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Baseline Projections of Transportation Energy Consumption by Mode: 1981 Update

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Center for Transportation Research

Energy and Environmental Systems Division
ARGONNE NATIONAL LABORATORY

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BASELINE PROJECTIONS OF TRANSPORTATION ENERGY
CONSUMPTION BY MODE: 1981 UPDATE

by

M. Millar, J. Bunch,* A. Vyas, M. Kaplan,
R. Knorr, V. Mendiratta, and C. Saricks

Energy and Environmental Systems Division
Center for Transportation Research

April 1982

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U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Conservation and Renewable Energy
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*Northwestern University, Evanston, Illinois

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SUMMARY

This report documents the methodology and results of research conducted by the Center for Transportation Research (CTR) at Argonne National Laboratory (ANL) for the U.S. Department of Energy's Office of Vehicle and Engine Research and Development (OVERD). Undertaken to provide a set of baseline projections of transportation activity and energy demand for use by OVERD in its technology and program-development activities, the projections incorporate least-surprise, or business-as-usual, assumptions about future economic activity and energy prices. Moderate levels of fuel-efficiency improvement, achieved through modifications in the technical and operating characteristics of vehicles, are also assumed.

The resulting projections of future transportation activity and energy demand are shown in Tables S.1 and S.2. Major findings are as follows.

- Energy consumption by light duty vehicles, especially automobiles, is expected to decline through the year 2000 as more fuel-efficient vehicles penetrate the fleet and real fuel prices continue to rise.
- Despite moderately increasing disposable incomes, the continuing rise in the cost of travel is expected to constrain passenger travel demand.
- While truck activity more or less parallels overall economic activity (GNP), truck energy consumption is expected to grow at a slower rate than the economy as a whole -- as increased dieselization and other new-truck efficiency improvements diffuse throughout the truck fleet.
- Rail freight activity is expected to grow somewhat faster than the overall economy, primarily as a result of increased coal production and use.
- Because of continuing increases in expenses for fuel and new fuel-efficient aircraft, air fares are expected to remain high, particularly as compared with the cost of competing modes. Thus, domestic air revenue passenger-miles (RPMs) are projected to increase slowly from their 1980 level, and energy consumption by domestic air carriers is projected to decline through the year 2000. In the absence of modal competition, international air RPMs are projected to grow somewhat faster, resulting in moderate growth in energy consumption by international air carriers. Total aviation energy consumption is projected to remain nearly constant through the year 2000.
- As a result of slow growth in transportation demand and significant efficiency improvements, especially in light duty vehicles and jet aircraft, total transportation energy consumption is expected to decline through the middle 1990s.

Table S.1 ANL-81 Projections of Transportation Energy Consumption by Mode and Submode

Transportation Mode and Submode	U.S. Consumption (quads) ^a				Average Annual % Change, 1980-2000
	1980	1985	1990	2000	
Automobile	9.74	8.72	7.88	6.70	(1.9)
Small	2.15	2.04	1.98	1.94	(0.5)
Medium	3.24	4.03	3.55	2.82	(0.7)
Large	4.36	2.66	2.34	1.93	(4.0)
Personal Light Truck	1.80	1.70	1.95	1.70	(0.3)
Bus	0.14	0.16	0.17	0.18	1.3
School	0.05	0.05	0.05	0.06	1.0
Transit	0.06	0.08	0.09	0.10	2.0
Intercity	0.02	0.03	0.03	0.03	1.4
Commercial Truck	2.92	3.32	3.57	4.08	1.7
Light	0.91	0.92	0.91	0.93	0.1
Heavy					
Local	0.70	0.80	0.89	1.01	1.9
Intercity	1.31	1.60	1.78	2.14	2.3
Rail	0.57	0.70	0.78	0.96	2.6
Freight	0.50	0.63	0.71	0.89	2.9
Passenger					
Transit/commuter	0.05	0.06	0.06	0.06	0.4
Intercity	0.02	0.01	0.01	0.01	(2.3)
Marine	1.36	1.60	1.80	2.24	2.5
Domestic freight	0.26	0.31	0.34	0.40	2.3
International freight	0.92	1.07	1.21	1.51	2.5
Recreational ^b	0.18	0.22	0.25	0.33	3.1
Aviation	1.37	1.24	1.18	1.21	(0.6)
General aviation	0.14	0.19	0.23	0.32	4.2
Domestic passenger	1.04	0.83	0.72	0.63	(2.5)
International passenger ^c	0.16	0.18	0.18	0.21	1.3
Domestic freight	0.04	0.04	0.05	0.06	2.4
Pipeline	0.86	0.97	1.00	1.50	2.8
Natural gas	0.69	0.79	0.81	0.90	1.3
Crude oil	0.08	0.09	0.09	0.10	1.3
Petroleum products	0.09	0.10	0.10	0.11	1.3
Coal slurry	0.00	0.00	0.00	0.39	d
Miscellaneous vehicle ^e	0.28 ^f	0.31	0.34	0.40	1.9
Total All Modes ^f	19.04	18.72	18.67	18.97	0.0

^aModal values may not equal submode totals, due to rounding.

^bProjections from ANL-79 (Ref. 2).

^cExcludes fuel purchases in U.S. by foreign carriers. Includes fuel purchases overseas by U.S. carriers.

^dDue to an extremely small base, the growth rate is meaningless.

^eIncludes motorcycles, snowmobiles, and the incremental energy used to tow nonmotorized recreational vehicles.

^fExcludes military consumption.

Table S.2 ANL-81 Projections of Transportation Activity by Mode and Submode

Transportation Mode and Submode	Activity (10 ⁹) ^a				Average Annual % Change, 1980-2000
	1980	1985	1990	2000	
Automobile (VMT ^b) ^c	1114.7	1263.1	1386.1	1515.7	1.5
Small	312.7	357.2	415.7	540.6	2.8
Medium	381.6	578.6	615.6	610.2	2.4
Large	420.3	317.3	353.6	363.4	(0.7)
Personal Light Truck (VMT)	197.3	216.0	265.0	296.1	2.1
Bus (VMT)	5.8	6.3	6.7	7.4	1.2
Commercial Truck (TMT ^d)	203.8	253.0	294.5	347.5	2.7
Light	77.2	90.5	104.9	127.1	2.5
Heavy	126.6	162.5	189.6	220.4	2.8
Rail					
Freight (TMT)	853.2	1077.1	1211.5	1521.8	2.9
Passenger (PMT ^e) ^f	4.8	4.4	4.0	3.2	(2.0)
Marine (TMT) ^g	602.0	711.3	780.6	934.8	2.2
Aviation					
Domestic passenger (PMT)	203.2	191.4	198.3	227.6	0.6
International passenger (PMT)	57.2	74.7	90.0	135.9	4.4
Freight (TMT)	5.1	6.0	6.7	8.1	2.4
Pipeline (TMT)	930.0	1053.7	1090.3	1402.8	2.1
Natural gas	347.2	393.4	404.8	449.5	1.3
Petroleum	581.5	658.9	684.2	756.4	1.3
Coal slurry	1.3	1.3	1.3	196.9	-

^aModal value may not equal submode totals, due to rounding.

^bVehicle-miles of travel.

^cIncludes electric vehicles.

^dTon-miles of travel.

^ePassenger-miles of travel.

^fIntercity only.

^gDomestic waterborne freight only.

In terms of energy conservation, the baseline projections in this study present a relatively optimistic prospect for the future. However, that optimism is qualified by two related concerns: (1) by year 2000, energy consumption is again likely to be rising as technological improvements now "in the pipeline" achieve most of their impact (no new technologies are foreseen in the baseline scenario); and (2) for certain transportation modes, commercial aviation in particular, much of the reduction in energy consumption comes as a result of reduced activity levels. The former indicates that research and development efforts should focus on technologies that can reach commercial readiness in the period beyond 1990. The latter issue illustrates the potential tradeoff between the economic costs of reduced levels of productive activity versus the economic benefits of energy conservation. While beyond the scope of this effort, the interrelationship of productive activity and energy conservation should be carefully considered in policy analyses.

This report is organized into the following major sections.

- Section 1 describes the baseline scenario, focusing on such parameters as economic and demographic factors, fuel prices, and transportation technologies. This section also contrasts the general assumptions of the baseline scenario with those contained in several similar forecasts.
- Section 2 describes the various methods used to project vehicle stocks, transportation activity, and energy consumption -- and presents key assumptions incorporated in the projections. It includes an overview of the approach, major data sources and techniques common to several of the projections, and discussions of the models used to project stocks of personal and nonpersonal vehicles, local and intercity passenger travel, and goods movement.
- Section 3 presents baseline projections both at the aggregate level, i.e., across modes, and at the disaggregate level by individual mode or submode. Projections are compared with previous ANL efforts and with the results of other researchers.
- Section 4 analyzes the sensitivity of our projections to alternate economic and fuel-price assumptions.

A reference list and appendixes describing the materials composition of new vehicles and base-year energy intensities follow Sec. 4.

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ABSTRACT

This report presents a comprehensive set of activity and energy-demand projections for each of the major transportation modes and submodes. Projections are developed for a "business-as-usual" scenario, which provides a benchmark for assessing the effects of potential conservation strategies. This baseline scenario assumes a continuation of present trends, including fuel-efficiency improvements likely to result from current efforts of vehicle manufacturers. Because of anticipated changes in fuel efficiency, fuel price, modal shifts, and a lower-than-historic rate of economic growth, projected growth rates in transportation activity and energy consumption depart from historic patterns. The text discusses the factors responsible for this departure, documents the assumptions and methodologies used to develop the modal projections, and compares the projections with other efforts.

1 THE BASELINE SCENARIO

The ANL/OVERD* transportation activity and energy demand projections reflect a set of business-as-usual assumptions about future economic, demographic, energy, and technological conditions. Together with the resulting activity and energy projections, they comprise a least-surprise, or baseline, scenario of the country's transportation future. While designed to represent a plausible, internally consistent future, this baseline scenario is unlikely to unfurl exactly as specified, i.e., in its every particular. Given that each of the underlying assumptions has a probability of occurrence somewhat less than one, the joint probability of the entire baseline scenario is probably quite low indeed. Nevertheless, as a best-guess image of the future, the scenario represents a point of departure for program development and evaluation, policy analysis, and a host of other planning activities.

The assumptions embedded in the baseline scenario (ANL-81) are discussed in the following sections. Many of these assumptions differ from those of two preceding OVERD baselines: the 1980 DOE Conservation and Solar Strategy Paper, prepared for DOE's Office of Policy, Planning, and Evaluation and later revised by Oak Ridge National Laboratory (CSSP-80), and

*The Center for Transportation Research (CTR) at Argonne National Laboratory (ANL) and the U.S. Department of Energy (DOE) Office of Vehicle and Engine Research and Development (OVERD).

the 1979 predecessor of this report (ANL-79).^{1,2} Generally speaking, these differences arise from developments that either were just beginning to be felt when the previous studies were prepared or that appeared after they were underway. Also, some recently released data run counter to what had been conventional pre-1981 wisdom among industry executives and analysts* -- and this is another factor responsible for differences between the ANL-81 projection and earlier efforts. When coupled with models calibrated to relationships found in these more recent data sources, relatively small differences in assumptions can produce relatively large differences in results. For a more detailed comparison of the assumptions in the present effort against those of previous OVERD baselines and other recent DOE projections, see Sec. 1.4.

The assumptions in this report are current as of early 1981 and represent future conditions or values considered at that time to have the greatest likelihood of occurring. It should be noted that the baseline scenario occasionally does not reflect, and in fact may run counter to, still more recent developments. While these developments may have important short-term impacts on travel demand and energy consumption for transportation, they are considered aberrations to established trends rather than reversals of the trends themselves. Thus, efforts were directed toward discriminating between long-term trends and short-term anomalies. The resulting scenario should incorporate current data and trends without attaching excessive importance to the most recent events.

1.1 ECONOMIC, DEMOGRAPHIC, AND SOCIOPOLITICAL FEATURES

In our baseline scenario, the three factors of greatest uncertainty are world oil price, the ability of the U.S. and other Western nations to maintain economic growth, and the ability of those nations to contain inflation. These factors are closely interrelated, but their relationship is complex. For example, the recent softening of world oil price has not sparked renewed economic growth nor, for that matter, reduced inflation. Because of this complexity, as well as the degree of uncertainty surrounding future oil prices and the response of the U.S. economy to such prices, we performed a sensitivity analysis on oil price and resulting economic activity. Termed "constrained growth," this alternative GNP-energy price track is discussed in Sec. 4.

The baseline scenario is derived from the TRENDLONG2006 solution to the Data Resources, Inc., (DRI) model of the U.S. economy.³ Table 1 presents the scenario's key features, most notably moderate future levels of inflation, energy prices, and overall economic activity.

*For example, widely held estimates of the number of trucks in operation, their annual mileage, and the diesel share of truck stocks are greater than results of the 1977 Truck Inventory and Use Survey indicate. While some of this difference may be attributed to survey procedures, including disputed expansion factors, and the standard error of the survey itself, much of the difference appears to arise from a real disparity between actual and perceived trucking operations.

Table 1 Key Economic Indicators of the ANL-81 Baseline Scenario
(Average Annual Rates of Change, in Percent)

Indicator	1980-85	1985-90	1990-2000	1980-2000
Real GNP	3.1	2.5	2.2	2.5
Real disposable income	3.0	2.5	2.3	2.5
Consumer Price Index	8.6	8.1	7.1	7.7
World oil price	1.3	3.5	2.9	2.6
Unemployment ^a	6.4	6.0	5.9	-

^aAnnual rate for 1985, 1990, 2000.

Table 2 presents the broad demographic features of the baseline scenario, while Table 3 presents the household-level demographic details used to project household vehicle holdings and travel demand. Together, these two tables illustrate the "least-surprise" aspect of the baseline scenario: gradual but steady growth in household income, modest reduction in average household size, increased labor force participation, a gradual shift in the age distribution of the population, and continuing urbanization. This latter feature is somewhat obscured because urban data tend to be available only on the level of the standard metropolitan statistical area (SMSA) -- and because the total population of all SMSAs in the country has been growing more from expansion of SMSA physical boundaries (i.e., by adding "collar" counties) or from designation of new SMSAs than from absolute growth within the urban areas themselves. Thus, maintenance of the urban share of total population by the 1977 SMSAs (Table 3) implies considerable growth in the urban share by all future-year SMSAs.

1.2 ENERGY AVAILABILITY AND PRICE

1.2.1 Availability of New and Conventional Fuels

The baseline scenario assumes continued availability of conventional fuels, primarily oil. While prices may be expected to rise, shortages and other supply interruptions are not anticipated.

The only "new" types of fuels included in the baseline scenario are alcohol blends and small quantities of electricity consumed by electric vehicles (EVs) powered by nickel-zinc or lead-acid batteries. The baseline scenario assumes no concerted alcohol fuels program; hence, alcohol constitutes an insignificant portion of gasoline consumption in year 2000. Electricity consumed by EVs is computed in the projections as an explicit function of the probability of a household's having an EV, the mileage accumulated on household trips, and the energy intensity of the EV. Synthetic fuels are not included in the baseline scenario.

Table 2 Demographic Indicators of the Baseline Scenario

Indicator	Size of Indicator					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Total population ^a (10 ⁶)	225.5	232.9	243.5	252.8	260.4	0.7
Total households ^b (10 ⁶)	80.4	87.1	94.4	99.5	103.9	1.3
Labor force ^c (10 ⁶)	105.7	115.0	122.4	127.5	132.9	1.2
Household size ^d	2.75	2.61	2.52	2.48	2.45	(0.6) ^e

^a1980 Population Estimate: U.S. Department of Commerce, Bureau of the Census, Data User News, Vol. 16, No. 5 (May 1981).

Projections: Series II, U.S. Department of Commerce, Bureau of the Census, Projections of the Population of the United States: 1977-2050, Series P-25, No. 704 (July 1977).

^b1980 Households Estimate: U.S. Department of Commerce, Bureau of the Census, Data User News, Vol. 16, No. 6 (July 1981).

Projections: S.J. LaBelle et al., Argonne National Laboratory, Argonne, Ill., unpublished information from the TAPCUT project (March 1981).

^c1980 interpolated from 1979 data. All data and projections by Howard N. Fullerton, Jr., Office of Economic Growth and Employment Projections, Bureau of Labor Statistics, The 1995 Labor Force: A First Look, Monthly Labor Review (Dec. 1980).

^dComputed as total population in households/total households. The former includes the institutionalized population, approximately five million persons according to the 1980 census.

^eIn tables throughout this report, figures in parentheses (other than units of measure) signify negative values.

1.2.2 Fuel Prices

As stated previously, world oil price is one of the principal uncertainties in the baseline scenario. Thus, two price tracks, linked to alternative levels of inflation and economic activity, were specified for sensitivity testing. (See Sec. 4.) Table 1 showed the growth rates for world oil price under the baseline. Table 4 shows the associated prices, in 1980 dollars, for crude oil and refined petroleum products. Gasoline price was obtained directly from the DRI macro solution and represents the average pump price for all grades of gasoline.^{3,4} By the year 2000, virtually all gasoline is assumed to be unleaded. Diesel and jet fuel prices were computed from the gasoline prices, assuming a gradual increase in the ratio between these prices and gasoline. This narrowing of the price gap between gasoline and these other fuels reflects two critical, related assumptions:

Table 3 Distribution of Households along Key Demographic Parameters, Baseline Scenario (Percent)

Parameter	1977	1980	1985	1990	2000
Residential location					
SMSA ^a	67.2	68.5	68.6	68.5	68.3
Non-SMSA	32.8	31.5	31.4	31.5	31.7
Income (\$1975)					
Low (<\$15,000)	62.8	61.4	60.3	58.3	54.5
Medium (\$15-25,000)	24.7	25.4	25.8	26.6	28.1
High (>\$25,000)	12.5	13.2	13.9	15.1	17.4
Household size					
1	21.5	23.3	25.4	26.6	25.1
2	30.5	31.0	31.4	31.9	35.7
3-4	33.4	33.2	33.2	33.2	33.1
5+	14.6	12.5	10.0	8.3	6.1
Education of household head					
<High school	34.4	31.3	26.4	21.6	14.7
High school graduate	32.6	33.1	34.1	35.1	36.8
Some college	14.4	15.8	17.6	19.3	22.0
College graduate	18.6	19.8	21.9	24.0	26.5
Workers/household					
0	24.7	25.9	27.9	26.5	27.9
1	42.9	42.4	41.7	41.2	41.7
2	26.2	25.8	25.0	27.2	25.5
3+	6.2	5.9	5.4	5.1	4.9
Age of household head					
<25	10.3	10.4	9.4	8.2	6.7
25-34	21.7	22.9	23.5	23.0	21.3
35-44	16.2	16.9	19.1	21.0	22.3
45-54	17.4	15.5	14.2	15.1	17.5
55-64	15.9	15.6	14.8	13.3	12.7
65+	18.5	18.7	19.0	19.6	20.0

^aPercentage of households located in any of 266 urban areas designated as Standard Metropolitan Statistical Areas by the U.S. Bureau of Economic Analysis as of 1977. Does not include households located in areas which have been or will be designated as SMSAs subsequent to 1977.

Sources: 1977 data from the Nationwide Personal Transportation Study, U.S. Department of Transportation, public use tape. Residential location projections based on Scenario II trends from U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Projections, public use tape. Other projections based on Scenario II, Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) project, Argonne National Laboratory, Argonne, Ill., unpublished information.

Table 4 Fuel Prices, Baseline Scenario

Fuel Type	Price (1980 \$)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Crude oil (\$/bbl) ^a	27.9	36.3	43.0	52.2	57.1	3.6
Gasoline (\$/gal) ^b	1.22	1.35	1.58	1.86	2.01	2.5
Diesel (\$/gal) ^c	1.03	1.24	1.49	1.79	1.95	3.2
Jet (\$/gal) ^c	0.97	1.08	1.33	1.63	1.80	3.1
Electricity (¢/kW) ^d	4.9	4.9	4.9	4.9	4.9	0

^aAverage refinery acquisition cost. Source: Data Resources, Inc., U.S. Long Term Review, Lexington, Mass. (Spring 1981).

