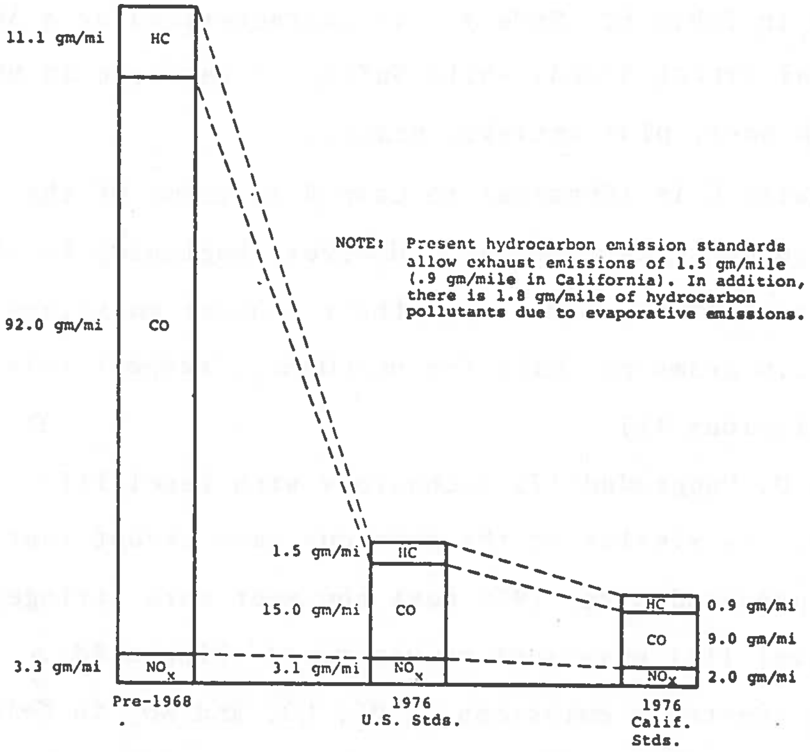
TABLE 4. AUTO EMISSIONS LEVELS (grams/mile)

Level	HC	CO	NO_x
Level I	1.5	15.0	3.1
Level II	0.41	3.4	2.0
Level III	0.41	3.4	0.4

TABLE 5. SAFETY AND DAMAGEABILITY LEVELS

LEVEL	Safety		Damageability
	Crashworthiness	Crash Avoidance	
LEVEL I	All FMVSS's* pertaining to crashworthiness which are effective for MY 1975 cars *and* those which will become effective during the 1976-80 period (protection for front, rear, side, rollover, fire), 30 mph frontal performance.	All FMVSS's* pertaining to crash avoidance which are effective for MY 1975 cars *and* those which will become effective during the 1976-80 period (braking performance, lighting, field of view and other).	Both Levels I & II correspond to existing standards (Part 581 requiring that front and rear bumper sustain 5 mph impacts without damage to vehicle (except for minor dents on bumpers).
LEVEL II	Same as Level I plus 40 mph passive frontal protection, 20 mph passive side protection and egress.	Same as Level I plus all weather brake performance (anti-lock brakes).	

*Federal Motor Vehicle Safety Standards



NOTE: Present hydrocarbon emission standards allow exhaust emissions of 1.5 gm/mile (.9 gm/mile in California). In addition, there is 1.8 gm/mile of hydrocarbon pollutants due to evaporative emissions.

FIGURE 9. RECENT AUTO-EMISSIONS LEVELS OF HYDROCARBONS, OXIDES OF NITROGEN, AND CARBON MONOXIDE

reduced emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen by 83, 83, and 11 percent respectively. The incremental requirements associated with the Safety and Damageability standards relative to the 1975 model year are shown in Table 6. Safety I is characterized by a 30 MPH frontal impact speed, while Safety II requires 40 MPH crashworthiness, plus antiskid brakes.

Scenario C is identical to Case B in terms of the auto design concepts produced. However, beginning in 1980, it requires that new cars lower their exhaust emissions to 0.41/3.4/2.0 grams per mile for HC/CO/NO_x, respectively (i.e., Emissions II).

Case D, "Upgraded '75 Technology with Level III Emissions," is similar to the previous case except that all vehicles produced after 1979 must now meet more stringent (i.e., Level III) emissions requirements (Figure 8d). These standards constrain emissions of HC, CO, and NO_x to below 0.4/3.4/0.4 grams per mile, respectively. Meeting these standards requires that cars be equipped with two- or three-way catalysts, and is assumed to lower fuel economy by about 10 percent.