^bIncluding taxes. Source: Data Resources, Inc., U.S. Long Term Review, Lexington, Mass. (Spring 1981).

^cIncluding taxes. Computed from gasoline price and extrapolated relationship between gasoline, diesel, and jet fuel prices.

^dSource: S.J. LaBelle et al., Argonne National Laboratory, Argonne, Ill. unpublished information from the TAPCUT project (April 1982).

1. Increased demand for middle distillate fuels by automobiles, trucks, and jet aircraft will raise the equilibrium price for diesel and jet fuels faster than for gasoline. This is consistent with industry sources and with projections developed for other studies.^{5,6,7,8}
2. Soft gasoline demand associated with improved vehicle fuel economy and increased diesel penetration of automobile and truck stocks will moderate the upward pressure on gasoline prices.

Together, these two assumptions result in a narrowing of the price gap between distillate and motor gasoline fuels. By the year 2000, diesel price is projected to be 97% of gasoline price, and jet fuel is projected to be 91% of gasoline price.*

Electric vehicles (EVs) powered by conventional lead-acid and nickel-zinc batteries (see Sec. 1.3.1) are included within the baseline vehicle stock. As shown in Table 4, the real cost of residential electricity (which will be used to recharge EVs) is assumed to remain constant at 4.9¢/kWh, mainly as a result of off-peak recharging and time-of-day pricing.

*Because of the lower tax rate on jet fuel the market price is considerably below that of gasoline and diesel fuel. While the price of jet fuel rises more rapidly over time than that of these other fuels (see Fig. 1), the tax differential is assumed to moderate its market price.

Fig. 1 Baseline Scenario Oil Prices Relative to 1980

1.3 TRANSPORTATION TECHNOLOGIES

1.3.1 Automotive Technologies

Steady but not remarkably rapid progress in vehicle technology is implicit in the baseline scenario. This applies to light trucks as well as automobiles. In heat-engine vehicles, fuel-efficiency improvements result primarily from downweighting, improved aerodynamics, higher compression, and reduced friction losses. In the diesel engine, additional improvements occur from somewhat higher operating temperatures and compression ratios. Turbocharging is also expected to become significant by 1990 as a means of maintaining performance at higher combustion pressures.

Changes in engine materials relative to the 1980 model year are projected to be more or less evolutionary through the 1990s, with an increase in the use of aluminum as a substitute for mild steel and iron. Around 2000, manufacturers are expected to be producing Otto-cycle engines in which magnesium has begun to replace significant amounts of cast iron. At the same time, ceramic components should begin to play a more important role in diesel engines.

Similar changes are expected to occur throughout the projection period in the materials used for auto and van body/chassis and drivetrains.

Again, components made of aluminum, and to a lesser extent carbon-fiber and plastic, replace steel and cast iron components in the housing.⁸ Appendix A of this report lists the materials composition of new automobile engines, drivetrains, and bodies for each of the projection years.

The propulsion technologies selected to represent those EVs expected to emerge at the end of the present decade are somewhat conservative. They assume continued range limitations, and hence limited potential for market penetration. Although the state-of-the-art lead-acid battery remains capable of further improvement in power density and range, efforts are assumed to be focused on the nickel-zinc oxide (Ni/Zn) battery, which currently has the commitment of a major automotive manufacturer. Thus, under the baseline scenario, the Ni/Zn EV is anticipated to be superior in both power and range to its lead-acid counterpart by century's end. However, materials and replacement costs are expected to continue to inhibit sales.

Several sources predicting alternative rates of progress in vehicle technology were examined prior to specification of the baseline vehicle characteristics. Of particular interest were the recent studies conducted at the Mellon Institute for the U.S. Department of Energy, and by DHR, Inc., for ANL.^{9,10} Generally speaking, (i.e., excluding hypothetical or low-likelihood scenarios) vehicle characteristics are reasonably similar across these efforts and between them and the analysis performed for ANL by Hudson and Putnam.⁸ Because of their far greater specificity by vehicle type, the Hudson-Putnam characterizations were used to represent the baseline vehicle stock.

Differences between the ANL-81 fuel-economy estimates and those reported by DOE and Oak Ridge (CSP-80), Data Resources, Inc. (DRI-Summer/81), and Energy and Environmental Analysis (EEA-7/81) are due to assumptions on post-1985 fuel economy improvements.^{1,3,11} By contrast, recent studies by Mellon, DHR, and the Office of Technology Assessment project that downweighting and other efficiency improvements now "in the pipeline" will continue well into the 1990s.^{9,10} DHR forecasts a 1987 average new-car fuel economy approximately equal to that projected by ANL as the fleet average in 1992; this is consistent with ANL's determination that the VMT-weighted average age of the automobile fleet is just over five years.

1.3.2 Truck Technologies

The baseline scenario assumes the continued penetration of several technological and operational improvements recently introduced into the truck fleet. Major technological improvements have been made at all points of thermal loss, from specific consumption of the engine itself, to drivetrain losses, accessory loads, rolling resistance, and aerodynamic drag.

In addition to producing conventional diesel engines, which may be expected to capture an increasing share of the new truck market, major engine manufacturers have been developing a wide range of turbocharged "fuel saver" engines that offer a fuel-savings advantage on the order of 7%.^{13,14,15} Manufacturers also have developed a number of axle and drivetrain improvements, including downweighting of the axle itself, the use of large single axles in place of duals, increased use of tag axles, and improved gear/axle ratios. These changes provide fuel savings on the order of 4%.^{16,17}

Research is continuing on methods to reduce accessory loads. To date, the cooling system has been the principal focus of these efforts. Tests have shown that the engine fan is required for only 5% of long-haul operation and that use of a fan clutch or variable fan drive can reduce this power drain and provide fuel savings of 4-6%.^{17,18} To date, the penetration of fan clutches into the new truck market has been the greatest of all fuel-conserving devices.¹⁹

In addition to the increased use of single and tag axles, rolling resistance is being improved by means of low-resistance tires. While radial tires may involve considerable incremental cost for multiwheeled vehicles, fuel-savings advantages on the order of 6% make them a feasible alternative for many intercity, and often local, operators.¹⁹ Aerodynamics is also being improved. Body/chassis manufacturers are modifying tractor designs, and component manufacturers are marketing a variety of wind-deflection devices to reduce aerodynamic drag. While the latter types of devices have long been available as optional equipment for heavy-duty trucks, they are now beginning to penetrate the market for smaller trucks. These devices provide fuel savings of 6-10%.^{20,21}

In the area of operating improvements, carriers are becoming increasingly aware of the driver's role in fuel consumption. A significant number of fleets have introduced driver training programs that emphasize compliance with the 55-mph speed limit. These programs often use road-speed governors and tachographs to enforce the limit.

Private and for-hire carriers are also placing greater emphasis on improved vehicle management through fuel-saving maintenance. Regular tire-inflation checks, the use of fuel additives, and routine engine checkups are becoming more prevalent.¹⁷ Another aspect of improved vehicle management, maximizing the utilization of power units by increasing load size, is also being stressed. As truck size and weight limits are increased and made more uniform across the country, increased efficiencies (on a ton-mile basis) may be anticipated. Where feasible, double-trailer loading may be expected to increase.

Together, these technological and operational improvements may be expected to produce significant increases in fleet-average fuel economy. Because penetration of these improvements is already well underway, their impact should be felt in the short- and mid-term future. By 1990, technological improvements should achieve full penetration into applicable new markets. Thus, fleet-average fuel economy should rise at a fairly rapid rate through the 1980s. In the 1990s that rate should decline as the more efficient vehicles of the 80s become the norm throughout the fleet. No advanced-technology vehicles are assumed under the baseline scenario.

1.3.3 Aircraft Technologies

Aircraft technologies are likely to undergo rapid changes throughout the 1980s and 1990s as the advances developed in NASA's Aircraft Energy Efficiency (ACEE) program reach technological readiness. The ACEE program began in 1976 and was originally scheduled for completion in 1985. The goal of the program was to achieve a 50% improvement in aircraft fuel efficiency

through the acceleration of certain key technologies. Six specific projects were chosen for research and development: (1) Engine Component Improvement (ECI); (2) Energy Efficient Engine (EEE); (3) Advanced Turbo Prop (ATP); (4) Energy Efficient Transport (EET); (5) Laminar Flow Control (LFC); and (6) Composite Primary Aircraft Structures (CPAS). Table 5 contains a brief description of these projects, including their readiness dates and potential fuel savings.^{22,23}

Each of the projects will reach technological readiness at a different date. The ECI and EET projects are currently furthest along. Parts of the ECI project are now operational and have begun to appear in present engines (i.e., Pratt and Whitney Jt9D Series). The soon-to-be-introduced B767s and B757s will include these improvements. EET improvements -- such as winglets; high-aspect, low-sweep, super-critical wings; propulsion/airframe integration; and active controls -- are being incorporated into future designs and into derivatives that will begin to appear in the middle 1980s. The project to develop a new turbo-fan jet also appears on schedule. This new aircraft should be in operation in the late 1980s. The remaining projects are not expected to reach technological readiness until the late 1980s, meaning they probably will not be on the market until the early 1990s.

Once a project reaches technological readiness, it still has to be incorporated into aircraft design, developed, and marketed. Its market penetration will depend upon four factors.

- The incentive for fuel-efficiency innovation due to the cost of fuel relative to total operating costs. In 1979, fuel cost represented more than 50% of direct operating cost, and this share has continued to rise -- jet fuel prices jumped 55% in 1980 alone.²⁴
- Deregulation has caused a shift in the optimal fleet mix of an airline, creating a demand for an advanced-design, short-range, 150-seat aircraft. This may be seen in Delta's recent request for a totally new aircraft to be designed and delivered by 1986 and to achieve 77.6 available seat-miles per gallon.²⁵ In 1980, the fleet averaged approximately 44.5 seat-miles per gallon.⁵
- The age of the current fleet and the probable replacement of the B707s, standard DC-8s, and B727-200s in the near future may limit the penetration of later technologies. A heavy commitment has already been made to the B767, B757, DC-9, A-310, and present design derivatives.
- The capability of the airlines to finance the necessary capital improvements. Estimates of this capital requirement range from \$60-80 billion over the next decade. At present the industry has only \$17.5 billion in debt and equity.²⁶ Thus, there is considerable doubt as to whether these demands can be met. Possible exceptions are Delta and other relatively high-profit airlines.

In combination, these factors will shape the technological changes that actually occur in the future. From now until the latter 1980s, current medium-range aircraft and their derivatives will continue to dominate the

Table 5 NASA's Aircraft Energy-Efficiency Projects

Project	Expected Technological Readiness	Potential Fuel Savings (%)	Objective(s), Status
Engine Component Improvement (ECI)	1981	1.8-5.6	Improve present design of engine components, including fans, front mounting, short cone nozzles, and high-pressure turbines.
Energy-Efficient Engine (EEE)	1983	14.5	Develop new turbo-fan engine technology with high bypass ratio and increased overall ratio of engine pressure. Develop higher operating temperatures, reduce weight. Anticipate aircraft to be in operation by early 1990s.
Advanced Turbo Prop (ATP)	1987-1988	15-20	Develop turbo-prop engine with cruise capabilities at mach 0.8 and with low levels of noise and vibration in propeller.
Energy Efficient Transport (EET)	1983	10-20	Improve aircraft aerodynamics and lift with winglets; high aspect, low-sweep, super-critical wings; tail-stability augmentation; propulsion/airframe integration; and high lift services. Currently being incorporated in future designs.
Laminar Flow Control (LFC)	1989	20-40	Develop practical, reliable, and maintainable suction system for reducing surface-airstream friction. (Most benefits to long-range aircraft.)
Composite Primary Aircraft Structures (CPAS)	1987-1989	10-15	Reduce aircraft weight by development of composite materials for primary structures including tails, vertical fins, wings, and fuselage. At present, epoxy and graphite composites are being incorporated into secondary structures.

Source: Ref. 23.

fleet, although the percentage of wide bodies will grow steadily.²⁷ Technological changes will be introduced primarily through modifications to existing derivative designs to reduce weight and improve fuel efficiency. For example, American and other airlines are contemplating converting their B727s to a two-engine design at a cost of \$12 million each, a sizable savings over the \$40 million cost of a new aircraft.²⁸ Other anticipated near-term improvements include engine modification and increased use of weight-reducing composite materials in such secondary structures as seats, doors, and landing gear covers.

In the mid-term (i.e., middle 1980s and early 1990s), the ACEE technologies should begin to enter the market. Radical design changes may take place, including such EET improvements as super-critical high-lift wings and active controls. The Delta-specified short-range aircraft should also be introduced during this period. This will be the period of most rapid technological change. Finally, throughout the 1990s aircraft efficiency should continue to improve as penetration of the above technologies proceeds and some of the more uncertain ACEE projects achieve technical readiness and appear on the market. Near the year 2000, the rate of efficiency improvement may be expected to slow, as full penetration occurs.

1.4 COMPARISON WITH PREVIOUS BASELINES

1.4.1 Input Assumptions

In addition to comparing the results of this baseline with those of other recent studies (see Sec. 3), it is also instructive to compare some of the input assumptions behind them.* As shown in Fig. 2, ANL-81 and NEPP-81 (U.S. DOE National Energy Policy Plan) incorporate nearly identical GNP assumptions. While CSSP-80 assumes a lower initial GNP, its higher growth rate results in slightly greater GNP by the year 2000. OPPE-81 (not shown in Fig. 2), developed by Oak Ridge National Laboratory, likewise tends toward a somewhat more optimistic assumption about GNP. In terms of growth rates, ANL-81, NEPP-81, and EIA-81 (U.S. DOE Energy Information Administration 1981 Annual Report to Congress) assume that GNP grows by approximately 2.5% per year between 1980 and 2000. CSSP-80 and OPPE-81 assume annual growth rates of approximately 3% and 2.8%, respectively.

Figures 3 through 5 respectively compare the world oil, gasoline, and diesel-fuel price assumptions of the various studies.** As can be seen in Fig. 3, between 1980 and 1985 the ANL-81 projection of world oil price rises at a somewhat slower rate than that of most others; beyond 1985 all have

*The 1979 doubling of world oil prices acts as a delimiter between economic and fuel-price projections. Pre-1979 efforts tend to incorporate significantly lower fuel-price projections and significantly higher economic projections than later efforts. Because of these systematic differences, this comparison is limited to post-1979 projections.

**The OPPE-81 projections use a single fuel-price variable, i.e., transportation petroleum fuel, whose value is expressed in 1980\$/10⁶ Btu. Over the projection period, this variable increases from \$7.64 to \$13.15.

Fig. 2 Comparative Projections of GNP

comparable slopes. The early-year differences in world oil price are attributable to the supply and price conditions prevailing when the various studies were initiated.

It is not so obvious why the projections of gasoline price differ as markedly as they do (see Fig. 4). Again, however, the year-2000 projections fall in roughly chronological order (i.e., those developed earliest tend to be highest, while those developed most recently tend to be lowest). Generally speaking, gasoline price is determined as the equilibrium solution in these projections, taking into consideration such variables as the cost to refineries of acquiring crude oil, refinery margins, demand for competing products (especially diesel fuel), and GNP. Thus, it is difficult to isolate the cause or causes of the apparent disparity in gasoline price.

Diesel price assumptions (Fig. 5) appear quite similar across the various efforts. The 1980 differences occur for any of three reasons: some projections include taxes while others do not, the 1980 data point may be either a mean annual value or a mid-year price, or because each projection uses a different estimating method (there being no standard time series of diesel fuel prices). Beyond 1980, differences in assumed crude oil price account for most of the differences in the slopes of the projections.

Fig. 3 Comparative Projections of World Oil Price

1.4.2 Base-Year Estimates

Most of the projections were generated before 1980 data were available. Thus, much of the base-year data represents estimates developed either by individual researchers or other recognized sources. The disparity between these estimates may be seen in Table 6, which compares 1980 values for GNP; fuel prices; and vehicle stocks, vehicle-miles traveled (VMT), fuel economy (in mi/gal) and fuel consumption for automobiles and light and heavy duty trucks. Some background about each of these estimates follows.

Official figures for GNP are periodically revised, often years after the fact. This regular revision explains the apparent differences between GNP as reported in the ORNL Transportation Energy Conservation Data Book, in NEPP-81, and in this effort (ANL-81) -- all of which are based on the same source (i.e., the National Income and Product Accounts of the U.S.). The GNP figures reported in CSSP-80 are projections.

Crude oil and gasoline prices are comparable across all studies except for CSSP-80. Again, the CSSP figures are projections. Diesel and jet-fuel prices differ by 10-15% across the other sources, partly because certain of the original sources include taxes while others do not and partly because sources based on the prices paid by surveyed carriers (i.e., airlines and trucking companies) may not be representative of the average retail price.

Fig. 4 Comparative Projections of Gasoline Price

Total vehicle-miles traveled (VMT) are estimated by the Federal Highway Administration (FHWA), based on state fuel tax receipts and estimated fuel economy. According to their latest estimates, published in Oct. 1981, automobile, single-unit truck, and combination-truck VMT were 1111.9, 324.6 and 60 billion, respectively, in 1980. The ORNL estimates are based on the FHWA totals. The ANL-81 estimate is a projection based on the 1977 Truck Inventory and Use Survey (TIUS) and the 1977 Nationwide Personal Transportation Study (NPTS). Both the ANL-81 and the NEPP-81 estimates fall within 2% of the FHWA auto estimate; the ANL-81 and CSSP-80 estimates of light plus heavy truck VMT also fall within 3-4% of the FHWA total truck estimate.

Annual estimates of the stocks of automobiles and trucks on the road at mid-year are developed by R.L. Polk and Co., based on state vehicle registrations and scrappage trends. Using this information, as well as the 1977 TIUS, which provides a breakdown of trucks in operation by size class, ORNL has estimated the stock of light and heavy duty trucks for 1978, 1979, and 1980. The ANL-81 projections of light and heavy duty trucks in operation fall within 5% of the ORNL truck stock estimates for 1980. The NEPP-81 stock figures, as indeed the DOE estimates of VMT, are derived from the data base of the Highway Fuel Consumption model developed for DOE by Energy and Environmental Analysis, Inc.,¹¹ and on the consumption figures presented in the Energy Information Administration's 1980 Annual Report to Congress.⁸⁸

Fig. 5 Comparative Projections of Diesel Price

The ANL-81 and CSSP-80 estimates of automobiles in operation are projections, the former for late in 1980, the latter for mid-1980. The difference between them and the R.L. Polk estimate, as reported by ORNL, arise partly from the fact that they are projections, and hence do not capture the severe 1980 sales downturn; and partly from recent revisions to the Polk data base, as a result of which 1.3 million passenger vans (previously classified as autos) were reclassified as trucks.

The estimates of VMT/vehicle are either based on the 1977 NPTS (automobiles) or TIUS (trucks), or they are computed from the stock and VMT estimates. Hence, the differences shown arise either from variations in these input values or from the use of alternative data sources (primarily NPTS versus TIUS for the light trucks, or FHWA versus NPTS for automobiles).

Total highway fuel consumption ranges from just under 110 billion gal in NEPP-81 to slightly more than 120 billion gal in CSSP-80. This relative agreement reflects the aggregate control total for VMT (FHWA) and fuel consumption (DOE) used by the several sources. Modal estimates tend to have been developed by the individual researchers and, thus, are subject to more variability. Generally, the various researchers base their 1980 fuel economy assumptions (in mi/gal) on vehicle sales and survival data and on an assumed relationship between the U.S. Environmental Protection Agency test and on-the-road fuel economy.

Table 6 Comparison of 1980 Estimates of GNP, Fuel Price, VMT, Vehicle Stock, and Fuel Use in Four DOE Studies

Statistic	1980 Value Estimated by Study			
	ANL-81	ORNL	NEPP-81	CSSP-80
GNP (\$10 ⁹ , 1980)	2,650	2,485	2,480	2,628
Price				
Crude oil (1980 \$/bbl)	27.90 ^a	28.07 ^a	28.08 ^a	36.30 ^b
Gasoline (1980 \$/gal)	1.22	1.21	1.22	c
Diesel (1980 \$/gal)	1.03	1.12	0.96	c
Jet fuel (1980 \$/gal)	0.97	0.87	0.9	c
Vehicle-Miles Traveled				
VMT/auto	10,500	10,600	10,500	11,700
Total VMT, all autos (10 ⁹)	1,114.7	1,111.9	1,097	1,229.3
VMT/light duty truck	9,600	10,100	8,700	11,800
Total VMT, all light duty trucks (10 ⁹)	274.5	303.9	244	293.7
VMT/heavy duty truck ^d	18,100	15,700	20,000	18,900
Total VMT, all heavy duty trucks (10 ⁹)	96.1 ^e	80.7	90 ^d	103.9
Vehicle Stocks and Fuel Use				
Total auto stock (10 ⁶)	106.0	104.6	104	103.5
Auto on-the-road fuel economy (mi/gal)	14.3	15.1	15.1	16.7
Total fuel consumption, all autos (10 ⁹ gal)	77.9	73.4	73.2	77.9
Total light duty truck stock (10 ⁶)	28.7	30.1	28	25.4
Light duty truck on-the-road fuel economy (mi/gal)	12.7	12.8	12.1	13.7
Total fuel consumption, all light duty trucks (10 ⁹ gal)	21.7	23.6	20	23.4
Total heavy duty truck stock (10 ⁶)	5.3	5.1	4.5	f
Total fuel consumption, all heavy duty trucks (10 ⁹ gal)	14.6	14.9	16.7	18.8

^aAverage refinery acquisition cost.

^bWorld oil price.

^cNot available.

^dIntercity VMT only.

^eAn additional 30.4 · 10⁶ VMT is projected by ANL-81 for local operation.

^fNot estimated directly.

Sources: ORNL -- G. Kulp et al., Transportation Energy Conservation Data Book, Ed. 5, Oak Ridge National Laboratory, Oak Ridge, Tenn. (Nov. 1981).

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to the National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

2 METHODOLOGY

The baseline projections were developed from a number of different models and analytical techniques. Some of these were developed by the CTR staff specifically for this effort; others were recalibrated or modified from earlier model versions to permit their use under somewhat different circumstances; still others were applied exactly as specified by other researchers. The subsections below focus on the background and application of the various models employed in the projection process, the data sources used in developing and calibrating them, and the assumptions made in exercising the models and producing the baseline projections. The discussion covers all aspects of the methodology used to project personal and nonpersonal vehicle stocks, local and intercity passenger travel, and goods movement, and is organized into these general projection categories. The discussion of the methods used for each of these types of projections is preceded by a brief overview of the approach, major data sources, and techniques common to several of the projections.

2.1 OVERVIEW

2.1.1 General Approach

The various methodologies used to project future vehicle stocks, transportation activity, and energy consumption share several distinctive features; together, these suggest the general approach, or basic theoretical framework, used in this study. This approach may be characterized in terms of the following key postulates.

- Passenger travel behavior is a function of such factors as the demographic characteristics of the tripmaker, the spatial distribution of travel opportunities, the extensiveness and level of service of the transportation network, and the cost of travel.
- The demand for goods movement is a function of such factors as the output and characteristic travel requirements of major freight-producing economic sectors, the spatial relationship between producers and consumers, and the service levels of the available transport network. In general, these factors tend to parallel those listed above. Travel cost is the notable exception, since cost sensitivity is typically most pronounced for low-value goods. For high-value goods, cost is typically passed on to the final consumer and therefore influences transportation activity primarily as it affects economic activity.
- At any point in time the composition of the personal vehicle stock is a function of such factors as the historical stock, the vehicle preferences of owners, and the characteristics of the choice set. Nonpersonal vehicle stocks are directly related to historical stocks and the level of economic activity in the sectors which they support.

Wherever possible, the baseline projections of future passenger and freight activity and vehicle stocks explicitly consider these factors. Local passenger travel demand is projected on the disaggregate household level,* as are personal vehicle stocks. Because demographic factors effectively drive these projections, future household demographics are projected in considerable detail as input to the process. This level of detail preserves the impact of related variables and biases within the data set. The intercity passenger travel projections are SMSA- and network-based. From a national perspective, the intercity network is far more manageable than the local network and thus more amenable to network modeling. Both local and intercity passenger travel, and indeed vehicle choice as well, are price-sensitive.

On the freight side, all the projections are tied to economic activity, either in terms of the quantity of goods to be transported or the number of vehicles needed to transport that quantity. Modal competition is preserved on the commodity level, where present tariff structures and other modal characteristics encourage or discourage it.

The projections are intended to reflect a "bottom up" approach to forecasting total transportation activity and energy consumption. Generally speaking, this implies disaggregation by mode and submode. Modes (or vehicles) which tend to compete with other modes (or vehicles) are projected with models that emphasize modal (or vehicle) choice. Modes (or vehicles) which tend not to compete are projected by either mode-specific models or trend extrapolation. Figure 6 is a simplified schematic of the key inputs, processes, and outputs associated with the major projections. Each of the flows depicted in Fig. 6 is described in greater detail in the sections, tables, and figures indicated. The major inputs are discussed below.

2.1.2 Major Data Sources

In 1977 the Bureau of the Census conducted three nationwide surveys as part of its Census of Transportation. These were: the Nationwide Personal Transportation Study (NPTS); the National Travel Survey (NTS); and the Truck Inventory and Use Survey (TIUS).^{29,30,31} These surveys provide a comprehensive "snapshot" of travel in 1977 and are the major data sources used in our analysis. Other sources are regional economic projections of the Bureau of Economic Analysis (BEA) and the Commodity Transportation Survey (CTS).^{32,33} Each of these five data sources is discussed below.

2.1.2.1 Nationwide Personal Transportation Study (NPTS)

NPTS is probably the most recent and comprehensive data set on passenger travel currently available. It was used in our analysis as the base data set for analyzing both personal vehicle stock and local travel projections; the methodology used in those analyses is explained later in this section.

The NPTS was a national household-based survey conducted throughout the U.S. from April 1, 1977, to March 31, 1978. Bureau of the Census sampling

*Because the level of aggregation of the baseline is national, local projections do not incorporate spatial or network variables.

Fig. 6 Chart of Major Passenger and Freight Projection Processes and Location of Descriptive Data in This Report

procedures were used to insure that each area of the country and time of year were statistically represented. A home interview was conducted in each of the 17,949 households sampled.

During the interview, detailed information was obtained on the household's demographic characteristics (i.e., age of members, education, income, etc.) and travel patterns -- and on the characteristics of motor vehicles and other transport modes available to the household. The survey was conducted either on the day following the household's designated "travel day" or as soon as possible thereafter. Information was obtained for all trips made by household members during the travel day as well as for trips of 75 mi or longer made in the previous 14-d period.

The NPTS data set contains this raw information, along with weighting factors for expanding the estimates to national household and person-based totals (i.e., household trips, person trips, etc.). The projection process made extensive use of these weights, both for obtaining base-year travel estimates and as a basis for developing future-year projections. (See Sec. 2.1.3.)

2.1.2.2 National Travel Survey (NTS)

Conducted by the Bureau of the Census, the National Travel Survey (NTS) documents nonlocal travel patterns of the U.S. population. According to the NTS, nonlocal travel pertains to trips >100 mi one-way. The NTS provides a "snapshot" of all save the following four types of travel during 1977:

- Travel connected with being part of an operating crew on a train, bus, plane, truck, or ship;
- Travel by a worker commuting to and from work;
- Travel by a student commuting to and from school; and
- Travel by members of the armed forces while on active duty.

Information was obtained primarily by personal interview from a national probability sample of approximately 25,000 housing units representing the total civilian noninstitutional population of the United States. At each sample household, interviews were conducted at approximately three-month intervals over the survey period to develop a record of all trips taken by household members during 1977.

The NTS data file provides information on 19,112 respondent households and 79,309 trips. The file includes such information as origin, destination, purpose, mode, trip length and activities engaged in during the trip. Origin and destination information is provided in the form of state or country codes for all trips and in the form of SMSA (standard metropolitan statistical area) codes for trips involving certain selected urban areas. Trip-origin information is provided from households in 30 SMSAs, and trip-destination information is provided from households in 52 SMSAs, including the 30 SMSAs that provide origin information. This SMSA-level origin and destination information provided the basis for calibrating the intercity passenger travel model.

2.1.2.3 Truck Inventory and Use Survey (TIUS)

The Truck Inventory and Use Survey (TIUS) documents the characteristics and use of the U.S. commercial truck fleet (i.e., excluding vehicles owned by federal, state, and local government agencies). The data are based on a stratified sample of more than 100,000 private and common-carrier trucks registered in each state. The survey has been conducted in 1963, 1967, 1972 and 1977. The data provide detailed information on total registrations, as well as various cross-classifications of the truck population within each state by vehicle utilization, size, fuel type, primary commodity transported, and area of operation.

2.1.2.4 Bureau of Economic Analysis (BEA)

The 1980 cycle of regional economic projections prepared by the Bureau of Economic Analysis was used to project future SMSA-level activity, which in turn generated future inter-SMSA travel demand. (See Sec. 2.5.) As part of its analytical activities, BEA projects state, county, and SMSA population, employment, and product, the latter two by several subcategories, out to the year 2050. Within a single national total, BEA specifies three alternative scenarios, each of which embodies alternative assumptions for allocating total national activity down to the local level. Scenario I assumes that SMSAs will maintain their 1969 share of total state activity. Scenarios II and III assume that the SMSA share will change over time at a rate corresponding to the 1969-1978 rate of change, modified by a set of decay factors. Under Scenario II, the decay factors are somewhat greater than under Scenario III, and hence the former may be considered an intermediate case. (For this reason, we used the BEA Scenario II for the baseline projections of this study.) For all three scenarios, the projections pertain to only those 266 SMSAs defined as of 1977.

2.1.2.5 Commodity Transportation Survey (CTS)

The Commodity Transportation Survey (CTS) provides data on the volume and geographic distribution of commodities that are shipped by manufacturers in the U.S. The data are based on a two-stage design sample that incorporates information on approximately 13,000 plants and 150 bills of lading from each sampled plant. The procedure provides data both on shipment size and origin/destination. The first surveys were conducted in 1963 and 1967. Subsequent surveys have been placed on a five-year cycle and are coordinated with the quinquennial Census of Manufacturers. The sample includes intercity commodity movements by rail (including piggyback), motor carrier, private truck, air, and water. Pipeline movements are excluded from the survey.

2.1.3 Major Techniques: Iterative Proportional Fitting and Disaggregate Categorical Analysis

Because of their key role in several of the projection methods, iterative proportional fitting (IPF) and disaggregate categorical analysis merit separate discussion preparatory to the detailed descriptions of each methodology. IPF is an established technique for survey analysis. IPF procedures

were originally developed to calculate "cell weights to be applied to sample data to ensure that the expanded sample jointly represents the population on several background distributions."³⁴ As a result, total population estimates can be derived from small samples, and sample weights may be adjusted to improve representativeness across known distributions (e.g., to correct for undersampling of a particular population group).

For the projection application, IPF was used to match a set of target distributions (margins) to a set of original cell distributions by computing associated least-change factors (i.e., weight adjustments close to one). A two-margin case may be illustrated as follows:

Let A^0 denote the original sample distribution along the two margins I and J, and let A_{ij}^0 denote an individual element or cell in the original $k \times n$ matrix A^0 :

$$A^0 = \begin{bmatrix} A_{11}^0 & A_{12}^0 & \cdot & \cdot & \cdot & A_{1j}^0 & \cdot & \cdot & \cdot & A_{1n}^0 \\ A_{21}^0 & & & & & & & & & \\ \cdot & & & & & & & & & \\ \cdot & & & & & & & & & \\ \cdot & & & & & & & & & \\ A_{i1}^0 & \cdot & \cdot & \cdot & \cdot & A_{ij}^0 & \cdot & \cdot & \cdot & A_{in}^0 \\ \cdot & & & & & & & & & \\ \cdot & & & & & & & & & \\ \cdot & & & & & & & & & \\ A_{k1}^0 & \cdot & \cdot & \cdot & \cdot & A_{kj}^0 & \cdot & \cdot & \cdot & A_{kn}^0 \end{bmatrix}$$

If U_1 and U_2 are defined as $n \times 1$ and $k \times 1$ unity vectors, then M_1^0 and M_2^0 may be defined as $1 \times n$ and $k \times 1$ vectors:

$$M_1^0 = U_2' \cdot A^0 \quad (1)$$

$$M_2^0 = A^0 \cdot U_1 \quad (2)$$

where:

U_2' = the transpose of vector U_2 .

Alternatively, the individual elements within M_1^0 and M_2^0 , S_i^0 and S_j^0 , may be viewed as column and row sums, as shown in Fig. 7, which are projected from the base year T_0 to a forecast year T_n .

Once the original distributions have been determined from the sample data, the IPF procedure modifies the original cell totals, A_{ij}^0 , to match the forecast target S_i^n within the vector M_1^n :

$$A_{ij}^n = \left(A_{ij}^0 \right) \left(S_i^n / S_i^0 \right) \quad (3)$$

$$A_{ij}^n = S_j^n / S_j^o \cdot A_{ij}^o$$

$$A_{ij}^n = S_i^n / S_i^o \cdot A_{ij}^o$$

$$W_{ij}^n = A_{ij}^n / A_{ij}^o \cdot W_{ij}^o$$

where:

A_{ij}^o = Original cell total

$S_i^n S_j^n$ = Target margins for categories i and j in margins I and J

$S_i^o S_j^o$ = Sample margins for categories i and j in margins I and J

A_{ij}^n = Forecast cell total

W_{ij}^o = Original household weight

W_{ij}^n = Forecast household weight

Fig. 7. Iterative Proportional Fitting over Time,
Two-Margin Case

The second target, S_j^n , is then matched by recalculating A_{ij}^n and repeating the procedure:

$$A_{ij}^n = \left(A_{ij}^o \right) \left(S_j^n / S_j^o \right) \quad (4)$$

This last calculation throws the first margin off. The first iteration is now complete, so convergence is checked. Iteration continues until the convergence criteria chosen are met for all margins. Revised weights are then computed by dividing the final cell totals by the original ones:

$$W_{ij}^n = W_{ij}^o \left(A_{ij}^n / A_{ij}^o \right) \quad (5)$$

The process converges rapidly and is easily expanded to several margins.

For this effort, IPF was used in the original context to forecast future-year household cell distributions. It was also applied to the NPTS data in a disaggregate categorical analysis to forecast stocks and personal vehicle travel. For the latter application, six distributions were projected exogenously for each forecast year. These were as follows.

1. Urban/rural split;
2. Age of household head (25 or younger, 26-35, 36-45, 46-55, 56-65, over 65);
3. Education of household head (did not finish high school, high school graduate, some college, college graduate);
4. Number of workers per household (none, one, two, three, or more);
5. Income group (low, medium, high); and
6. Household size (one, two, three or four, five or more).

The IPF was then applied to the NPTS data set (partitioned into household cells) to create a "synthetic," or simulated, forecast-year NPTS sample, and new weights were obtained. Because the IPF matches base-year to future-year distributions with the least possible change in the sample distributions, its results preserve as much of the original sample intercorrelations as possible and represent a plausible future population. Assuming that these distributions capture shifts over time in those factors that influence travel behavior, the simulated sample can then be used to forecast future-year travel.

The advantages of this approach are as follows:

- Once the simulated sample is created many different shifts and relationships can be analyzed because no information is lost from the original sample.
- The technique is similar to traditional categorical analysis in which rates are applied to cell totals. However, since the weights are applied to individual records and aggregation occurs at the end of the process, intercorrelations and variances are preserved.

- Since there is usually a high correlation between the controlled margins and the free margins, forecasts can be developed for free margins. This is the method whereby future auto ownership distributions (i.e., total vehicle holdings) were obtained for input into the stock selection model.
- Finally, since the intercorrelations and variances are preserved, it is theoretically possible to obtain confidence intervals on the estimates. This is now being explored.

Some reservations are as follows:

- As in all models, behavior is assumed to remain constant with respect to the independent variables. If inappropriate margins are chosen or a fundamental change occurs in travel behavior, the estimates may be inaccurate.
- The relative importance of different variables and behavioral elasticities cannot be obtained except through sensitivity analysis. Coefficients are not obtained.

The different applications of the technique are explained more fully in the sections that follow.

2.2 PERSONAL VEHICLE STOCKS

The overriding feature of the methods used to project small, medium, and large gasoline and diesel autos and light trucks is their disaggregate nature. Automobiles and vans were projected by means of IPF (see above) and UTK's Disaggregate Vehicle Stock Allocation Model (DVSAM).^{*} That model allocates vehicle types to household types based on vehicle characteristics and household preferences. Other light trucks were projected by means of the IPF and categorical analysis. The latter is a generic technique whereby changes over time in the number of households and their demographic characteristics are associated with changes in the demand for light trucks. Each of these models and techniques is discussed below.

2.2.1 Automobiles and Vans

2.2.1.1 Background and Description of Stock Model

The 1977 Nationwide Personal Transportation Study (NPTS) household trip files provide an extremely rich and detailed empirical data base for the examination of disaggregate vehicle preference and holdings structures. This cross-sectional survey provides considerable information on the connections between demographic variables (household income, age and education of household head, total family size) and automobile ownership or availability by vehicle type. Unfortunately, however, NPTS provides no information on the

vehicle type. Unfortunately, however, NPTS provides no information on the evolution over time of vehicle holdings patterns by households of specific types. Assuming that these patterns are stable through time, the demographic detail within NPTS may be viewed longitudinally (i.e., the vehicle holdings patterns of low-income households remain constant, but individual low-income households change their holdings patterns as they move into middle income cells). This in turn assumes that demographic or economic variables are the principal determinants of total personal vehicle holdings over time. Thus, changes in the demographic structure of the national population, disaggregated to the household level, account for growth or decline in the total personal vehicle fleet. From this perspective, a given household type or "cell" classified by values of the demographic variables listed above will hold as many automobiles in 2000 as it does in 1977, although not necessarily the same types of automobiles.

In summary, the selection of a household vehicle holdings model was based on two convictions: that individual households change their total holdings only as their respective demographic status changes, and that the characteristics of the vehicles held are a joint function of the household demographic profile specified for a given projection year and the "attractiveness" (i.e., salability) of the available stock of personal vehicles.

The Lave-Train Utility Function. In order to identify what makes a vehicle attractive to the people in a given type of household, it was necessary to use a predictive choice model that would be sensitive both to the level of demographic detail in the 1977 NPTS and to a discrete set of future vehicle characteristics.⁸ Such a model was developed by Lave and Train. In a recent application for Lawrence Livermore Laboratory, the Lave-Train model was used to project the demand for various alternative future automobiles.³⁵ This application shares certain features with the present effort.