Case E, "Upgraded '75 Technology With Improved Safety," is similar to Case B, except that there is an additional emphasis on safety (Figure 8e). Auto design concept #4,

TABLE 6a. INCREMENTAL IMPROVEMENTS FOR SAFETY AND DAMAGEABILITY LEVEL I RELATIVE TO 1975 MODEL YEAR

	Crashworthiness			
Protection	Criteria	Impact Object	Impact Speed	Impact Angle
Frontal	**	Fixed flat barrier	30 mph	0° ± 30°
Side	**	4000 # moving barrier	20 mph	90°
Rear	Proposed improvements to seating systems (Std 207)			
Rear	**	Moving barrier	30 mph	180°

TABLE 6b. INCREMENTAL IMPROVEMENTS FOR SAFETY AND DAMAGEABILITY LEVEL II RELATIVE TO LEVEL I

	Crashworthiness			
Protection	Criteria	Impact Object	Impact Speed	Impact Angle
Frontal	*,**	Fixed flat barrier	40 mph	0° ± 30°
Side	*,**	4000 # moving barrier	20 mph	90°
Ejection	Egress requirement additions to Std 206			

*FMVSS-301

**FMVSS-208

initiated into production in 1980 is assumed to meet Level II Safety and Damageability requirements. The safety-enhanced vehicles are phased in gradually, achieving 100 percent of production in 1990.

Case F "Fuel Economy Emphaisized with Level II Emissions" (Figure 8f), resembles Case B in terms of phasing. However, the auto design concept introduced in 1980 has a lightweight diesel engine, weight-conscious structure, and upgraded drive-train. Auto concept #7 is introduced into production at the rate of 10 percent per year, and represents 100 percent of the new-car fleet by 1990. The superior fuel economy of the diesel allows the attainment by 1990 of a new-car fleet fuel economy of 31.3 mpg (expressed in terms of gasoline-equivalent gallons).

Representative results for the scenarios described above are presented in Figures 10 through 19. Average new-car fuel economy over the interval of 1976 through 2000 is presented in Figure 10, for those scenarios which rely exclusively on gasoline-consuming vehicles. As expected, Case B achieves the highest fuel economy, reaching 26.3 miles per gallon. All the safety and emissions variations on Case B result in some fuel-economy degradation, yet exceed the fuel efficiency of the reference case.

Average fleet fuel economy corresponding to these scenarios is presented in Figure 11. It should be noted that improvements in fleet fuel economy lag behind new-car fuel

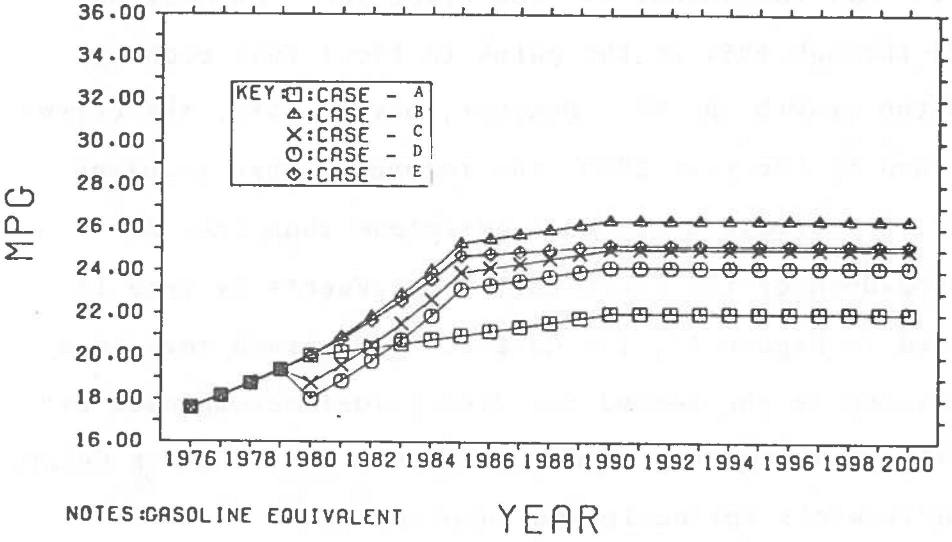


FIGURE 10. AVERAGE NEW-CAR FUEL ECONOMY (MILES/GALLON)