Originally calibrated as a new car market model, the Lave-Train model involved formulation of a multinomial logit function of the following independent variables:

- Initial cost of auto divided by household income class
- Initial auto cost divided by household income, quantity squared
- Operating cost per mile (sum of nonfuel running cost, which is a constant specific to each vehicle and year, and fuel cost, which varies according to vehicle efficiency and fuel price)
- Number of seats, weighted according to family size (i.e., "extra" seats are assigned a value of one-half when total seats exceed the number of family members)
- Dummy variable, applied only to smaller cars and increasing their attractiveness, if the household owns more than two autos

- Class of number of persons in the household; one of two coefficients is applied to that number, with the coefficient chosen depending on whether a car in the choice set accommodates either more than five passengers or five or fewer passengers
- Vehicle miles traveled (VMT) per month by the household, applied to full-size cars only
- Auto weight times age class of respondent (head of household)
- Above variable, quantity squared
- Auto weight times education class of respondent (head of household)
- Above variable, quantity squared
- Performance index (horsepower-to-weight ratio) times age class of respondent (head of household)
- Dummy variables for each of nine automobile types (sports/specialty, two subcompacts, two compacts, one intermediate, two "standard" sizes, and one "luxury"), to account for such factors as comfort, perceived safety, and "bandwagon" trend effects not explicitly covered by the other variables.

Modification of the Lave-Train Utility Function. CTR staff modified the Lave-Train function to run in an incremental logit form and re-estimated dummy coefficients. The modified model, called the Disaggregate Vehicle Stock Allocation Model (DVSAM), was used to estimate vehicle stocks for each of the projection years. To do so, the model employs an incremental logit equation to estimate vehicle holding probabilities for existing-technology vehicles and a simple logit equation to estimate holding probabilities for new-technology vehicles.

The principal purpose of using an incremental analysis, as opposed to running the Lave-Train model directly, is to reduce errors associated with using a new car sales model for predicting holdings. This is accomplished by incorporating given information on the distribution of holdings (in this case, the NPTS household file partitioned by demographic and vehicle-holding characteristics) and using the model mainly to predict changes in this distribution. In order to maintain consistency with the vehicle total treated in the Lave-Train choice set, and to avoid diluting future probability distributions through the introduction of spurious choices, the DVSAM permits a maximum of 10 types of vehicles in any run of the model.

Given a change in the utility of auto type a_i to household type h (as that utility is computed by the Lave-Train function) -- and given the base probability of that household holding that type of auto -- the predicted probability of such a holding can be expressed

$$p'^h(a_i) = \frac{p^h(a_i) \exp(\Delta U_{a_i}^h)}{\sum_A p^h(a_j) \exp(\Delta U_{a_j}^h)} \quad (6)$$

where:

$\Delta U_{a_i}^h$ = the change in utility of vehicle type a_i to household h ,

$p^h(a_i)$ = the base probability of household h holding vehicle type a_i ,

A = the choice set of vehicle types available in both base and forecast years, and

a_j = all competing vehicle types in the set.

Because this choice set expands in each successive projection year (from five vehicles in 1980, to six in 1985, eight in 1990 and nine in 2000), it is necessary to partition the logit procedure to predict the share of newly introduced vehicles according to their computed absolute utility. Shares of all vehicles in a given year are first distributed according to a standard logit formula (using absolute utilities); then the normalized percentage share of all vehicles appearing for the first time in that year's choice set (i.e., new-technology vehicles) is subtracted from one. The remaining percentage represents the aggregate share of conventional, or established, vehicles. This share is distributed among those vehicles by incremental logit according to the computed change in the utility function from base to forecast year. Thus, five established vehicle technologies and one new one are projected for 1985, six established and two new vehicle technologies for 1990, and eight established technologies and one new one for 2000. In each case, standard and incremental logit formulas are applied sequentially.

Although each vehicle in a choice set competes predominantly on the basis of the Lave-Train household and vehicle variables listed above, a penalty was imposed in the utility function for limited-range (i.e., battery-powered) vehicles. This reflects the inability of such vehicles to serve 100% of a given household's requirements for daily vehicle-miles of travel. Maximum ranges were specified for all electric vehicles, depending on battery technology and projection year. From these maximums, a value was computed to correspond to the fraction of daily household VMT beyond the range capability of the specific battery-powered vehicle. This value was multiplied by the Lave-Train coefficient associated with a range-limited vehicle and the result was multiplied by the coefficient of operating cost in the utility function;³⁵ the product was added to the utility function, as computed by the normal procedure, and the sum became the new (and diminished) absolute utility value.

An initial test of the model was to develop a 1980 stock distribution from the empirical 1977 values. As expected, the model failed to replicate the dramatic movement to smaller cars since about 1978. In the 1977 holdings, the considerable bias toward large cars (with curb weights exceeding 3700 lb in more than 43% of automobiles and vans) creates an inertia in the logit distribution that imposes past results on future projections. This is particularly strong when, as in the baseline vehicles, fuel economy and performance improve at a consistent pace across all vehicle types. Because of this inertia in the original Lave-Train model, the function was calibrated away from 1977 "equilibrium" by systematically modifying the dummy variable

coefficients for all vehicles with standard spark-ignition (Otto-cycle) engines in order to replicate the approximate 1980 holdings distribution. This recalibration was accomplished through use of a recursive technique developed by CTR staff, to alter the utility values. In this technique, the upper and/or lower bounds of the percentage share of holdings that may be specified for any vehicle type(s) with which a dummy variable is associated; next, the current value of the share is multiplied by the log ratio of the nearest desired bound and the current value; finally, the utility computation/logit procedure iterates to closure.

Not only was this technique able to produce a more acceptable shares distribution for the five vehicle types available in 1980, but it also provided a means to control for under- or over-representation of specific vehicles in future-year choice sets. Such maldistribution could arise because the basic model does not recognize supply constraints on new technologies and cannot control such factors as accelerated scrappage of vehicles with declining relative utility for a household. Thus, when projecting vehicle holdings for 1985, 1990, and 2000, upper bounds were imposed on the penetration of diesel vehicles. In 1985, an accelerated scrappage rate was assumed for large vehicles, thereby reducing their share.

Although the decision to calibrate to a 1980 holdings distribution resulted in a large increase in the value of the coefficient associated with the dummy variable for four-passenger vehicles with Otto-cycle engines, it was encouraging to note that this calibrated value did not result in the small car completely overwhelming the automotive fleet by 2000. This result occurs because the coefficients for all car sizes increased, thereby reducing the relative increase in the small-car coefficient.

Stock projection results for all years are discussed in Sec. 3.2. Aggregate totals were developed by multiplying IPF-computed household cell totals for the projection year by the 1977 NPTS auto ownership rate for each cell. Estimates of vehicles not actually owned by households were developed and subtracted from the DVSAM result. Total automotive stocks were then computed as the sum of the latter value plus fleet auto stock.

2.2.1.2 Development of Input Data

NPTS Data Set. It was assumed that the distribution of small, medium, and large* auto and van holdings in the weighted NPTS household file represented a base set of household vehicle holdings consistent with an ownership-choice distribution generated by the Lave-Train utility function. That is, a computed value on a vehicle for each household type could be considered the

*"Small" corresponds to two auto-size categories established by the U.S. Environmental Protection Agency (EPA), minicompact and subcompact, and was assumed to carry four passengers. "Medium" corresponds to compact and intermediate EPA size classes and was assumed to carry five passengers. "Large" corresponds to the standard, or full-size, EPA classification and was assumed to carry six passengers. Vans were classified as standard (large) vehicles. The "luxury" class is not used in the baseline projections.

relative probability of a household of that type owning (holding) that vehicle, such that the total share of vehicle size i , S_i , is obtained as the ratio of ρ_i , the aggregate probability of size i , to the aggregate probability across all sizes. The two probabilities are expressed as follows.

$$S_i = \left(\rho_i / \sum_i \rho_i \right) \quad (7)$$

$$\rho_i = \sum_h \left(p_i^h H^h \right) \quad (8)$$

where:

S_i = total share of vehicle size i ,

ρ_i = aggregate probability of size i ,

p_i^h = probability of owning vehicle size i for household segment h (where i = small, medium, or large), and

H^h = the proportion of households in household segment h .

In order to reveal disaggregate automobile preferences, the NPTS household data file was first partitioned into 576 cells representing a five-dimensional array of relevant demographic variables that characterize a household: number of automobiles owned (two classes); income (three classes); number of family members (four classes); formal education of household head (four classes); and age of household head (six classes). For a further discussion of the procedure used to partition the NPTS data set, see Sec. 2.1.2.

The NPTS-weighted number of households in each cell was computed, as was the distribution (by percentage) of small, medium, and large vehicles held in each cell. Curb-weight thresholds corresponding to the approximate break-points between EPA subcompact/compact, intermediate, and large classes by model year determined the allocation to the three aggregated size classes for each model year. The final form of the base-year holdings file was thus an array of 576 cells by 8 terms, with the first five terms of each record being integer values defining the demography of the cell and the last three terms being the empirical distribution of small, medium, and large cars. This file became the point of departure for the computation of the future holdings distribution.

Characterization of Baseline Vehicles. For 1980 a vehicle holdings file using 1977 NPTS data was created. For all subsequent projection years, the output vehicle holdings file from the DVSAM run for the preceding forecast year was used as the base-year file.

The personal-vehicle choice set selected for the baseline projection does not diverge significantly from technologies currently available in the automotive market. Vehicles equipped with Otto-cycle engines are characterized for small, medium, large, mini (two-seater), and van markets -- and these vehicles continue to dominate the fleet well into the future. Because of the

limit of 10 vehicle types in the DVSA, shares of Otto-cycle vehicles within each size class have been preallocated among the three fuel-system options now in use: uniform charge (UC), indirect-injection stratified charge (SC), and turbocharge (TC). A single diesel-powered automobile, incorporating characteristics of mid-size and full-size vehicles, is used as proxy for all diesel cars until after 1990, at which time an efficient four-passenger diesel car (proxy for mini and small vehicles) is added to the choice set.* Thus, two diesel automobiles are represented in year 2000.

The vector of attributes for characterizing the fleet of vans assumes that virtually all vans have Otto-cycle engines through 1985, but that diesel-powered vehicles represent 10% of the van fleet by 1990 and 20% by 2000. Although conservative estimates now project a significant participation by electric-powered vans in the commercial fleet by 2000, we have assumed no penetration of such vans into the personal-vehicle stock. However, two electric-powered automobiles (EVs), one incorporating state-of-the-art and one near-term technology, have been included in the baseline fleet. These are both characterized as five-passenger (medium) cars and are powered, respectively, by lead-acid (Pb/acid) and nickel-zinc oxide (Ni/Zn) battery packs.

Averaging Vehicle Characteristics Vectors. Table 7 presents average purchase price, curb weight, number of seats, and fuel economy for the entire automotive fleet by projection year. In the special case of operating cost, fuel cost is determined from fuel price and vehicle fuel economy. The latter is a function of vehicle weight and power and is computed using an algorithm developed by General Motors and reported by M.F. Chang, et al.³⁶ The algorithm computes fuel economy as a function of rolling resistance and idle fuel flow rate. Changes in operating cost (\$/mi) on a disaggregate, household level between successive DVSA runs are computed for use in the VMT-elasticity calculation described in Sec. 2.4.1.

The procedure employed to estimate the average fuel-consumption characteristics of a fleet, i.e., for the entire age-weighted spectrum of vehicles on the road in each of the projection years, was as follows.

1. Using data from NPTS and R.L. Polk (the latter as reported in Ref. 37) on the distribution of vehicles by age, a percentage distribution of vehicles by age (up to 16 years and above) was estimated for calendar years 1985, 1990, and 2000. Weight, power, operating cost, and fuel economy values for the new cars in bracket years were linearly interpolated across the intervening years (that is, a "1982" car or van was assigned values equal to those of 1980 plus two elevenths of the difference between those of 1980 and 1990). The "fleet average" then resulted from an age-weighted summation over these derived values.

*While small numbers of small diesels will be on the road before 1990, they are assumed to represent an insignificant share of the vehicle fleet. Hence, they are not explicitly modeled until after 1990.

Table 7 Characteristics of the Automotive Fleet by Projection Year

Year, Car Size/ Engine Type	Average Used-Car Price (1975 \$)	Nonfuel Operating Cost (1975 ¢)	City Fuel Economy (mi/gal)	No. of Seats	Curb Weight (lb)
1985					
Small/Otto-cycle	2200	3.40	21.7	4	2370
Midsize/Otto-cycle	2700	3.94	17.7	5	3110
Large/Otto-cycle	3410	4.60	15.2	6	3700
Van ^a	4100	3.87	17.8	15	3650
Composite size/ diesel	4940	4.60	19.7	6	4080
Mini/Otto-cycle	2550	3.18	24.0	2	2160
1990					
Small/Otto-cycle	2240	3.40	27.6	4	2100
Midsize/Otto-cycle	2860	3.94	22.3	5	2740
Large/Otto-cycle	3670	4.60	19.1	6	3280
Van ^a	4000	3.87	19.5	15	3640
Composite size/ diesel	3780	4.30	26.6	6	3540
Mini/Otto-cycle	2000	3.18	30.4	2	1900
Pb-acid/electric	2500	15.56 ^b	0.438 ^c	5	3620
Ni-Zn/electric	3480	16.19 ^b	0.453 ^c	5	3100
2000					
Small/Otto-cycle	2250	3.38	34.1	4	1800
Midsize/Otto-cycle	2920	3.96	28.1	5	2320
Large/Otto-cycle	3770	4.69	24.0	6	2790
Van ^a	3750	4.04	28.1	15	3310
Large/diesel	3970	4.96	35.8	6	2850
Mini/Otto-cycle	2020	3.17	38.1	2	1600
Pb-acid/electric	2980	14.96 ^b	0.35 ^c	5	3200
Ni-Zn/electric	4430	14.40 ^b	0.38 ^c	5	3400
Small/diesel	2500	3.73	49.0	4	1850

^aComposite: Approximately 10% diesel in 1990 and 20% diesel in 2000.

^bIncludes cost of battery-pack replacements during expected vehicle life.

^ckWh/mi.

Source: Charles L. Hudson et al., Vehicle Characterization for the TAPCUT Project: Performance and Cost, Argonne National Laboratory, Argonne, Ill., ANL/EES-TM-171 (Nov. 1981).

2. An estimate of the average used-car purchase price by vehicle type was obtained by assuming a depreciation of 10% of new-car price for each year in the fleet, such that the average vehicle "holding" cost by type in a given year = new-car cost $\cdot (0.9)^{5.7}$ (or about 54% of new-car cost unadjusted for the cost of financing).
3. Although three Otto-cycle technologies have been characterized as possibilities for the future fleet (see above), it is not known which of these will dominate the market or which, in fact, will be offered by manufacturers in any given year. In order to avoid a priori assumptions about availability, a standard logit treatment was applied to the utility functions representing full-size UC, SC, and TC automobiles as characterized for 1985, 1990, and 2000 fleets. That is, representatives of each Otto-cycle engine option were competitively evaluated within each size class at the household level as if they were the only three vehicles in the market. Because the pace of technological advancement is virtually equal across all three options into the future, the percentage shares distributed by the logit function were approximately 41/36/23 (UC/SC/TC) in all years. This result was used to apportion elements of each vector of Otto fleet characteristics by the appropriate weight.

2.2.1.3 General Remarks

Although the DVSAM is structured to be sensitive to demographic changes, the baseline scenario contains few such changes; the attributes of the vehicles themselves therefore dominate the distribution of probable holdings. Improvement in overall socioeconomic conditions, though slow, still implies that some zero-car households become one-car households and that some one-car households become two-car households -- without much measurable movement in the opposite direction. Thus, the fleet continually grows at a rate at least equal to, if not greater than, the rate of household growth.

The DVSAM is based on a number of historical assumptions about desirable automotive parameters, ownership cost and travel elasticities, and trends in the composition of the automotive fleet in nonprojection years. If these factors remain reasonably stable over time, the model can produce reliable, household-based estimates of the demand for holdings by vehicle type. Because the DVSAM is quite responsive to the data that drive it, substantive improvements to the model may have to await the availability of another NPTS or comparable survey conducted after 1979, when the full impact of the shift in preference to smaller vehicles has been recorded.

2.2.2 Other Light Trucks*

The stock model does not accommodate "other-than-van" light trucks, since their characteristics are not captured by the model's vehicle descriptor

*All personal light trucks $\leq 10,000$ lb gross vehicle weight (gvw), excluding vans.

variables. Therefore, their stocks were estimated directly from the "synthetic" NPTS file created by IPF and disaggregate categorical analysis. (See Sec. 2.1.3). Briefly, this process consisted of: (1) modifying NPTS household weights to match those implied by the future-year household demographic distribution of the baseline scenario; and (2) applying these revised weights to households holding "other" light trucks and summing to obtain the total. To obtain total personal vehicle stocks, the projection of "other" light trucks was combined with the stock model results. Vehicles not actually owned by the household were estimated by running crosstabs of vehicle type by ownership category off the synthetic NPTS file (i.e., the file with IPF-adjusted household weights) for each projection year. These vehicles were then deducted from the projections of household-held vehicles to yield household-owned vehicles.

2.3 NONPERSONAL VEHICLE STOCKS

Fleet automobiles, commercial and government trucks, and buses represent the nonpersonal vehicle stocks projected as part of the baseline. Since each of these stocks was projected somewhat differently, each is discussed separately below.

2.3.1 Fleet Automobiles

Automobiles are considered to be in fleet use if their owners register more than an arbitrarily defined minimum number of the vehicles. Various sources define minimum fleet size as four vehicles, 10 vehicles, or 25 vehicles.^{38,39,40} Because the baseline projection of total automobiles is the sum of all fleet and all personal autos, the least restrictive definition of "fleet" (four or more automobiles) was selected for this analysis. However, in order not to double-count commercially owned vehicles that are used by households as though they were household-owned, only projected household-owned autos were added to projected fleet autos in generating the stock totals.

Automotive fleets include:

- Business fleets, either owned or leased,
- Utility fleets,
- Government fleets, including police,
- Taxis,
- Rental cars, and
- Individually leased vehicles.

While it may be argued that each of these fleets responds to different conditions and should therefore be projected independently, the level of understanding and degree of detail necessary for such an analysis simply are not available at this time. Moreover, business fleets and individually leased vehicles, which together account for approximately 70% of all vehicles in fleets of 10 or more, are in themselves aggregate categories. In the absence

of more disaggregate detail on these latter types of fleets, which dominate the fleet stock, a disaggregate approach would be pointless.

Thus, fleet autos were projected in the aggregate. The number of autos in fleets of four or more units and those in fleets of 10 or more units were regressed against real GNP over the period 1966-1979*, yielding R^2 values of 0.67 and 0.98 respectively.** The latter was selected for the fleet auto projection, with total fleet autos (i.e., those in fleets of four or more units) then estimated from the number projected to be in fleets of 10 or more units. The equations were:

$$f = 1484g - 1674.6 \quad (9)$$

$$F = (0.016y - 30.49)f \quad (10)$$

where:

f = autos in fleets of 10 or more,

g = gross national product, expressed in 1972 \$,

F = autos in fleets of four or more, and

y = projection year.

For the year 2000, the first term in Eq. 10 was arbitrarily lowered from 0.99 to 0.95 because it was assumed that, beyond some point in the function, the relationship probably becomes nonlinear. Whether that point is between 1995 and 2000 or somewhat earlier may be debated.

As might be expected, Eq. 9 underpredicts fleet stocks in recession years. However, the underprediction is quite small and certainly less than might be expected were fleet auto sales the dependent variable.

2.3.2 Commercial Trucks

The number of vehicles comprising the commercial truck fleet may be viewed as a function of the quantity of goods or services supported by that fleet. This implies that truck stocks are related to economic activity and should be projected accordingly. The truck-stock projection, part of the FRATE (Freight Responsive Accounting for Transportation Energy) model, embodies this approach. (For a description of FRATE, see Sec. 2.6. The

*At the time of this analysis, 1980 data were not yet available. Historical time series for fleet auto stocks were obtained from Bobit data;^{38,39,40} historical time series for GNP were obtained from the DRI data base.³

**The lower R^2 obtained for vehicles in fleets of four or more may be attributed to the opposing effects of a historical decline in the number of vehicles in fleets of four to nine units, as compared with a steady increase in the number of vehicles in fleets of 10+. This also may be seen in the ratio of vehicles in 10+ fleets to vehicles in 4+ fleets. Over the 14-yr period of 1966-1979, this ratio has grown steadily from 0.47 to 0.67. Regressing the ratio over time yields an R^2 value of 0.96.

following discussion focuses only on historical stock trends and the stock projection algorithms within FRATE.)