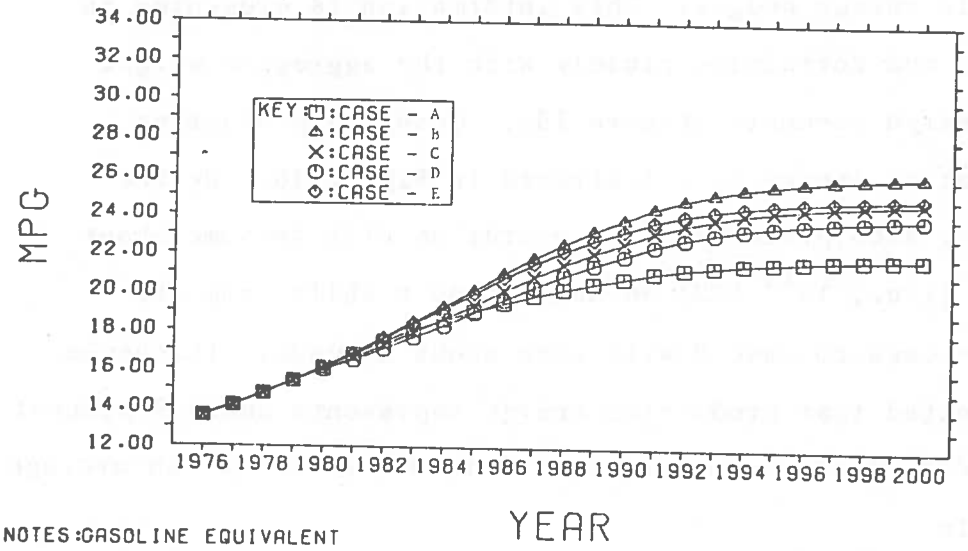


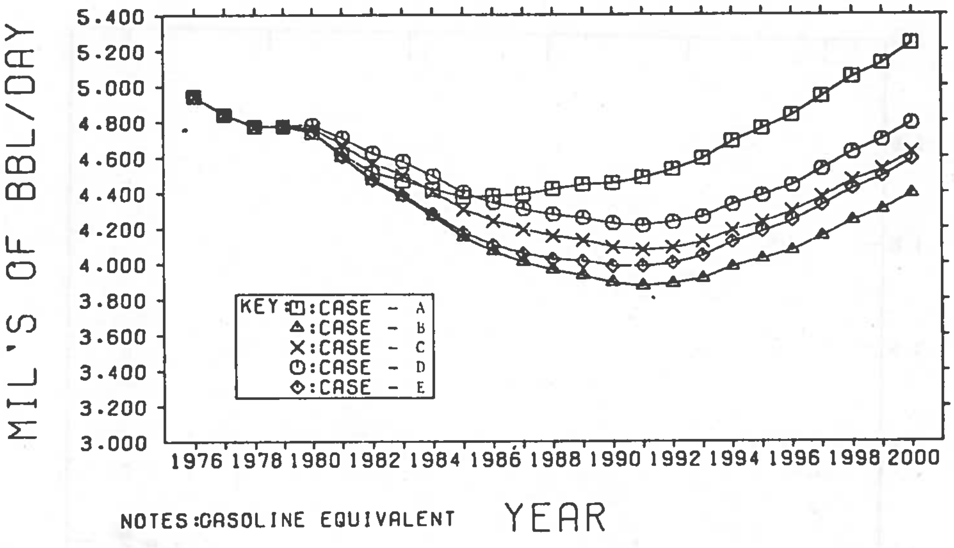
FIGURE 11. AVERAGE FLEET FUEL EFFICIENCY (MILES/GALLON)

economy by about 10 years. This delay reflects the time it takes to scrap the older design concepts.

Total fuel consumption for the cases is compared in Figure 12. All the scenarios show fleet fuel consumption declining through 1985 as the gains in fleet fuel economy outweigh the growth in VMT. However, beyond 1985, the curves diverge, and by the year 2000, the reference case requires about 800,000 barrels a day more petroleum than Case B.

A breakdown of the fleet fuel requirements by type is illustrated in Figure 13, for Case F. This graph reveals a phased buildup in the demand for diesel fuel accompanied by a reduction in demand for leaded gasoline, and, after a delay, lower requirements for nonleaded gasoline.

The above discussion has focused exclusively on the propulsion energy requirements of an auto. Production and fabrication energy is another important element in a vehicle's life-cycle energy budget. This information is presented in Figure 14 and correlates closely with the aggregate weight of the design concepts (Figure 15). Combined production and operating energy is illustrated in Figure 16. By the year 2000, auto production and operation will consume about 10 quads (i.e., 10^{15} BTU) annually, and a shift from the reference case to Case B will save about 2 quads. It should also be noted that production energy represents about 9 percent of the total energy consumed by the future auto over an average life-cycle.



NOTES:GASOLINE EQUIVALENT

FIGURE 12. COMPARISON OF ANNUAL FLEET FUEL CONSUMPTION TRENDS FOR SELECTED SCENARIOS

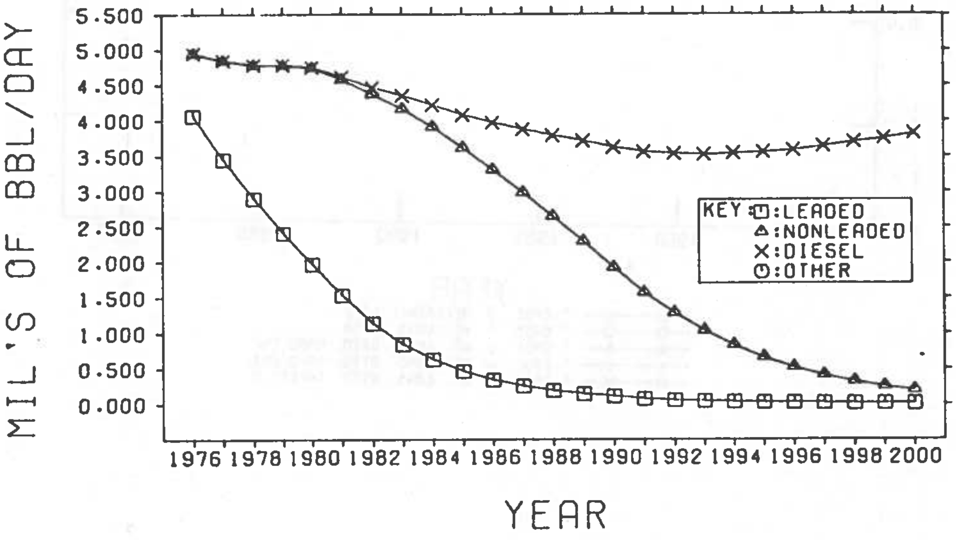


FIGURE 13. ANNUAL FLEET FUEL REQUIREMENTS BY TYPE FOR CASE F (WEIGHT-CONSCIOUS DIESEL)