Truck types are generally characterized by body configuration, axle arrangement, and gross vehicle weight. In this analysis, truck types are based on GVW, since weight or capacity limitations affect energy consumption to a greater degree than either body type or wheelbase characteristics. The GVW of a truck includes the curb weight of the vehicle and its carrying capacity. Table 8 shows the size categories and associated weight ranges, as defined in the Truck Inventory and Use Survey (TIUS), that were used for the baseline projections of intercity and local truck stocks.

Table 8 Truck Size and Weight Categories

Size Class	Weight Class	Gross Vehicle Weight (lb)
Light	1-2	0-10,000
Medium	3-5	10,000-19,500
Heavy	6	19,501-26,000
Heavy-Heavy	7-8	>26,001

Source: U.S. Dept. of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey, Washington, D.C. (1981).

Within FRATE, local and intercity truck stocks are projected independently. While some older intercity trucks are known to eventually filter down to local operations, little is known about the dynamics of this process. Hence, local and intercity areas of operation are treated separately within FRATE.

2.3.2.1 Intercity Trucks

Intercity trucks move the largest proportion of revenue ton-miles and consume the most energy of all freight modes.* The major commodities carried by intercity trucks are shown in Table 9. Since truck travel has penetrated nearly all commodity sectors, no single sector dominates truck activity. Conversely, however, such sectors as construction and wholesale and retail trade are virtually captive to truck transport.

Historically, the truck share of ton-miles (TMT) generated by the commodity sectors listed in Table 9 has been increasing. Production by these commodity sectors also has been growing faster than GNP. Thus, trucks may be expected to increase their share of total ton-miles.

Within FRATE, total TMT is used to determine future truck stocks. The calculation can be expressed as follows.

$$TRKSTK_{ijt} = \left(\frac{TRKTMS_{jt}}{TRUKLF_{jt} \quad ATRKVM_{jt}} \right) FULDIS_i \quad (11)$$

*While railroads and pipelines account for a larger proportion of total ton-miles, the actual revenue generated per ton-mile is greatest for trucks.

Table 9 Major Commodities Moved by Intercity
Truck, 1980

Commodity Sector	Ton-Miles ^a (10 ⁹)	Percent of Truck Total
Construction	86.035	14.2
Wholesale and retail trade	81.111	13.3
Farm products	71.034	11.7
Canned, frozen, other foods	40.996	6.7
Chemicals	29.292	4.8
Petroleum products	26.446	4.4
Forestry and fishery products	24.117	4.0
Paper products	23.241	3.8
Lumber and wood products	22.253	3.7
Total	404.525	66.6

^aEstimated by CTR staff based on 1972-1980 growth of economic activity in commodity sectors.

Source: U.S. Department of Commerce, Bureau of the Census, 1972 Commodity Transportation Survey, Washington, D.C. (1976).

where:

- i = index of fuel type -- gasoline and diesel;
- j = index of truck size -- medium, heavy, and heavy-heavy;
- t = index of projection years;

TRKSTK = intercity truck stock;

TRKTMS = ton-miles traveled by truck;

TRUKLF = truck load factor in tons/vehicle;

ATRKVM = average annual miles/vehicle; and

FULDIS = distribution of trucks by fuel type.

As the equation shows, load factors for each size class, average annual mileage by trucks of the size class, and ton-mile activity determine the future intercity truck stock. Increases in load factors, particularly of the heavy-heavy stock, would serve to decrease the total stock demand in FRATE. Annual VMT increases could also decrease the stock demand within each size class. While changes in load factor and VMT* can easily be accommodated in the model, they are held constant for the baseline projections.

2.3.2.2 Local Trucks

In FRATE, local truck stocks are calculated somewhat differently from intercity stocks because of inherent differences in their utilization

*For further detail on annual vehicle-miles per vehicle, see Sec. 2.6.2.

patterns. Trucks that travel "locally" (i.e., within 200 miles of their base of operations) are generally characterized by relatively low load factors and annual mileage. Because of the typical stop-and-go driving cycle of pickup and delivery operations, their average speed and fuel economy are also lower than those of comparable intercity vehicles.

Because of these factors, as well as a general lack of data on local freight movement and the significant numbers of service vehicles (which do not carry goods) in the local truck fleet, it is inappropriate to project that fleet and its energy consumption based on FRATE TMT projections. Rather, the local stock projection relies on DRI output indexes for only those sectors associated with local truck ownership and use. These sectors are agriculture, forestry and lumber, mining and quarrying, construction, manufacturing, wholesale trade, retail trade, for-hire trucking, utilities, services, and daily rental.*³¹ Light trucks (i.e., <10,000 lb gvw) are included in the local stock subroutine since they comprise a significant portion of local truck travel.

Local truck stocks are calculated as follows:

$$STOCK_{ijt} = \sum_k TRUK77_{ijk} \cdot INDEX_{kt} \quad (12)$$

where:

- i = index of fuel type -- gasoline and diesel;
- j = index of truck size -- light, medium, heavy, and heavy-heavy;
- k = index of TIUS major use sectors;
- t = index of projection years;
- STOCK = local truck stock;
- TRUK77 = 1977 TIUS local truck stock; and
- INDEX = DRI projected index of output.

Figure 8 illustrates the current distribution of local trucks by major-use sector. Within agriculture, light trucks dominate the fleet. While construction vehicles are more evenly distributed across vehicle-size classes, the heavy-heavy category dominates in that sector. Local service trucks are concentrated primarily in the light size class.

Within the light size class, recent trends are noteworthy. Not only have light truck sales grown substantially over the past decade, but the characteristic vehicle design has shifted away from the standard pickup model. Japanese-built compact trucks have gained an increasing share of the pickup market as increasing emphasis has been placed on fuel economy. This trend may

*Local trucks used for personal transportation are also reported in TIUS. Since these are projected by other methods (see Sec. 2.2), they are not included in the FRATE local truck module.

Fig. 8 Base-Year Distribution of Commercial Local Trucks among Sectors of Major Use

be expected to continue, with the import share ultimately stabilizing once significant numbers of U.S.-built compact trucks appear on the market.

2.3.3 Government Trucks

The projection of government truck stocks contained in the previous edition of this report was retained in the present effort.² That projection relies on trend analysis for estimating vehicle stocks and vehicle utilization (i.e., miles/vehicle). Energy is then calculated as a function of these variables and assumed future fuel economy.

Trends in government-owned light trucks show a slow but consistent average annual growth rate of 0.9% per year. Government light trucks constituted 10% of total trucks in 1963, 1967, 1972, and 1977, the years for which Truck Inventory and Use Survey (TIUS) data are available.* Since employment and output are not significant variables for projecting government light trucks, simple trend extrapolation was used to project the year 2000 stock. Government truck activity and energy consumption were then projected as a function of future stocks, vehicle utilization, and vehicle fuel economy. Since government use of light trucks is largely for services, mileage and capacity requirements were assumed to be relatively low. Annual vehicle-miles per vehicle were projected to increase over time based on historic trends in the federal vehicle fleet reported by the General Services Administration.

*TIUS does not report government light truck stocks. The government share of commercial light trucks was estimated by CTR staff from data on the federal light truck fleet and total state and local trucks.^{41,42}

2.3.4 Buses

2.3.4.1 School Buses

Despite recent declines in the school-age population, the school bus fleet has grown consistently, producing a steady increase in the ratio of school buses to school-age children. This fact is attributable to the growing suburban population, the consolidation of many neighborhood schools, the rise in busing for nontraditional purposes (e.g., day care), and the use of student busing to achieve racial balance in inner-city schools.

Because of these recent and not-readily-forecast factors, this analysis relied on a relatively simple method of projecting school bus stocks and activity. Major assumptions were as follows.

- The size of the school-age population will vary with the Census Bureau's Series II projection of persons 5-17 years of age;⁴³
- The school bus stock will grow with total population through the 1980s (i.e., at approximately 0.8% per year); and
- As the school-age population resumes growing in the late 1980s,⁴³ the school bus stock will begin to grow with the school-age population.

School bus activity and energy consumption were then projected as a function of future stocks, vehicle utilization, and vehicle fuel efficiency.

2.3.4.2 Transit Buses

Transit bus stocks were projected as a function of urban population. The stock projection was taken directly from ongoing CTR research.⁴⁴ The selected projection corresponds to a low-growth scenario. This is consistent with this report's baseline scenario, as described in Sec. 1.1, because the baseline assumes that urban population will grow primarily in relatively low-density areas, which have relatively low levels of transit service. The projection assumes that current policies, including federal capital assistance, continue and that transit fares rise with inflation.

2.3.4.3 Intercity Buses

The stock of vehicles in intercity common-carrier service and the annual VMT/vehicle of that stock have been extremely stable over the recent past. In 1980 there were some 20,300 vehicles operated either by intrastate carriers or by Class I, II, or III interstate carriers. This total includes buses in tour and charter, as well as scheduled, service. Because of the historic stability in common-carrier load factors and vehicle utilization, stocks and VMT were projected from the PMT projections. (See Sec. 2.5.1.) Fuel consumption was projected in terms of energy intensities, based on both passenger-miles and vehicle-miles.

2.4 LOCAL PASSENGER TRAVEL

Passenger travel is defined as "local" when passenger-miles and vehicle-miles occur on trips with a one-way distance <100 mi. Bicycle and walk trips are not included since for our purposes those methods of travel do not enter into the final energy calculations. Trips with a one-way distance of ≥ 100 mi are considered to be intercity travel and are calculated by the intercity model described in Sec. 2.5.

2.4.1 Local Automobiles and Light Trucks

VMT and energy used on local trips in automobiles and light trucks were projected using a combination of the stock model (DVSAM), IPF, and disaggregate categorical analysis -- the results of which were then modified to capture the effect of fuel price through an elasticity measure. A flow chart of the process is presented in Fig. 9.

The IPF procedure is described in Sec. 2.1.3. Briefly, it simulates a forecast year NPTS file by calculating new household weights or expansion factors to match demographic projections of U.S. households. In the 1977 NPTS data file, each respondent household represents some number of total U.S. households as shown by the original weights. The new weights change the number of households represented by each NPTS household.

Disaggregate categorical analysis was used to estimate future-year travel behavior. It assumes that travel behavior (VMT for each household) remains constant within each cell as defined by the demographic variables. Aggregate VMT changes across cells as the household weights are modified by the IPF. Travel sensitivity to cost of travel (primarily fuel price) also changes VMT, as explained later.

For all automobile and van trips, the vehicle ownership (holding) probabilities produced by the stock model were used to distribute household trips to available vehicle types. Household VMT was found by summing the trip distance for all trips made by household members using an automobile or van. This distance was then multiplied by the ownership probability for each vehicle type. When aggregated across household trips, this result represents the mileage traveled by each vehicle type in the forecast year.*

For "other" light trucks (such as pickups, recreational vehicles, and campers) the IPF results were applied directly. The household VMT generated by these vehicles was expanded using the new household weights and then summed across households.

*Another method of distributing household VMT would be to compute the probability of using a particular type of vehicle as a function of the probability of owning that particular vehicle, the characteristics of the vehicle, and the characteristics of the trip. No satisfactory way to do this was found, and therefore the straight ownership (holding) probabilities were used.

Fig. 9 Automobile and Light Truck Projection Process

Because this approach is not sensitive to changes in the cost of travel, price elasticity was added to the structure. First, the percentage change in the real cost of travel between successive projection years (in ¢/vehicle-mile) was calculated in the stock model. Travel cost included vehicle purchase cost, nonfuel operating cost, and fuel cost. Each cost element was computed from input vehicle characteristics, output ownership probabilities and, in the case of fuel cost, fuel price as well. Generally speaking, fuel cost was the most dynamic cost element. Changes over time in travel cost were then used to modify each household's computed VMT according to a VMT-price elasticity obtained from the literature.^{45,46,47} Note that VMT can go up as well as down when energy intensities improve faster than fuel prices, thereby causing an actual drop in the per-mile cost of travel.

As Table 10 shows, there is a wide variation in the travel elasticities reported in the literature. In this analysis a post-1980 elasticity of -0.11 was used. This relatively inelastic value was chosen for the following reasons: (1) as households reduce local VMT in the short run, fewer additional opportunities remain for further reducing VMT in the face of continued price changes; (2) elasticity is probably nonlinear -- as opportunities are taken, the average elasticity, when applied over a five-year period, may be expected to drop; and (3) the rate of price change probably affects the rate of change in VMT. More rapid price changes may be expected to cause larger changes in VMT. Because this is a travel (as opposed to an energy) elasticity, long-run elasticity is not necessarily greater than short-run elasticity.

After the elasticities were applied to VMT, the last step was to forecast energy consumption. Again, energy intensities were obtained from the stock model inputs and output. A degradation factor of 15% was applied to adjust for the discrepancy between possible and actual on-the-road fuel economy and to account for the deterioration of efficiency as vehicles age. For "other" light trucks, average fuel economy was estimated independently and applied directly to the forecast VMT.

Table 10 VMT Elasticity Estimates

Study	Variable	Short-Run Elasticity
FEA ^a	Auto VMT per capita	-0.12
Chase ^a	Auto VMT	-0.50
Schuessler & Smith ^a	Auto VMT	-0.15 to -0.25
Rand ^a	VMT per capita	-0.38
DOE ^b	VMT	-0.13 to -0.24

^aDescribed and compared in Refs. 45 and 47.

^bRef. 46.

2.4.2 Transit Systems

Transit activity was projected as a function of vehicle stocks and vehicle utilization. The vehicle stock projection was discussed in Sec. 2.3.4. Vehicle utilization was estimated from American Public Transit Association (APTA) data on revenue vehicle-miles and vehicle stocks.⁴⁸ Since the 1972 amendments to the Urban Mass Transportation Act (which provided federal assistance to transit operators), revenue vehicle-miles per vehicle have fluctuated, reaching a high of 31,237 in 1977 and then falling to 29,683 in 1979.* Thus, the 1972-79 average of approximately 29,500 mi/vehicle was assumed for the baseline projections.

In 1979 the 91 transit systems reporting to APTA achieved an average fuel efficiency of 3.84 mi/gal.⁴⁹ Because mileage typically is reported for revenue-miles only, while gallons are total, actual fuel economy may have been considerably less than this value. In future years, when virtually all vehicle-miles are traveled in relatively less efficient advanced-design buses, fleet average fuel economy may be expected to deteriorate from 1979 levels. Thus, the baseline projection assumes a constant value of 3.3 mi/gal.

2.4.3 School Buses

Like transit bus activity, school bus activity was projected as a function of vehicle stocks and vehicle utilization. The vehicle stock projection was discussed in Sec. 2.3.4. While vehicle utilization has fluctuated somewhat over time, it has averaged approximately 7,200 mi/yr over the past several years.⁵⁰ This value was assumed to represent the fleet-wide average miles/vehicle for all projection years.

School-bus fuel efficiency was assumed to improve somewhat, as a result of increased diesel penetration. Since school buses and class 3-5 trucks have similar weight and usage characteristics, the dieselization assumptions for medium trucks in local operation were applied to school buses as well. This resulted in the following distribution of gasoline- and diesel-powered vehicles.

	<u>Gasoline</u>	<u>Diesel</u>
1980	0.987	0.013
1985	0.939	0.061
1990	0.811	0.189
2000	0.636	0.364

Gasoline vehicles were assumed to achieve their 1972-76 average fuel economy of 7.4 mi/gal throughout the projection period.⁵¹ Diesel vehicles were assumed to achieve 10.4 mi/gal, or a 40% improvement over gasoline-vehicle fuel economy.

*As of this writing, 1980 data are not yet available. The apparent decline between 1977 and 1979 is a result of much slower growth in vehicle-miles than in vehicle stocks. While APTA claims that its data pertain to buses only, significant post-1977 growth in the minibus and van stocks of transit properties may distort the data.

Within gasoline and diesel vehicle stocks, average miles/vehicle varied as diesel penetration increased. Again assuming that gasoline/diesel relationships for medium trucks in local operation would also apply to school buses, the utilization of gasoline-powered school buses is estimated at approximately 67% of the utilization of diesel-powered school buses in the base year.³¹ Holding fleet-average utilization constant, gasoline and diesel utilization becomes:

	<u>Gasoline</u>	<u>Diesel</u>
1980	7154	10678
1985	6990	10433
1990	6587	9831
2000	6105	9113

Within the two fuel types, utilization declines over time as diesels initially penetrate those markets in which they offer the greatest operating cost savings (i.e., vehicles with relatively greater utilization).

2.5 INTERCITY PASSENGER TRAVEL

2.5.1 Intercity Automobiles and Common Carriers

This section describes the methods used in projecting future intercity passenger travel and associated fuel consumption. The following steps provide an overview of the process.

1. Detailed modeling of city pairs to estimate SMSA-to-SMSA passenger-miles of travel (PMT) by trip purpose and mode.
2. Computation of growth rates from a 1977 base year for SMSA-to-SMSA PMT by mode, using the results from step 1.
3. Application of the above growth rates to 1977 estimates of intercity PMT (intercity travel is defined as all trips >100 mi one way)* to estimate future-year intercity PMT by mode.
4. Application of vehicle load factors to convert automobile and light truck PMT into vehicle-miles of travel (VMT).
5. Application of VMT-based or PMT-based energy intensities to convert PMT and VMT to energy consumption by mode.

*Typically, no distinction is made between travel <100 miles and ≥100 miles by common carrier modes (i.e., Amtrak, intercity bus, and commercial air carrier). Because the growth rates derived from the intercity model were applied to these aggregate traffic data, the projections of air, bus, and rail PMT include some short distance (i.e., <100 mile) travel as well as long distance travel.

2.5.1.1 Modeling SMSA-to-SMSA Passenger-Miles of Travel

SMSA-to-SMSA travel for the base year and all future years was modeled with the CTR Passenger Oriented Intercity Network Travel Simulation (POINTS) model. The POINTS model estimates passenger demand for the four major modes (auto/light truck, air, bus, and rail) that compete for this market. Like most recent approaches to intercity travel demand modeling, POINTS is a direct-demand model. It simultaneously estimates: (1) the total number of trips and the geographic distribution of their origins (trip generation); (2) the joint probability distribution of trip origins and destinations (trip distribution); and (3) the mode by which the travel occurs (mode split). All of these aspects of SMSA-to-SMSA travel are modeled as a function of (and are therefore sensitive to) the amount of activity (population, employment, sales, etc.) at the origin and destination cities and the transportation level-of-service that connects them. While POINTS shares these attributes with other direct-demand models, two significant characteristics distinguish it from most other models of the type. Intended to overcome certain theoretical deficiencies in the traditional direct-demand formulation, these characteristics are:

1. An explicit representation of origin and destination accessibility; and
2. The inclusion of an internally consistent multimodal travel function based on utility-maximizing (hedonic) principles and on an explicit specification of the most probable distribution of value of time.

A direct-demand model can be written in simplest terms as

$$V_{ijm} = K P_i F_{ijm} A_j \quad (13)$$

where:

V_{ijm} = the volume of trips by mode m between origin i and destination j ;

P_i = a function of trip-producing activity at origin i ;

A_j = a function of trip-attracting activity at destination j ;

F_{ijm} = a function of travel impedances, usually time (T) and cost (C), by mode m between i and j ; and

K = a constant of proportionality.

In the traditional direct-demand model the multiplicative factors in Eq. 12 are usually represented as power products:

$$V_{ijm} = K P_i^{a_1} A_j^{a_2} T_{ijm}^{a_3} C_{ijm}^{a_4} \quad (14)$$

Although this is a very simple representation of the many alternative direct-demand models that have been formulated, all have preserved this basic form.