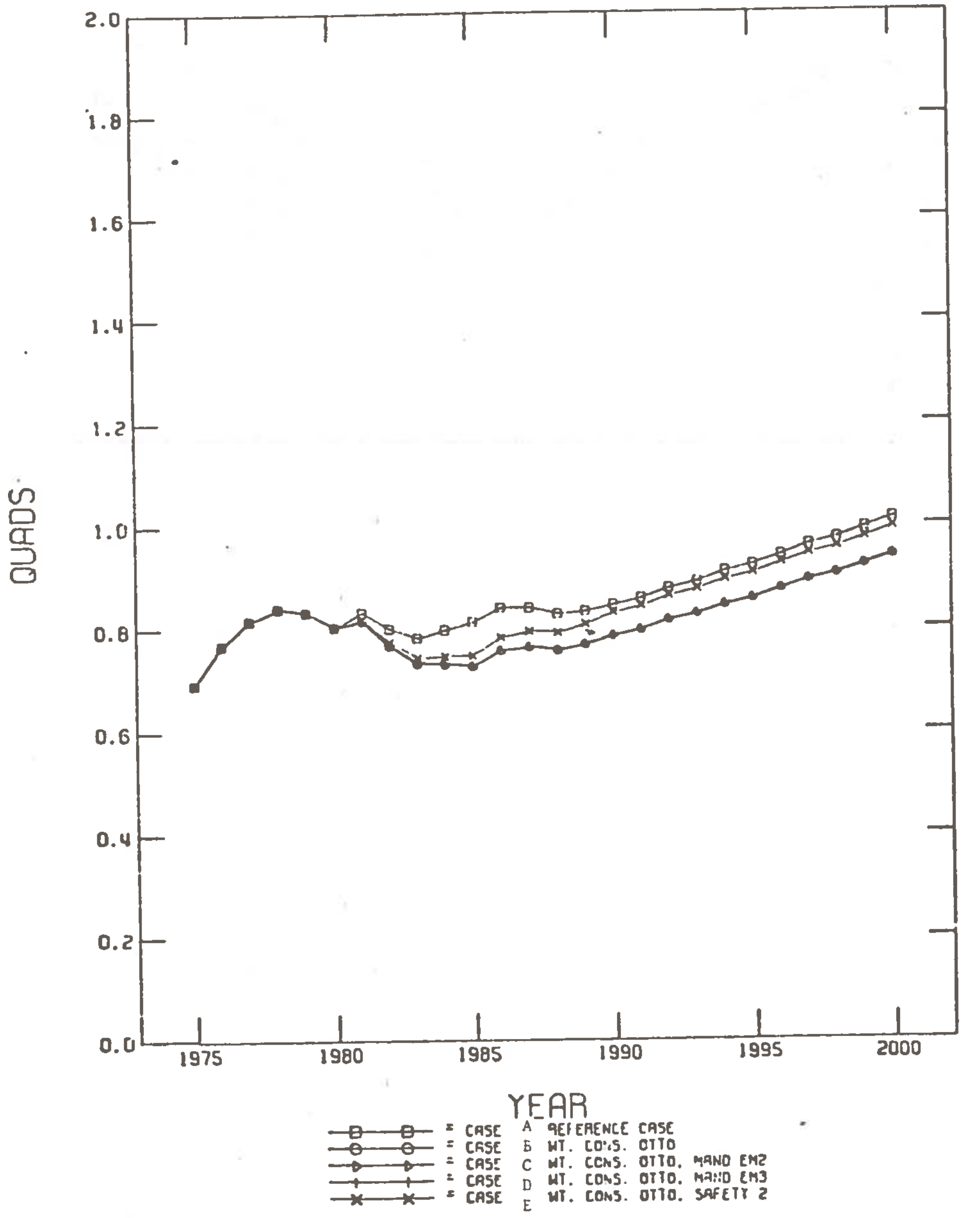


FIGURE 14. AUTO PRODUCTION AND FABRICATION ENERGY CONSUMPTION REQUIREMENTS FOR SELECTED SCENARIOS

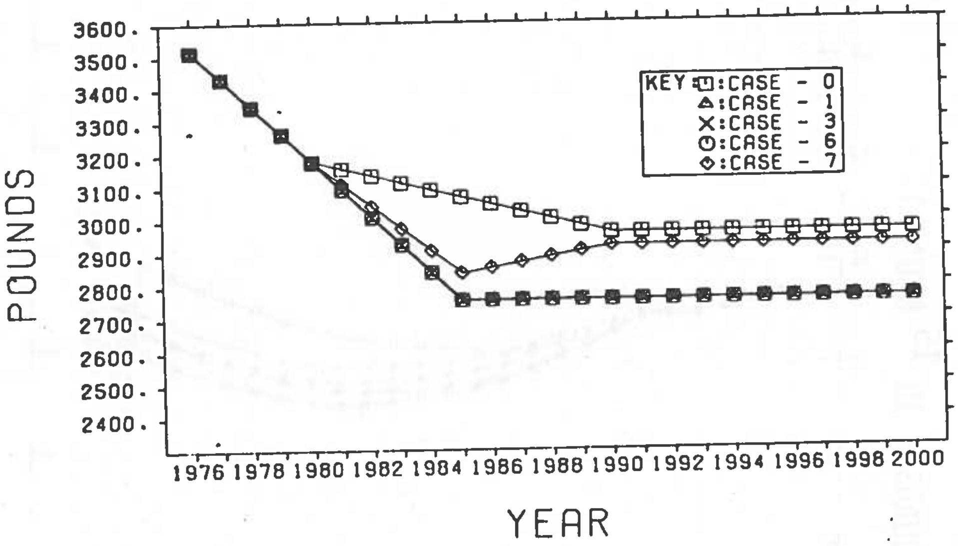


FIGURE 15. AVERAGE NEW-CAR WEIGHT VS. TIME

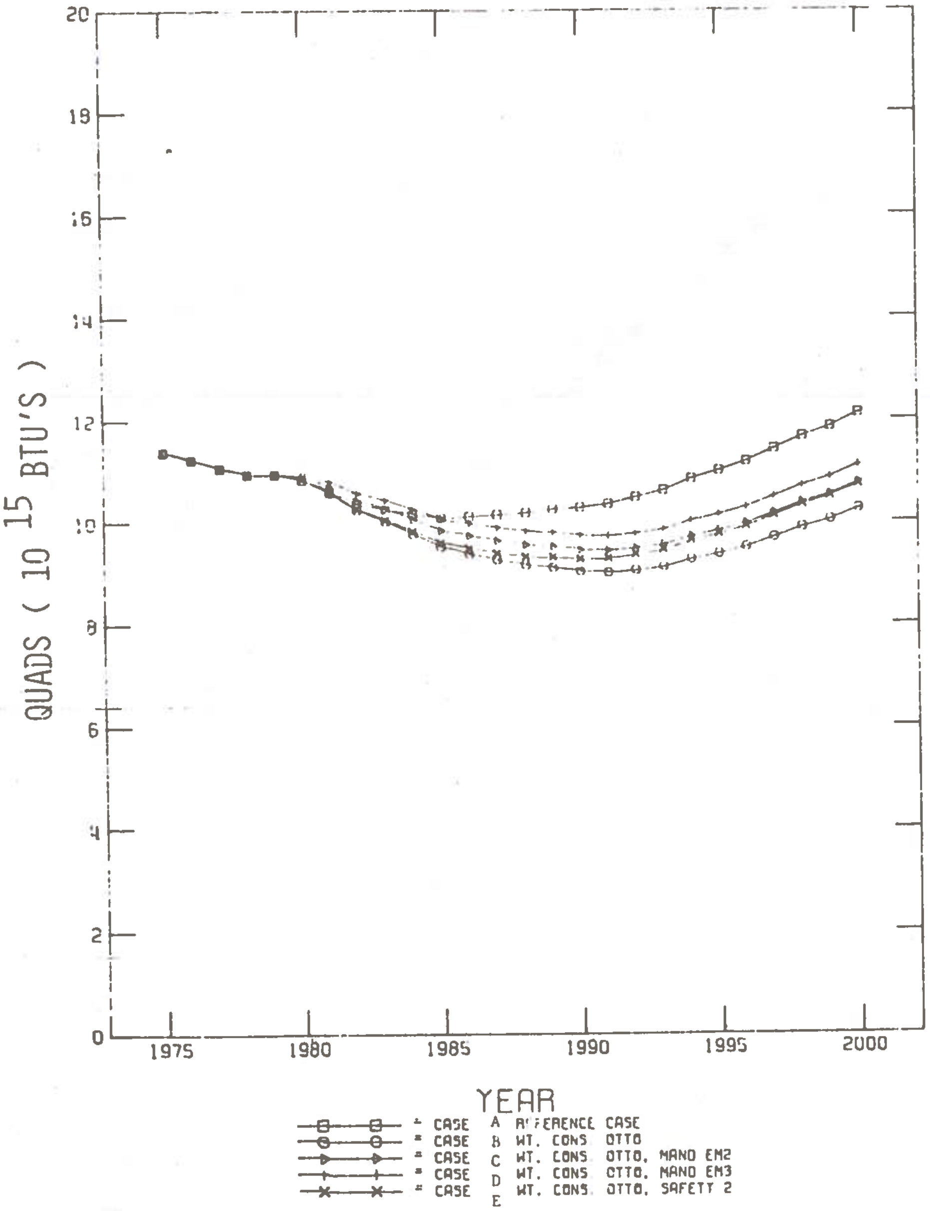


FIGURE 16. AUTO ENERGY CONSUMPTION REQUIREMENTS FOR SELECTED SCENARIOS -- ANNUAL PRODUCTION PLUS OPERATING ENERGY

Annual production requirements for carbon steel and stainless steel, two of the 24 materials tracked are presented in Figures 17 and 18, respectively. The increase in stainless-steel demand exhibited by Case D is associated with the requirements for a catalyst. Additional details on production energy and materials consumption appear in Reference 7.

Finally, the investment components, expressed as changes from the reference case, are illustrated in Figure 19 for scenario F. This information has been disaggregated by the INFORUM postprocessor into five sectors as follows: motor-vehicle industry Producers' Durable Equipment (PDE), material-related industries PDE, distribution-related industries PDE, all other industries PDE, and private construction. Figure 19 reveals that increased investment in the early years, required for motor-vehicle production and diesel fuel distribution facilities, is offset by capital savings in the later years.

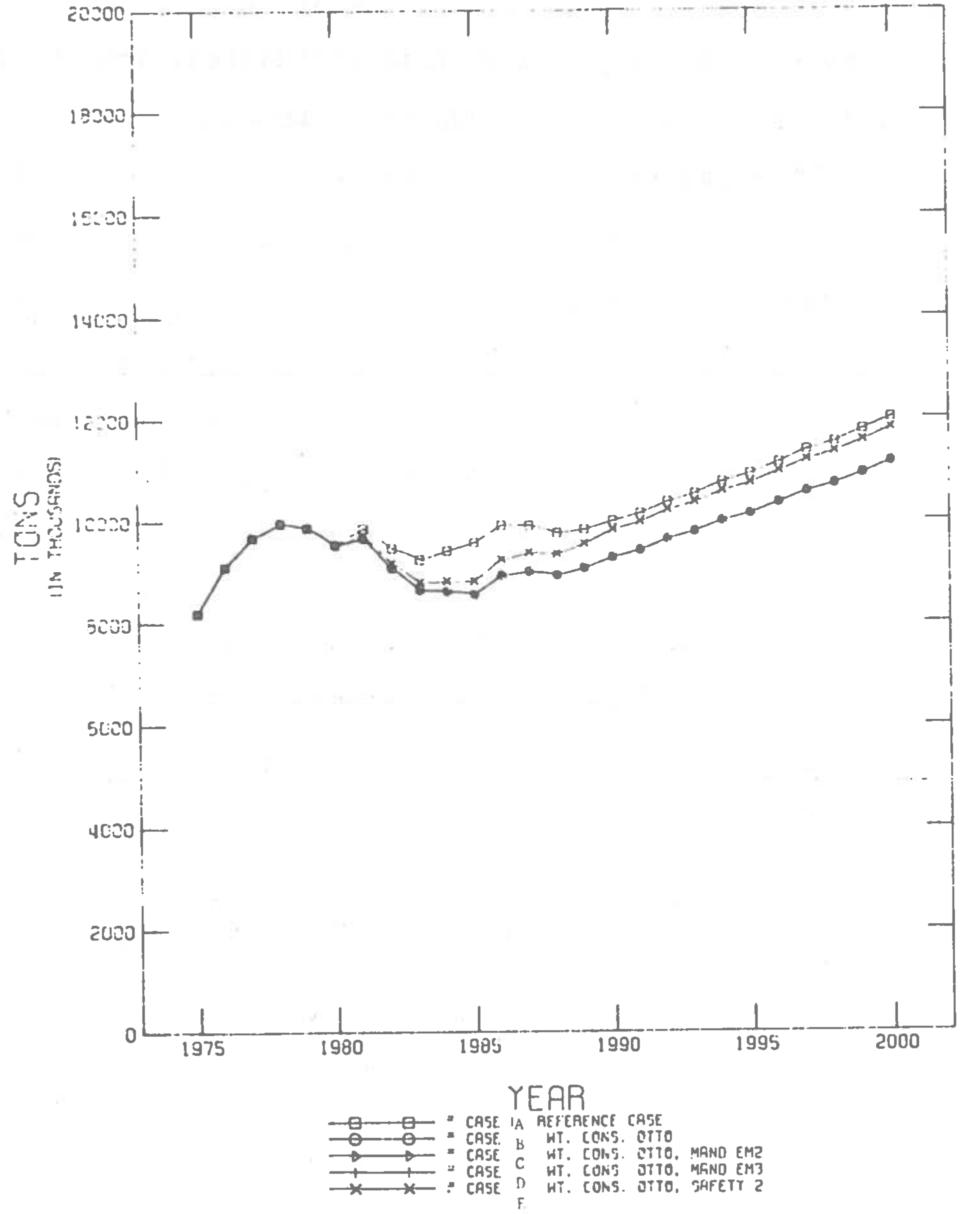


FIGURE 17. AGGREGATE ANNUAL CONSUMPTION OF CARBON STEEL FOR SELECTED SCENARIOS

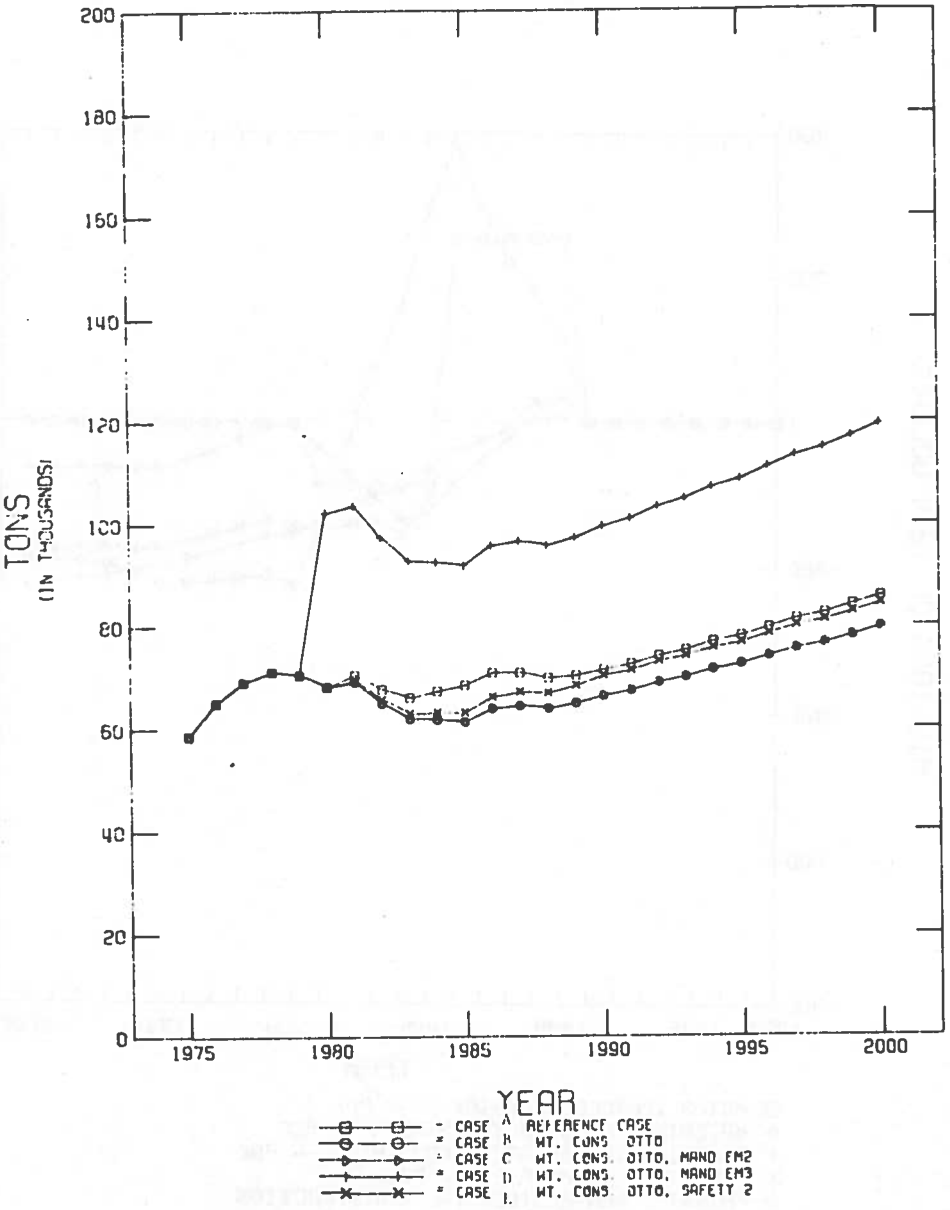


FIGURE 18. AGGREGATE ANNUAL CONSUMPTION OF STAINLESS STEEL FOR SELECTED SCENARIOS