One consequence of the above formulation is that the number of trips generated at each origin is directly proportional to the access of the origin to all destinations.⁵² When all variables are as defined above and when I_i is the accessibility of origin i to destination j :

$$V_{im} = K P_i \sum_j F_{ijm} A_j = K P_i I_i \quad (15)$$

The proportionality of the number of each origin's trips to its access to all destinations is not a desirable trait since the implication is that there is no competition between destinations. An increase in the attractiveness of one destination (with all others held constant) will induce a proportional gain in travel between it and all other places, while the interchanges between all other places will remain unchanged. Since it is reasonable to believe that some "new" travel will be induced and some "old" travel will be redirected, access is included in POINTS as an explicit variable with a coefficient less than zero but greater than minus one. Thus, the trip-generating implications of improved access are mitigated but not totally eliminated.

Similar problems exist with most of the functional relationships of the travel-impedance measures. In the simplest of formulations, Eq. 14, competition between modes is completely ignored. In the commonly used logit formulation, the inclusion of new modes does not alter the relative split among previously existing modes.⁵³ Several other formulations that avoid such logical inconsistencies rely on separate equations for trip distribution and mode split, thus sacrificing some of the theoretical attractiveness of the simultaneous nature of direct-demand models.⁵⁴ One approach that avoids these inconsistencies while preserving simultaneity is the behavioral utility-maximizing approach.⁵⁵ In this approach, it is assumed that the mode selected for each trip is that which maximizes the trip's utility, and that each tripmaker has a constant trade-off rate between the attributes of the modes. If only two attributes (e.g., time and cost) are of interest, Schneider has developed a formulation based on utility-maximizing principles in which the most probable distribution of trade-off rates (value of time) across travelers is specified by the entropy-maximizing principles popularized by Wilson.^{52,56}

Schneider's formulation is presented graphically in Fig. 10. The figure shows a case in which four alternative modes are available for a given origin-destination pair and where the modes are arranged in attribute space (time and cost) as represented in part a of the figure. Then, the disutilities of travel by each mode for travelers with varying time-value of money (β) are defined according to entropy maximization as the four negative exponential curves displayed in part b. In the example, mode M1 is the fastest and most expensive. Therefore, for travelers with the lowest time-value of money (highest value of time, $\beta = 0$), the utility derived from traveling is highest by M1. The utility of travel by this mode drops rapidly as travelers who value money higher are considered. At the opposite extreme, M4 is the slowest and least expensive mode. Since cost represents a relatively much smaller component of the total disutility of travel for M4, the curve decays at a much slower rate as β increases in value. Consequently, travelers with very high values of β (i.e., low values of time) will maximize the utility of their travel by choosing M4. In this example, travelers with values of β greater than zero but less than β_1 will prefer M1; those with a time-value of money

a) Modal Attribute Space

b) Modal Utility vs. Time Value of Money

c) Distribution of Time Value of Money

Fig. 10 Multimodal Utility Maximization with a Distributed Population: Four-Mode Case

between β_1 and β_2 will prefer to travel by M3; and those whose value of β is greater than β_2 will choose M4.

According to this paradigm, M2 in this example will not be considered attractive by any traveler. It can be shown that only modes that form a convex surface when arrayed in attribute space are competitive (i.e., attractive to some portion of the population).

The aggregate mode split for each interchange is defined by the proportion of travelers in each range of β . If the population of travelers is distributed with respect to β according to the probability density function, $P(\beta)$, as shown in part c of the figure, the proportion of travelers traveling by each mode is determined by the following integrals:

$$\left. \begin{aligned} P1 &= \int_0^{\beta_1} P(\beta) d\beta \\ P3 &= \int_{\beta_1}^{\beta_2} P(\beta) d\beta \\ P4 &= \int_{\beta_2}^{\infty} P(\beta) d\beta \end{aligned} \right\} \quad (16)$$

and a consistent aggregate measure of the relative utility of travel for the interchange is defined by:

$$\begin{aligned} F_{ij} &= \int_0^{\infty} \int_0^{\beta_1} \exp[-\alpha(T_1 + \beta C_1)] P(\beta) d\beta d\alpha + \\ &\quad \int_0^{\infty} \int_{\beta_1}^{\beta_2} \exp[-\alpha(T_3 + \beta C_3)] P(\beta) d\beta d\alpha + \\ &\quad \int_0^{\infty} \int_{\beta_2}^{\infty} \exp[-\alpha(T_4 + \beta C_4)] P(\beta) d\beta d\alpha \end{aligned} \quad (17)$$

The principal difficulty in applying this approach lies in determining the appropriate probability density function for β . Some researchers have postulated a log-normal distribution; others, like Cardell and Dunbar, have assumed it to be empirically defined by the distribution of a surrogate variable like income.⁵⁵ Schneider has deduced a "most probable" distribution of β , according to entropy-maximizing principles, as:

$$P(\beta) = \frac{\int_0^{\infty} \exp\left[-\alpha \frac{(T^{-1} + bC^{-1})}{(T^{-1} + \beta C^{-1})}\right] d\alpha}{\int_0^{\infty} \int_0^{\infty} \exp\left[-\alpha \frac{(T^{-1} + bC^{-1})}{(T^{-1} + \beta C^{-1})}\right] d\alpha d\beta} \quad (18)$$

A major advantage of incorporating the probability density function in Eq. 17 is that the integrals are solvable in closed form and do not require time-consuming numerical integration.

With the travel function defined by the above logic and an explicit representation of accessibility, two direct-demand models (one for business travel and one for nonbusiness travel) have been included in POINTS. These are described by Eqs. 19 and 20.

$$V_{ijm}^{BIZ} = \frac{K^{BIZ} (GVPOP_i \text{ GVPOP}_j)^{\gamma^{BIZ}} F_{ijm}^{BIZ}}{(I_i^{BIZ} I_j^{BIZ})^{\delta^{BIZ}}} \quad (19)$$

$$V_{ijm}^{NBIZ} = \frac{K^{NBIZ} (HTPOP_i \text{ HTPOP}_j)^{\gamma^{NBIZ}} F_{ijm}^{NBIZ}}{(I_i^{NBIZ} I_j^{NBIZ})^{\delta^{NBIZ}}} \quad (20)$$

where:

V_{ijm}^{BIZ} = the number of business trips, by mode m, between origin SMSA i and destination SMSA j;

V_{ijm}^{NBIZ} = the number of nonbusiness trips by mode m between origin SMSA i and destination SMSA j;

GVPOP = the SMSA population weighted by the percentage of government employment;

HTPOP = the SMSA population weighted by the percentage of total services receipts generated by the hotel sector;

I_i^{BIZ} = the access of SMSA i to the business-travel attraction variable, GVPOP;

$$I_i^{BIZ} = \sum_j \sum_m F_{ijm} \text{ GVPOP}_j^{\gamma^{BIZ}};$$

I_i^{NBIZ} = the access of SMSA i to the nonbusiness travel attraction variable, HTPOP;

$$I_i^{NBIZ} = \sum_j \sum_m F_{ijm} \text{ HTPOP}_j^{\gamma^{NBIZ}};$$

$\gamma^{NBIZ}, \gamma^{BIZ},$

$\delta^{NBIZ}, \delta^{BIZ}$ = calibration parameters which determine the utility curves of activity and accessibility for trip purposes BIZ and NBIZ, respectively;

K^{BIZ}, K^{NBIZ} = constants of proportionality for trip purposes BIZ and NBIZ; and

F_{ijm} = the solution to Eq. 17, with $P(\beta)$ defined as in Eq. 18.

$$\begin{aligned}
 F_{ij1} &= \frac{K_2 \left(2\sqrt{a(T_1 + bC_1)} \right)}{a(T_1 + bC_1)} \left(1 - \frac{1}{(1 - R_1 S_{12})} \right) \\
 F_{ij2} &= \frac{K_2 \left(2\sqrt{a(T_2 + bC_2)} \right)}{a(T_2 + bC_2)} \left(\frac{1}{(1 + R_2 S_{12})} - \frac{1}{(1 + R_2 S_{23})} \right) \\
 &\vdots \\
 F_{ijn} &= \frac{K_2 \left(2\sqrt{a(T_n + bC_n)} \right)}{a(T_n + bC_n)} \left(\frac{1}{1 + R_n S_{n-1,n}} \right)
 \end{aligned} \quad (21)$$

where:

$K_2 \left(2\sqrt{a(T_m + bC_m)} \right)$ = the modified Bessel function of the second order;

T_m = the travel time between SMSAs i and j , by mode m ;

C_m = the travel cost between SMSAs i and j , by mode m ;

$S_{m,m+1} = \frac{(T_{m+1} - T_m)}{(C_m - C_{m+1})}$, when the modes are ranked by ascending travel time.

$R_m = C_m/T_m$

a and b = calibration constants that specify the average sensitivity of trips to the impedance measure $(T + \beta C)$ and the average value of β , respectively.

Despite the theoretical advantages of the POINTS travel-demand model, at least two disadvantages are associated with it. First, the utility-maximizing logic precludes the choice of "inferior" modes. An "inferior" mode, in the context of the paradigm, is any mode that lies above the convex surface formed by the line segments that connect the competitive modes (e.g., M2 in part a of Fig. 10). In reality, many such modes do attract some (though usually few) trips. Such behavior can be explained either by including additional dimensions in the attribute space or by explicitly defining a random error term to account for travelers' perceptions. In practice, however, difficulties of measurement and mathematical tractability preclude such extensions.

An even more pragmatic problem associated with the POINTS demand model is its highly nonlinear form. It is difficult, if not impossible, to transform Eqs. 19 and 20 into linear forms. Thus, standard algorithms to estimate the model's parameters based on goodness-of-fit to observed data cannot be used. As a consequence, a heuristic process must be used for parameter estimation.

2.5.1.2 Development of POINTS-Model Input Data

For intercity travel modeling, two data bases were required. One data base provided projection-year information to be input to the POINTS model while the other data base provided base-year information necessary to calibrate the model. Both contained demographic and transportation-system data. The base-year data base provided additional information on actual travel demand.

Each urban area was considered as a traffic zone within a multimodal transportation system. Urban areas were specified according to the Census Bureau's definition of standard metropolitan statistical areas (SMSAs). Since intercity travel modeling considers only those trips longer than 100 miles, and many of the SMSAs are within 100 miles of one another, urban areas less than 100 miles apart had to be consolidated into larger urban areas. This reduced the 266 SMSAs (defined as of 1977) into 142 urban areas for the POINTS model. Table 11 lists these 142 consolidated urban areas.

The Bureau of Economic Analysis (BEA) 1980 cycle of regional economic projections provided the required population and employment data.³² BEA projections are classified by SMSA for three scenarios. Scenario I assumes that within a state each SMSA will maintain its 1969 share of the state's economic activities. Scenario II assumes that the SMSA share will change as a result of 1969-to-1978 shifts, moderated by a set of decay factors. Scenario III assumes that the SMSA share will change as a result of the 1969-1978 trend, with still greater moderation from decay factors.⁵⁸ In each scenario, national totals remain constant. For this project Scenario II was selected and the BEA projections were aggregated from the 266 SMSAs to the 142 urban areas.

Four transportation networks (highway, air, bus, rail) were coded. Each of the 142 urban areas was coded as an origin-destination node. Eleven Canadian cities also were coded as nodes to allow for alternate travel routes available through Canada. Several nodes were coded for the rail network to represent nonurban route intersections. Travel times, distances, tolls, and fares were obtained for each modal network as follows.

1. Highway. Highway travel time, distance, and toll information was obtained from the American Automobile Association maps of each state. Each link represented a highway connection between two urban areas.
2. Air. The air network was coded using a hub/nonhub concept. The Civil Aeronautics Board identifies 25 airports as large air traffic hubs. With the exception of Honolulu, each hub has direct air service to the other 24 hubs. Honolulu was connected to four hubs: Seattle, San Francisco, Los Angeles, and Chicago. Five nonhub urban areas (Portland, Salt Lake City, Albuquerque, Cincinnati, and Buffalo) were connected to four hubs each. The remaining 112 urban areas were assumed to have feeder services to one or two hubs.

Air miles were obtained from the 1980 Origin-Destination Survey of Airline Passenger Traffic.⁵⁹ Fares and travel times were obtained from the Official Airline Guide.⁶⁰ Standard coach fares were coded. Where several fares were

Table 11 Consolidated Urban Areas Developed for the POINTS Model

Node	SMSA or Combination of SMSAs ^a	Node	SMSA or Combination of SMSAs	Node	SMSA or Combination of SMSAs
1	New York, NY ^b	48	Syracuse, NY	95	Eugene-Springfield, OR
2	Chicago, IL ^b	49	Northeast Pennsylvania (Scranton-Wilkes Barre)	97	Portland, ME
3	Los Angeles-Long Beach, CA ^b	50	Charlotte-Gastonia, NC	97	Saginaw, MI
4	Philadelphia, PA-NJ ^b	51	Orlando, FL	98	Fayetteville, NC
5	Detroit, MI ^b	52	Tulsa, OK	99	Columbus, GA-AL
6	Boston-Lowell-Brockton-Lawrence-Haverhill, MA-NH ^b	53	Omaha, NE-IA	100	McAllen-Pharr-Edenburg, TX
7	San Francisco-Oakland, CA ^b	54	Richmond, VA	101	Roanoke, VA
8	Washington, D.C.-MD-VA ^b	55	Grand Rapids, MI	102	Lima, OH
9	Dallas-Ft. Worth, TX ^b	56	Greenville-Spartanburg, SC ^b	103	Savannah, GA
10	St. Louis, MO-MD-IL ^b	57	Fresno, CA	104	Lubbock, TX
11	Pittsburgh, PA ^b	58	Tucson, AZ	105	Springfield, MO
12	Houston, TX ^b	59	Harrisburg, PA	106	Wheeling, WV-OH
13	Minneapolis-St. Paul, MN-WI ^b	60	El Paso, TX	107	Springfield, IL
14	Cleveland, OH ^b	61	Mobile, AL	108	Forth Smith, AR-OK
15	Atlanta, GA ^b	62	Johnson City-Kensport-Bristol, TN-VA	109	Green Bay, WI
16	San Diego, CA ^b	63	Chattanooga, TN-GA	110	Asheville, NC
17	Miami, FL	64	Austin, TX	111	Champaign-Urbana-Rantoul, IL
18	Milwaukee, WI ^b	65	Wichita, KS	112	Waco, TX
19	Seattle-Everett, WA ^b	66	Albuquerque, NM	113	Fort Myers, FL
20	Denver-Boulder, CO ^b	67	Fort Wayne, IN	114	Yakima, WA
21	Cincinnati, OH-KY-IN ^b	68	Davenport-Rock Island-Moline, IA-IL	115	Amarillo, TX
22	Tampa-St. Petersburg, FL ^b	69	Charleston-North Charleston, SC	116	Anchorage, AK
23	Buffalo, NY ^b	70	Columbia, SC ^b	117	Reno, NV
24	Kansas City, MO-KS ^b	71	Little Rock-North Little Rock, AR	118	Alexandria, LA
25	Phoenix, AZ	72	Peoria, IL	119	Altoona, PA
26	Indianapolis, IN	73	Beaumont-Port Arthur-Orange, TX	120	Tallahassee, FL
27	New Orleans, LA	74	Shreveport, LA	121	Waterloo-Cedar Falls, IA
28	Portland, OR-WA ^b	75	Bakersfield, CA	122	Boise, ID
29	Columbus, OH	76	Des Moines, IA	123	Mansfield, OH
30	Hartford-New Britain-Bristol, CN	77	Las Vegas, NV	124	Abilene, TX
31	San Antonio, TX	78	Spokane, WA	125	Wichita Falls, TX
32	Rochester, NY	79	Madison, WI	126	Wilmington, NC
33	Louisville, KY-IN	80	Binghamton, NY-PA	127	Fargo-Moorhead, ND-MN
34	Sacramento, CA	81	Corpus Christi, TX	128	Eau Claire, WI
35	Providence-Warwick-Pawtucket, RI	82	Pueblo, CO	129	Monroe, LA
36	Memphis, TN-AR-MS	83	Huntington-Ashland, WV-KY-OH	130	Lafayette, LA
37	Dayton, OH	84	Evansville, IN-KY	131	Sioux City, IA-NE
38	Albany-Schenectady-Troy, NY	85	Lexington-Fayette, KY	132	Williamsport, PA
39	Birmingham, AL	86	Huntsville, AL	133	Tyler, TX
40	Toledo, OH-MI	87	Santa Barbara-Santa Maria-Lompoc, CA	134	San Angelo, TX
41	Oklahoma City, OK	88	South Bend, IN	135	Billings, MT
42	Norfolk-Virginia Beach-Portsmouth, VA-NC	89	Jackson, MS	136	Odessa, TX
43	Salt Lake City-Ogden, UT	90	Augusta, GA-SC	137	Dubuque, IA
44	Greensboro-Winston Salem-High Point, NC	91	Erie, PA	138	Columbia, MO
45	Nashville-Davidson, TN	92	Duluth-Superior, MN-WI	139	Great Falls, MT
46	Honolulu, HA	93	Montgomery, AL	140	La Crosse, WI
47	Jacksonville, FL	94	Manchester-Nashua, NH	141	Laredo, TX
				142	Knoxville, TN

^aStates coded according to U.S. Postal Service System.^b-- of the 26 SMSAs for which full origin-destination detail is coded on the NTS tape and which was used to calibrate the model.

noted, the highest fare was used. Travel times on commuter airlines were omitted unless there was no other air service. Where direct hub-to-hub flights were not available, links representing average nondirect service were coded.

3. Bus. The bus network was coded to represent scheduled routes and services. The Dec. 1980 edition of Russell's Official National Motor Coach Guide was used to obtain travel times.⁶¹ Where there were several routes between two urban areas, the most direct route was selected. In cases where travel times were different in each direction, an average of the two travel times was used. The associated travel distances were obtained from AAA state and regional maps. The Greyhound Lines Handy Reference Guide for Chicago was analyzed to develop a fare-estimating procedure.⁶² This guide provides fares between Chicago and all other urban areas. Bus fares for all 142 urban areas (in cents per mile) were estimated as a function of distance based on the relationship determined from the Chicago data.
4. Rail. Rail travel times were obtained from the Amtrak National Train Timetable.⁶³ Since many of the rail routes intersect at nonurban stops, these transfer points were coded as intermediate nodes. In all, 20 nodes were added to the network. All motor coach services in the Amtrak timetable were coded. Regular one-way fares from Amtrak's All American Train Fares were used for each link.⁶⁴

Four network files were created. Frequencies for the air network were included on each link record, while frequencies of rail routes were coded as a separate file to be input directly to the path builder. Rail route numbers were coded on each link to permit the path builder to identify transfer between routes. These network files were subjected to several edit checks before proceeding to build minimum-impedance paths.

The paths were built by employing an algorithm that can estimate layover times at transfer points for the air and rail networks.⁶⁵ The highway and bus networks were assumed to have no layover times. For long trips on highway and bus networks, additional time and cost penalties were input exogenously to the POINTS model.

The path-building algorithm builds paths between origin and destination nodes that minimize the sum of link impedances. Impedance is computed as:

$$I = aT + bC + cD \quad (22)$$

where:

I = impedance,

T = time in minutes,

C = cost in cents per mile,

D = distance in miles, and

a , b , and c = coefficients denoting relative importance of each variable.

Layover times were computed using the frequency of service on connecting links. It was assumed that frequencies cover a 12-h period, which represents a typical travel interval. Most airline and rail services cover such a period. For very heavily traveled routes, this period may be longer than 12 h, while for small urban areas it may be considerably shorter. Layover times are dependent on inter-arrival times on one link and inter-departure times on possible connecting links. These inter arrival/departure times, in turn, depend on frequencies. Two methods are employed in computing layover times, one based on uniform probabilities and the other based on random service. For each transfer point, layover times were computed using both random and uniform probability methods. An average of the two values was taken for minimum-impedance path-building.