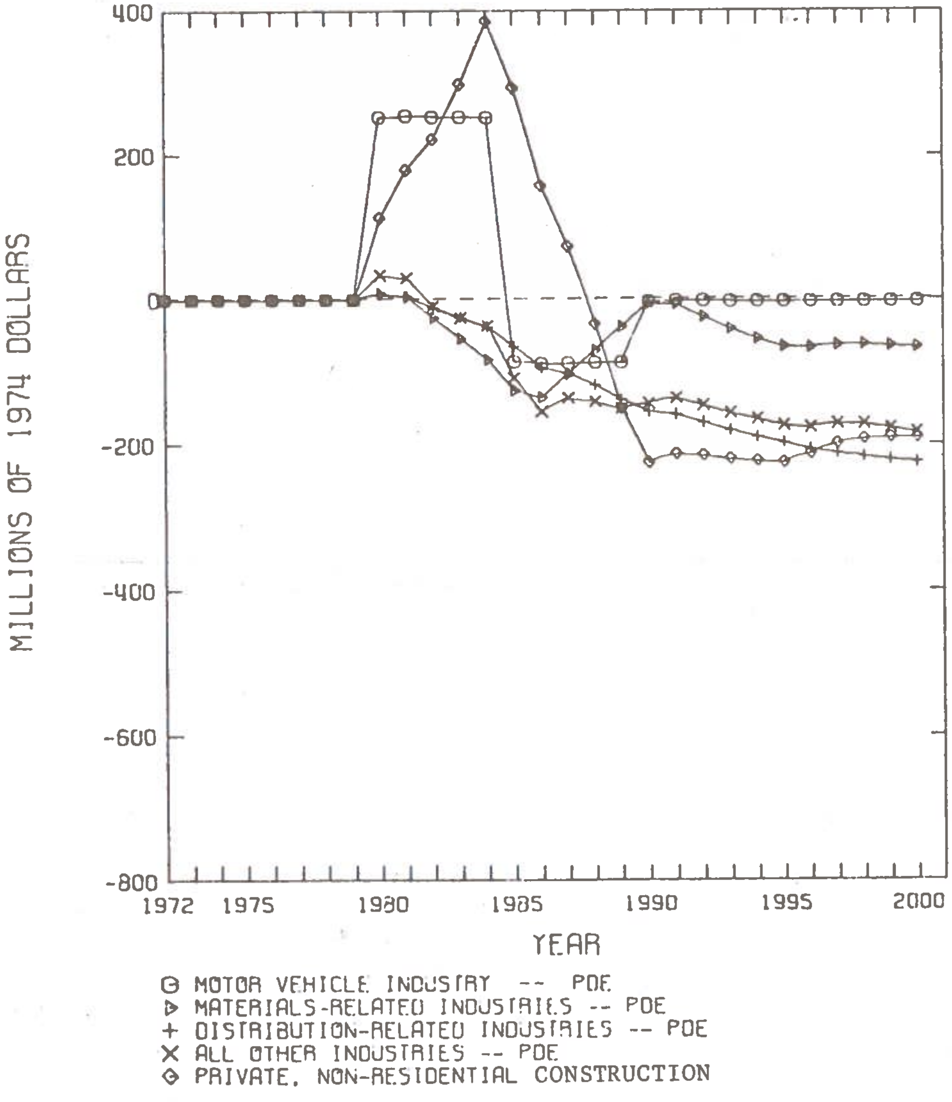


FIGURE 19. INVESTMENT COMPONENTS VS. TIME AS DELTAS FROM BASE CASE FOR SCENARIO F (WEIGHT-CONSCIOUS DIESEL)

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