The minimum-impedance paths were traced, and SMSA-to-SMSA skim trees were developed for time, distance, toll, and fare. Within the POINTS model, highway and bus costs were computed as a function of distance. For highway and bus modes, time and cost penalties for overnight stays were added.

The observed calibration trip tables were constructed from detailed information, provided on the 1977 NTS tape,³⁰ about each trip -- including origin, destination, purpose, mode, and length. Origin and destination information is provided in the form of state or country codes for all trips, as well as SMSA codes for trips involving certain selected urban areas. Origin information is provided for 30 SMSAs and destination information for 52 SMSAs, the latter including the 30 origin SMSAs. After consolidating nearby SMSAs, the 30 origin SMSAs were reduced to 26 urban areas for the POINTS model.* Although an additional 22 destination SMSAs were available on the file, their usefulness for calibration purposes was limited since the POINTS model deals with both productions and attractions. Data on attractions alone were not sufficient.

The NTS file was searched for all trips between pairs of the 26 urban areas. These trips were disaggregated by purpose and mode. Two purposes, business and nonbusiness, were assigned. Four mode categories (highway, air, bus, rail) were developed from the modes on the data file. Eight trip matrixes, one for each purpose-mode combination, were developed. Base-year population and employment data were obtained from the BEA regional projections file for the selected 26 urban areas. The 1980 modal network files were assumed to represent the 1977 transportation system with respect to travel times and distances. Travel costs were deflated back to 1977 values.

2.5.1.3 Calibration of the Intercity Passenger Model

The calibration of the POINTS travel-demand model attempts to replicate multimodal intercity travel between all pairs of the 26 urban areas indicated in Table 11. These 26 areas were chosen because they are the only ones coded

*The 26 calibration SMSAs are indicated in Table 11. The calibration trip tables exclude trips between SMSAs within 100 miles of each other (e.g., Chicago-Milwaukee, New York-Philadelphia, etc.) because such trips violate the NTS definition of intercity travel and thus are not recorded on the NTS calibration data set.

explicitly for both trip origin and destination in the 1977 National Travel Survey (NTS). However, because the POINTS model considers destination competition (through the access term), modeling travel between pairs of the 26 urban areas was performed in the context of all U.S. SMSAs. The POINTS calibration process is shown in Fig. 11.

Data on intercity travel times and costs by mode and trip end were entered for 142 consolidated SMSAs. Trip-end data included one-way access/egress times and costs by mode, population, government employment, total employment, hotel receipts, and total retail receipts. The four calibration coefficients (a , b , γ , δ -- from Eqs. 19 and 20) were systematically varied in successive applications of the POINTS model. Following each model run, the trip interchanges (by mode) corresponding to each pair of the 26 urban areas were extracted from the trip tables produced by POINTS for the 142 SMSAs. The synthetic 26-area trip tables were compared to the observed 26-area trip tables derived from the NTS data. Coefficients of determination (R^2) were computed and compared, as were trip-length distributions by mode and mode-split estimates by distance of travel. The process continued until the "best" fit was obtained. The word "best" is used here to mean best under the circumstances rather than to mean an absolutely optimal fit. Because the calibration process was one of trial and error, it is entirely possible that a better fit could have been obtained (although a much better one would be unlikely). The final calibration coefficients and the R^2 between observed and synthetic trip interchanges are shown in Table 12.

Table 12 POINTS Model Calibration Coefficients and Measures of Goodness-of-Fit

Calibration Coefficient or Coefficient of Determination	Type of Trip		All
	Business	Nonbusiness	
Calibration Coefficient			
a	0.00028	0.000018	
b	0.017 (min/¢) ^a	0.05 (min/¢) ^a	
γ	1.30	1.35	
δ	0.35	0.40	
Calibration of Determination (R ²)			
All modes	0.756	0.923	0.910
Auto	0.761	0.966	0.960
Air	0.604	0.595	0.645
Bus	0	0.056	0.278
Rail	0.979	0.133	0.833

^aIn 1977 dollars.

Fig. 11 The POINTS Calibration Process

2.5.1.4 Predicting SMSA-to-SMSA Travel

The calibrated POINTS model was used to predict SMSA-to-SMSA passenger-miles traveled (PMT) by auto, air, bus, and rail for three forecast years (1985, 1990, 2000). Forecasts were made for the fuel-price assumptions of the baseline scenario and for a variation of the baseline, as discussed in Sec. 4. BEA projections of SMSA population and employment for each of the forecast years were entered in the model. Inter-SMSA travel times, access/egress times and costs, and percent hotel receipts remained unchanged in all forecast years. Auto operating cost per mile and common carrier fares were modified to account for the effects of changing fuel prices and vehicle fuel efficiencies. These cost factors are shown in Table 13.

Initial POINTS forecasts indicated rather large increases in PMT by bus. The model predicted an increase in the bus share of PMT from approximately 2% to almost 9% under baseline fuel prices. This was considered to be unreasonable, and the POINTS estimate was adjusted. The adjustment process made the simple assumption that the combined share of surface common carriers (bus and rail) would remain constant over time. The excess PMT was reapportioned among the auto and air modes in proportion to their originally modeled shares. The adjusted SMSA-to-SMSA passenger-miles of travel (business and nonbusiness combined) are shown in Table 14.

Table 13 Modal Cost Factors
(1977 = 1)

Mode	1977	1985	1990	2000
BIZ auto	1	1.12	1.18	1.35
NBIZ auto	1	1.25	1.30	1.47
Air	1	0.98	1.05	1.09
Bus	1	1.06	1.08	1.12
Rail	1	1.11	1.21	1.45

Table 14 SMSA-to-SMSA Passenger-Miles of
Travel (10⁶)

Mode	1977	1985	1990	2000
Auto	82,070	83,181	90,569	96,412
Air	118,970	140,359	145,468	166,917
Bus	4,214	4,802	5,214	6,092
Rail	988	982	894	721
All	206,242	229,334	242,145	270,142

2.5.1.5 Predicting Intercity Travel

Comparison of the 1977 POINTS estimate of SMSA-to-SMSA passenger-miles of travel (206.24 billion) to the NTS-reported intercity PMT (381.86 billion) demonstrated the necessity to account for other than SMSA-to-SMSA travel (i.e., SMSA to non-SMSA, non-SMSA to SMSA, and non-SMSA to non-SMSA). Total intercity PMT was estimated by computing percentage changes in SMSA passenger-miles traveled (by mode) between the base-year estimate and each POINTS forecast. These "growth factors" were applied to base-year modal PMTs. The resulting intercity PMTs are discussed in Sec. 3.

Intercity Energy Intensities

Estimates of energy intensities by intercity passenger mode are shown in Table 15. The major assumptions underlying these estimates are as follows.

1. Bus. The bus energy-intensity estimates are based upon information provided by the American Bus Association.⁶⁶ Improvements in fleet-average mi/gal of 5% by 1985 and 10% by 1990 are assumed. No improvements are assumed beyond 1990. These estimates are based on technological efficiency changes, primarily downweighting and a shift to turbocharged V-6 engines by major bus operators.

2. Rail. Intercity rail energy intensity has been dropping slightly over time, at an average annual rate of -1.4% from 1975-1978.⁴¹ As Amtrak attempts to improve the efficiency of its operations and to increase load factors, this trend should continue. Therefore, an average annual rate of change of -1% has been assumed through 1990. Beyond 1990, energy intensity is assumed to remain constant.

3. Auto. Intercity energy intensities for automotive travel were derived from the stock model outputs. First, highway mpg (mi/gal) was calculated for each vehicle type using the equations shown below:

$$\text{Combined mpg} = 1.18 \text{ city mpg} \quad (23)$$

$$\text{Highway mpg} = \frac{\text{Combined mpg} - 0.55 \text{ city mpg}}{0.45} \quad (24)$$

The result was then degraded to an on-the-road fuel-economy estimate using historical trends and limited survey data.^{67,68,69} The degradation accounts for driving conditions, vehicle maintenance, climate, etc., and corresponds to the difference between on-the-road fuel economy of new vehicles under relatively favorable conditions and on-the-road fuel economy of the entire fleet across a range of conditions. The degradation factors were:

- 1980: 12% all vehicles
- 1985-2000: 20% gasoline-powered vehicles
- 10% diesel-powered vehicles
- 0% battery-powered vehicles.

Table 15 ANL-81 Estimates of Intercity Fuel-Efficiency by Mode, 1977-2000

Mode	Fuel-Efficiency Measure	1977	1980	1985	1990	2000
Bus	● Passenger-mi/gal ^a	141.5	144 ^b	151.2	158.4	158.4
	● Vehicle-mi/gal ^c	6.1	5.9	6.2	6.5	6.5
	● % change (both) from 1980	3.4	-	5	10	10
Rail	● Btu/passenger-mi	3369	3308	3137	2967	2967
	● % change from 1980	3.1	-	5	10	10
Auto	● Passenger-mi/gal	34.5	41.3	52.9	64	82.4
	● Vehicle-mi/gal	15.2	18.2	23.3	28.2	36.3
	● % change (both) from 1980	20.2	-	44.8	71.6	99.5
Air	● Passenger-mi/gal ^d	19.9	26.4	31.0	37.0	48.8
	● % change from 1980	33.6	-	17.5	40	85

^aAll services. Increase between 1977 and 1979 is attributable to increased charter share.

^b1979 estimate.

^cScheduled services only.

^dTotal domestic air carrier.

Sources of historical data:

Bus -- American Bus Assn., Bus Facts, Washington, D.C. (1981).

Rail -- G. Kulp et al., Transportation Energy Conservation Data Book, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1981 and previous Eds.

Auto -- CTR staff estimates based on fleet-average fuel economy as reported by U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, Washington, D.C. (annual).

Air -- R. Wilson, Options for Fueling America's Transportation, presented at the 60th Annual Meeting of the Transportation Research Board, Washington, D.C. (Jan. 13, 1981).

Finally, a harmonic mean was computed from mpg estimates for the auto, van, and light truck categories. The results show a steady and significant improvement from 1977 to 2000.

4. Air. Improvements in future aircraft fuel efficiencies are expected to come as a result of both airline operational changes and new aircraft technologies. Anticipated technology improvements were discussed in Sec. 1.3.3. Operational improvements include: reduced cruise speed; optimized climb/descent and cruise profiles; reduced weight (including reductions of inflight fuel reserves); improved air-traffic control procedures; improved

engine-maintenance techniques; improved inflight fuel management; increased load factors; improved aircraft-loading practices; and improved aircraft aerodynamics.^{5,70} These kinds of improvements were responsible for a 50% increase in fuel efficiency in the 1970s, and estimates indicate that they can potentially reduce fuel use another 13-17%.⁷⁰ Advanced air-traffic control and inflight fuel-management systems seem particularly promising. Since many of these improvements are now being implemented, their marginal contribution may be expected to occur in the near term and to decline to the point of negligibility in the 1990s.

Due to the time lag between technological readiness, market introduction, and achievement of significant penetration, new technologies will begin to appear in the middle and late 1980s. Their impact, however, will not be felt until the late 1980s and early 1990s. In the late 1990s, the impact of these improvements may be expected to slow as full penetration occurs.

When the anticipated effects of operational and technological improvements are combined, total improvement in fuel efficiency over 1980 levels may be expected to follow this pattern:

1980-1985	a 17.5% improvement over period from base
1985-1990	a 22.5% improvement over period from base
1990-1995	a 30% improvement over period from base
1995-2000	a <u>15%</u> improvement over period from base
	an 85% total improvement over 1980.

The increase from 1990 to 1995 is due to the expected influx of NASA Aircraft Energy Efficiency (ACEE) project improvements. The rate drops from 1995-2000, as the operational and technological improvements considered in the baseline scenario achieve full market penetration.

The above estimates of future aircraft fuel-efficiency improvements compare quite well with other sources. Wilson predicts a continued 5%/yr improvement into the 1990s; Operations Research, Inc., uses approximately 4.25%/yr in its work for NASA; and the Aspen Institute for Humanistic Studies predicts a 3-5%/yr improvement.^{5,71,72} By contrast, the International Civil Aviation Organization (ICAO) forecasts only a 20% increase in the 1980s, followed by a 15-20% increase in the 1990s.⁷³ (It should be noted that all these rates of increase start from a 1980 base and are not compounded.)

2.5.2 International Air

In order to compute total revenue passenger-miles (RPMs) and energy usage in the commercial air sector, international RPMs and energy use had to be projected. International air passenger travel is defined here to include only travel with origin or destination in the U.S. carried on U.S. flag carriers.

In the first edition of this report, international air RPMs were forecast by applying a Federal Aviation Administration model using the sum of American, British, West German, and Japanese GNP, expressed in nominal U.S.

dollars (BIG4GNP), and international air passenger yield or revenue per revenue passenger-mile (IYIELD).⁷⁴ This model was no longer considered satisfactory and was re-estimated for the present forecasts with the following changes.

- The variables BIG4GNP and IYIELD were converted into constant 1980 dollars. This removed the effect of inflation on RPMs in the model. Previously, higher inflation caused an increase in RPMs, an effect not intuitively obvious.
- The model now calculates total international RPMs instead of scheduled international RPMs only. In recent years the percentage of chartered passenger flights has dropped sharply. It is believed that this demand has been absorbed by the scheduled flights as they have become more cost-competitive and have begun to take on the characteristics of traditional charter service.
- More recent data, through 1980, were used for calibration.^{75,76}

The new model, using the modified FAA variables, is expressed:

$$Q = 27847.43 - 6324.88 Y + 16.1633 G, \text{ and } R^2 = 0.914 \quad (25)$$

where:

- Q = annual estimates of international revenue passenger-miles, scheduled + unscheduled (in 10^6)
- Y = yield, or revenue per revenue passenger-mile, for international operations (in ¢/mile, 1980 \$)
- G = annual gross national product of the U.S., U.K., West Germany, and Japan, (in 10^9 1980 U.S. \$).

The input data and assumptions used in the forecasts were as follows.

- In general, average yield changes in proportion to average cost.⁷⁷
- International yield will be somewhat less sensitive to increased costs due to deregulation and stiff competition from "no frills" airlines.
- U.S. gross national product will grow at the rates projected for the baseline scenario. Real gross national product of the U.K., West Germany, and Japan will grow at the rates projected by the Institute for Energy Analysis.^{78,79,80}

The projections developed by means of the above model and assumptions are presented in Sec. 3.1. The following assumptions were used to translate model results into projections of energy consumption by international air passenger travel.

- Load factors will increase gradually from their 1980 level of 0.64 to 0.67 by 1990.⁸¹

- Energy intensity will improve at the same rate as for U.S. domestic air services. (For a further discussion of assumed aircraft energy-efficiency improvements, see Secs. 1.3.3 and 2.5.1.5.)
- U.S. flag carriers will maintain their current share of the international air travel market.

2.5.3 General Aviation

Future general aviation activity was projected by means of the same model used in the previous edition of this report. Originally developed by Ratchford, the model was applied in a form derived by SRI.^{82,83} Inputs included a measure of general aviation price, real per-capita disposable income, the number of persons >18 years of age (i.e., the universe of potential general aviation pilots), and the price of competing commercial aviation services. Mathematically, this is expressed

$$\dot{Q} = \dot{X} - 1.839\dot{G} + 2.797\dot{Y} + 0.816\dot{C} \quad (26)$$

where:

- $\dot{Q}$ = the rate of change in quantity of general aviation activity, expressed in vehicle-miles traveled, from a base year;
- $\dot{X}$ = the rate of change in the population >18 years of age;
- $\dot{G}$ = the rate of change in real general aviation cost, expressed in \$/mile;
- $\dot{Y}$ = the rate of change in real per-capita disposable income; and
- $\dot{C}$ = the rate of change in commercial airline fares, expressed in constant dollar yield.

Each of these rates of change was projected independently, based on the following assumptions.

- The population >18 years of age will grow at approximately 1%/yr through 1985 and 0.8%/yr through 2000;⁴³
- General aviation real cost per mile will increase at its historic (1965-75) rate of 2.1%/yr;⁸⁴
- Real per capita disposable income will increase at an annual rate of 2.3% between 1980 and 1985, 1.8% between 1985 and 1990, and 2% between 1990 and 2000;³
- Commercial air carrier yield will increase at 0.6%/yr through 1990, and 0.8%/yr between 1990 and 2000.

2.5.4 Other

In developing "bottom up" projections of future transportation energy consumption a number of relatively minor modes must be considered in some fashion. While these modes individually consume relatively small quantities of energy, their collective consumption is significant and may be expected to remain so. The modes grouped under the category "other" include: recreational boating, transit and commuter rail, motorcycles and mopeds, snowmobiles, and various kinds of nonmotorized recreational vehicles that cause incremental fuel consumption by a towing vehicle.

2.5.4.1 Recreational Boating

As in other transportation modes, the energy consumed by recreational boating is a function of motorized stock, usage per unit, and energy intensity. However, unlike most other modes, recreational boat activity does not necessarily involve transportation activity and energy consumption. A significant portion of recreational boating is in a passive mode, either at dockside or at anchor on the open water. Thus, even though the vessel may be in use for more than 500 hours per year, actual engine-hours may be significantly below that figure.^{85,86} This characteristic creates practical difficulties, as available data tend to report vessel-hours, as opposed to engine-hours, of use.

Since energy intensity and usage patterns tend to vary by vessel size, two engine size classes were defined and projected independently.* Stocks with engines of 50 hp or less, generally outboard motors, were extrapolated based on historical trends in total outboard engines owned. Stocks with engines of more than 50 hp, generally inboard or inboard-outboard motors, were extrapolated from historical trends in total inboard engines owned.⁸³

Current data on recreational boats and boating activity are sketchy. Due to wide differences in state registration requirements, registrations are generally not considered a reliable data source. Estimates by the Boating Industry Association and trade journals like Boating Industry Magazine are considered preferable sources. In addition, the U.S. Coast Guard periodically conducts a Nationwide Boating Survey, which estimates total stock, activity, and energy consumption from data obtained in a random sample of households. Since the most recent (1976) survey is widely disputed, the 1973 survey was the principal data source for Coast Guard information. This analysis used Coast Guard information on the size distribution of motorized craft and annual boat-hours by engine size. Base-year estimates of stock, activity, and energy consumption were developed independently.

For each of the two horsepower categories, the following additional assumptions were developed.

*Because of the wide range of vessel types, with associated energy intensities and usage patterns, several size classes would have been desirable. Unfortunately, existing data would not support more than two such classes. Even the two-group classification used in this analysis required a number of simplifying assumptions.

1. 50 hp or less. Since these engines tend to be used primarily for fishing, engine-hours were assumed to represent only 15% of annual boat-hours. This reflects the large amounts of time spent at anchor versus traveling to and from fishing sites and moving from one spot to another. Since fishing tends to involve "fast" movements to and from fishing spots, with long time spans of inactive engine use in between, it was assumed that 70% of total engine-hours are run at full-throttle and 30% of total engine-hours are run at low throttle. Applying fleet-average full throttle and low throttle consumption rates yields total estimated fuel consumption.
2. More than 50 hp. Although a wide variety of boat types have engines in this class, 50 hp engines, engine-hours and primary use again provide a reasonable means for estimating energy consumption. Boats with engines of more than 50 hp tend to be used for fishing, cruising, and water skiing. Engine-hours were assumed to represent 40% of annual boat-hours for these relatively more active uses. Since a variety of activities, with a variety of speeds, are involved, it was assumed that half of these engine-hours are at low throttle and half are at full throttle. Again, applying fleet-average fuel consumption rates yields total estimated fuel consumption.

For 1980, recreational boating energy consumption was assumed to be 0.19 quad, based on a recent estimate developed for the U.S. Department of Transportation by Jack Faucett Associates.⁸⁷ Future energy consumption was projected as a function of future stocks, assuming constant usage patterns (i.e., annual boat-hours per boat, engine-hours as a percentage of boat-hours, and percentage of engine-hours at full and low throttle). However, since a disproportionate share of future stock growth is expected to occur in the larger engine sizes, future energy consumption is expected to grow somewhat more rapidly than future stocks.

2.5.4.2 Motorcycles and Mopeds

In the previous edition of this report, major increases were projected in motorcycle and moped stocks. These projections were based on motorcycle/moped sales trends through the mid-1970s and assumptions regarding the future competitiveness of these vehicles against automobiles. Since new automobiles were assumed to achieve no more than the mandated 27.5 Corporate Average Fuel Economy (CAFE) by 1985 (considerably less on the road), two-wheel vehicles appeared to represent an attractive alternative. In the current effort, automotive fuel-efficiency assumptions are vastly different and so, too, is the motorcycle/moped projection. While a separate, detailed analysis has not been conducted, motorcycle and moped stocks are assumed to increase gradually over time. The composition of the stock is assumed to shift somewhat, as increasing numbers of larger displacement (i.e., >750cc) motorcycles and smaller displacement (<50cc) mopeds enter the fleet. On balance, energy consumption is assumed to grow at an average annual rate of 1% through the year 2000.

2.5.4.3 Snowmobiles

The projection presented in the previous edition of this report has been retained for this effort. According to that projection, the energy consumed by snowmobiles remains quite stable over time. While snowmobile stocks grow, their extremely low utilization and fuel-consumption rate keep their total consumption essentially constant through year 2000.

2.5.4.4 Nonmotorized Recreational Vehicles

The incremental energy consumed in towing a nonmotorized recreational vehicle (RV) is on the order of 0.04 quads.* Moreover, since the baseline scenario assumes increasing fuel prices and slow growth in personal light truck stocks (including recreational vehicles), it appears likely that the nonmotorized RV market will remain depressed. Thus, incremental towing energy was assumed to remain constant for the baseline projection.

2.5.4.5 Transit and Commuter Rail

The projections shown in Ref. 2 have been retained for this edition. Modest increases in commuter rail energy consumption raise total consumption by transit and commuter rail to 0.06 quads by the year 2000.

2.6 GOODS MOVEMENT

The demand for movement of goods, whether of production inputs from initial processing facilities to secondary fabricating facilities or of finished goods to intermediate and final consumers, is closely related to the level and composition of production which, in the aggregate, comprises gross national product. Production volume (tons) is translated into freight activity (ton-miles) through the distribution system, which is composed of truck, rail, marine, pipeline, and air transport modes. Projecting future freight activity is thus inseparable from projecting future production or economic activity and the spatial relationship between final and intermediate producers and consumers.

This fundamental relationship underlies the baseline projections of freight activity and energy demand. The projections are derived from the FRATE model (Freight Responsive Accounting for Transportation Energy), which in turn is driven by the DRI forecast. The following discussion focuses on the FRATE model, its linkage to the DRI model, and the sector-specific economic trends within the baseline scenario likely to impact future freight activity.

*Assuming 1975 highway fuel economy of 15.4 mi/gal without an RV and 9.6 mi/gal with an RV; nonmotorized RV stocks of 2,353,000; and annual utilization of 3400 mi/RV.

2.6.1 Model Background and Description

FRATE is an interactive accounting model that projects intercity and local freight activity, vehicle stocks, and energy consumption as a function of anticipated growth in specific commodity sectors; modal split of commodity traffic among competing transport modes; and vehicle load factors, utilization, and energy intensity. The FRATE model was developed to link commodity-specific transportation data with commodity-level economic projections. FRATE may be driven by any external input/output or other econometric model with sectors defined on the basis of standard industrial classification (SIC) codes.

As stated above, the baseline projection of freight transportation activity and energy demand is driven by the production output levels of the DRI model. The DRI forecasting procedure contains 54 behavioral equations to calculate manufacturing-sector output and final GNP.² The model is capable of simulating the effects of increased energy prices and supply variations on production. Through FRATE, these variations directly and indirectly influence freight transportation activity and energy consumption.

The FRATE model is composed of the 37 commodity sectors listed in Table 16. These are based on the transportation commodity classification (TCC) codes used in the quinquennial Commodity Transportation Survey (CTS).³³ The TCC codes are similar to SIC codes, which define the economic sectors of most input/output tables and econometric models. It is through this relationship that FRATE is linked to an econometric driver.

It should be noted that TCCs are not necessarily equivalent to SICs. For certain commodities TCCs may be equated to one or more first-level SICs; for other commodities TCCs may be equated to one or more second-, third-, or fourth-level SICs. Thus, in order to link FRATE with a selected econometric driver, an appropriate mapping between TCC and SIC codes must be devised. From this mapping, CTS transportation-activity data, in the form of freight tons and ton-miles hauled, can be matched to economic-activity sectors -- and future transport activity can then be projected as a direct function of future economic activity.

The FRATE-DRI mapping process involved considerable compromise because certain DRI sectors are extremely specific while others are quite broad. For example, the DRI model specifies several machinery and equipment sectors. Since machinery and equipment account for a relatively small share of total ton-miles (TMT), a high level of detail is not necessary for a TMT profile of these movements. By contrast, DRI provides very little detail about primary-product sectors like agriculture and mining, which account for a considerable proportion of total ton-miles. Thus, for those primary-goods sectors not explicitly specified in DRI, future transport activity was assumed to grow as a direct function of some surrogate variable, generally the growth rate for employment within an appropriate sector.

The limitations of matching primary-sector output to more aggregate indicators are well recognized. However, it should be emphasized that any mapping of transport and economic activity sectors will be flawed because of inherent differences in sectoral coverage. The ideal mapping would involve building an input/output table specifically geared to transportation commodity

Table 16 FRATE Model Commodity Sectors

Code ^a	Commodity Sector
1	Farm products
2	Forestry, fishery products
3	Metal mining
4	Coal
5	Nonmetal mining
6	Crude oil
7	Construction
8	Meat and dairy products
9	Canned, frozen, and other foods
10	Candy, cookies, beverages, tobacco
11	Basic textiles and leather
12	Apparel and related products
13	Paper products
14	Industrial chemicals and synthetic materials
15	Drugs, paints, other chemicals
16	Petroleum products
17	Rubber and miscellaneous plastic products
18	Lumber and wood products
19	Furniture and fixtures
20	Stone, clay, and glass products
21	Iron and steel products
22	Primary nonferrous metal products
23	Fabricated metal products
24	Metal cans and miscellaneous
25	Industrial machinery
26	Other machinery
27	Communications equipment
28	Electrical products
29	Motor vehicles and equipment
30	Transportation equipment
31	Instruments, cameras, etc.
32	Wholesale and retail trade
33	Business and personal services
34	Communications
35	Other
36	Postal services
37	Natural gas

^aCommodity classification code used in the FRATE model.

classifications. Since it is unlikely that the incremental benefit of such an undertaking would outweigh the considerable effort involved, the present mapping, with all its limitations, is considered a reasonable compromise.

2.6.2 Model Application

The FRATE projection procedure may be separated into four discrete operations: calculation of ton-miles by commodity sector, distribution of commodity-level ton-miles among competing modes, computation of commodity-level energy consumption, and computation of energy consumption by vehicle type. These four operations are discussed below. The calculation of vehicle stocks, while related to the latter operation, is discussed in Sec. 2.3.2.

2.6.2.1 Ton-Miles by Commodity Sector

Estimates of 1977 and 1980 ton-miles traveled (TMT) were developed from results of the 1972 Commodity Transportation Survey (CTS) and an analysis of post-1972 TMT growth in specific sectors. At the time of this analysis, the 1977 CTS was not yet available. Additional data sources used as control totals for the 1977 estimates included: the Transportation Energy Conservation Data Book, the Energy Information Administration's Annual Report to Congress, and the Brookhaven Energy Transportation Submodel (BETS) Documentation and Results.^{41,88,89}

Beyond 1980, production growth rates from the DRI economic forecast were applied to the 1980 ton-mile estimates to project future-year ton-miles by commodity sector.

2.6.2.2 Modal Split by Commodity Sector

Projected ton-miles were then allocated among truck, rail, water, air, and pipeline modes by means of a modal-split subroutine. Commodity-sector modal distributions were obtained from the 1972 CTS; they were then updated to reflect the most recent runs of the National Energy Transportation (NETS) model and the National Transportation Policy Study Commission (NTPSC) flow forecasts for 1980.^{90,91} For the baseline scenario, commodity-sector mode shares were assumed to remain constant over time.*

2.6.2.3 Energy Consumption by Commodity Sector

In the FRATE system, energy consumption is calculated by applying an energy-intensity estimate to ton-miles by commodity sector, or through a submodal analysis. The former calculation may be expressed

*This assumption will be revised, upon analysis of the 1977 CTS and incorporation of a recently developed mode-split model into FRATE.

$$MDENGY_{ij} = \sum_k TMT_{jk} MSPLT_{ijk} EICOMS_{ijk} \quad (27)$$

where:

i = index of modes -- truck, rail, marine, air and pipeline;

j = index of base year and projection years;

k = index of commodity sectors;

MDENGY = projected energy consumption;

TMT = projected ton-miles traveled;

MSPLT = mode-split factor for TMT; and

EICOMS = energy intensity, in Btu/TMT.

Commodity-level energy intensities (EI) are presented in Appendix B of this report. The values show that commodities characterized by the lowest load factors and highest degree of empty backhaul exhibit high energy intensities. For example, in the farm, mining, chemical, and petroleum product sectors, shipments tend to have short haul lengths, and loads tend to be full (or nearly so) on the front haul. Thus, those sectors appear relatively energy-efficient. By contrast, the apparel, furniture, machinery, and motor vehicle sectors have much higher EI values, since they have lower load factors, longer lengths of haul, and fewer backhaul loadings.⁹²

2.6.2.4 Energy Consumption by Vehicle Type

For intercity trucks, energy consumption is computed both on a commodity-level basis (Eq. 27) and as a function of projected vehicle stocks, utilization, and vehicle efficiency.* The latter procedure may be expressed as:

$$TRUKEN_j = \sum_k \sum_i TRKSTK_{ijk} ATRKVM_{ij} MPG_{ijk} FACTOR_k \quad (28)$$

where:

i = index of truck-size categories -- medium, heavy, and heavy-heavy;

j = index of base and projection years;

k = index of fuel type, gasoline or diesel;

TRUKEN = intercity truck energy-consumption in Btu;

TRKSTK = truck stock;

*For local trucks energy consumption is computed only on a per-vehicle basis, using Eq. 27.

ATRKVM = average annual miles/vehicle;

MPG = intercity truck fuel-efficiency in mi/gal; and

FACTOR = conversion factor from gallons of fuel to Btu.

Intercity truck stock (TRKSTK) is projected as a function of ton-miles by particular commodity sectors and average load factor (tons/vehicle) by vehicle size (See Sec. 2.3.2). Since ton-miles are also a key independent variable in Eq. 26, the results from Eq. 26 are normalized within FRATE to match those from Eq. 27. Local truck stock is projected as a direct function of commodity-sector growth (i.e., without the intervening variables, ton-miles and tons/vehicle).

Average annual miles/vehicle (ATRKVM) are specified exogenously by vehicle size and fuel type. For the baseline scenario, these were assumed to remain constant within vehicle size classes. For intercity trucks, gasoline and diesel vehicle utilization (i.e., miles/vehicle) was assumed to be equivalent throughout the projection period. This results in a relatively conservative projection of truck vehicle-miles (VMT) and energy consumption, because increased diesel penetration improves the efficiency of the truck stock but does not generate additional travel. For local trucks, gasoline and diesel vehicle utilization was assumed to differ, primarily because of the considerably longer lifetimes of local trucks and the much larger proportion of gasoline vehicles in that stock. Table 17 shows the vehicle-utilization assumptions of the baseline scenario, by area of operation, vehicle size, and fuel type.³¹

Table 17 Average Annual Miles Per Vehicle,^a
Intercity and Local Trucks

Size Class	Intercity Trucks ^b	Local Trucks	
		Gasoline	Diesel
Light	c	8844	13445 ^d
Medium	21705	7669	11380
Heavy	23391	8333	13889
Heavy-Heavy	61297	10419	21551

^aConstant, all projection years.

^bGasoline and diesel vehicle utilization assumed equivalent. For further discussion, see text.

^cAll commercial light trucks assumed to be in local operation.

^dBecause diesel and LPG-fueled light trucks have similar usage patterns, the latter are combined with diesels in the FRATE model.

Source: U.S. Department of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey, public use tape.

Fuel efficiency is also specified exogenously by vehicle size and fuel type. As shown in Table 18, between 1980 and 1990 the average efficiency of the gasoline truck fleet is assumed to improve by slightly more than 15% within all vehicle sizes; diesel efficiency is assumed to improve by approximately 16.5% over this period. The efficiency assumptions shown in Table 17 are based on those of the previous OTP baseline (CSSP-80), vehicle characterizations for the CTR's Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) project, recent work by Energy and Environmental Analysis, Inc., and recent sales trends as reported by Oak Ridge National Laboratory.^{1,8,11,93} All efficiency improvements are assumed to come from more widespread use of such conventional fuel-saving technologies as aerodynamic devices, "fuel saver" (or high torque-rise, low RPM) diesel engines, radial tires, road speed governors, and tag axles. Beyond 1990 the fuel efficiency of new registrations is assumed to remain constant, but fleet-average fuel efficiency continues to improve as older, less efficient vehicles are retired from the fleet. (For a further discussion of truck technology assumptions in the baseline scenario, see Sec. 1.3.2.)

In addition to improved energy efficiency within size class/fuel type categories, fleet-average efficiency also improves as a result of increased diesel penetration into all size classes. By the year 2000, heavy-heavy truck stocks are assumed to be exclusively diesel. Heavy truck stocks are assumed to be more than half diesel, medium truck stocks are assumed to be more than one-third diesel, and light truck stocks are assumed to be nearly one-fifth diesel.

2.6.3 Commodity Sector Trends and Impacts

As stated previously, DRI economic sector growth rates were applied to 1980 estimates of intercity ton-miles by commodity sector. The following discussion focuses on the production trends in four key sectors: coal, petroleum,* electrical machinery, and construction. Together, these sectors account for 42% of total 1980 ton-miles and a significant share of TMT in certain modes.

Both coal and petroleum are primary products. Because of their bulk, primary products accounted for 53% of total ton-miles in 1977. Although projections indicate that this share will decline in the future, the movements of primary products are expected to continue to represent a major share of total freight activity. Within primary products, the coal and petroleum sectors have been exhibiting, and are likely to continue to exhibit, the most significant changes over time. Coal production is projected to increase substantially throughout the forecast period, while crude oil and petroleum products are projected to increase through 1990 and to decline thereafter.

Figure 12 displays baseline forecasts of production growth for the coal, petroleum, electrical machinery, and construction sectors. During the past decade, the coal industry has experienced a series of production

*"Petroleum" is actually divided into two sectors, crude petroleum and refined products. Because of similarities in their growth trends, they are combined in the following discussion.

Table 18 Estimated Fleet-Average Fuel Economy by Size Class and Fuel Type, Intercity and Local Trucks (mi/gal)

Fuel Type and Size Class by Type of Travel	1977	1980	1985	1990	1995	2000
Intercity						
Medium						
Gasoline	9.00	9.76	10.49	11.24	11.84	12.00
Diesel	11.07	12.05	13.06	14.05	14.80	15.00
Heavy						
Gasoline	6.09	6.60	7.10	7.61	8.06	8.20
Diesel	7.34	7.99	8.66	9.31	9.86	10.03
Heavy-heavy						
Gasoline	3.93	4.26	4.58	4.91	5.11	5.16
Diesel	4.50	4.90	5.31	5.71	5.94	6.00
Local						
Light						
Gasoline	9.95	10.24	11.74	13.60	14.89	15.43
Diesel	15.08	15.51	17.79	20.61	22.56	23.38
Medium						
Gasoline	7.82	8.47	9.11	9.76	9.76	9.76
Diesel	8.60	9.36	10.14	10.91	10.91	10.91
Heavy						
Gasoline	5.54	6.01	6.46	6.92	6.92	6.92
Diesel	6.12	6.66	7.22	7.76	7.76	7.76
Heavy-heavy						
Gasoline	3.85	4.17	4.49	4.81	4.81	4.81
Diesel	4.50	4.90	5.31	5.71	5.71	5.71

Sources: ANL estimates based on: D. Greene et al., Energy Saving Impacts of DOE Conservation and Solar Programs, Oak Ridge National Laboratory (May 1981); Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, quarterly report; C. Chen et al., Motor Vehicle Quarterly MPG and Market Share Newsletter, Oak Ridge National Laboratory, quarterly report; and Argonne National Laboratory, unpublished information.

Fig. 12 DRI Projections of Growth in Coal Mining, Petroleum, Electrical Products, and Construction Sectors Relative to 1977

declines associated with strikes by the United Mine Workers that have shut down the deep mines in the eastern part of the country. Despite sharply lower output during these periods, ton-miles of coal have continued to increase over the years.* In the future, this growth trend may be expected to continue as a result of increased coal demand, both for domestic use and for export. Regional shifts in coal production that tend to increase the average length of haul, and thus increase TMT still more, are not considered explicitly in the baseline projection. Even so, coal TMT is projected to increase faster than GNP under the baseline scenario.

In contrast to coal, the output of crude oil and petroleum products is projected to be only slightly higher in year 2000 than in 1980. As shown in Fig. 12, petroleum production peaks around 1990.

In 1977, the energy sectors accounted for 40% of total ton-miles. By the year 2000, increased coal production is more than offset by production

*Because the measure is ton-miles, not tons, a considerable portion of this increase may be attributed to the continuing shift in coal production from eastern deep pit mines to western strip mines. Because western coal shipments typically have longer lengths of haul, this production shift tends to produce an increase in ton-miles, irrespective of production growth.

increases in the nonenergy sectors, and thus energy sector ton-miles are projected to decline to approximately 25% of the total. Marine and pipeline modes are most affected by stable to declining petroleum output; rail is most affected by the growth in coal output.

On the whole, manufacturing-sector output is projected to grow more rapidly than energy-sector output. This trend affects trucking more than any other mode. The electrical-machinery sector illustrates this pattern. By the year 2000, the output of electrical machinery is projected to reach 220% of 1977 levels (see Fig. 12). This compares with GNP, or total output, growth of 175%.

Figure 12 also displays trends in construction employment, the indicator used to project construction-sector output. Construction employment, in turn, is based on DRI projections of new housing starts. As Fig. 12 indicates, the construction industry is likely to remain unsettled. Through 1985, modest growth is projected, with recovery from the present slump occurring around 1983. Beyond 1985, however, growth slows considerably.

Because construction sites typically are accessible only by truck, the construction industry is totally dependent on trucking. Movements of construction materials are characterized by a limited cargo and a short length of haul. Thus, many vehicles are utilized to transport a relatively small share of ton-miles. The trends indicated in Fig. 12 suggest that slow growth in the construction industry may adversely affect future truck sales and stocks.

3 RESULTS

3.1 OVERVIEW

As stated previously, the baseline scenario projects a least-surprise, business-as-usual future. There are, however, several surprises in the baseline projections. Because of fairly high fuel prices (roughly \$2/gal gasoline in constant 1980 dollars but four times that value in nominal year-2000 dollars), as well as moderate inflation and relatively modest economic growth, passenger and freight travel demand grow slowly under the baseline scenario. Energy consumption in many transport modes grows even less, as efficiency improvements outstrip growth in travel demand.

In the baseline scenario, efficiency improvements are assumed to come as a result of the marketplace responding to continued high fuel prices. Admittedly, this is a debatable feature of the scenario, as relatively slow economic growth may preclude or at least hinder the formation of capital not only for purchasing new fuel-efficient equipment but also for developing the manufacturing facilities to produce that equipment. Such investment constraints are likely to most affect introduction of aircraft of the post-B757 and -B767 generation and light-duty vehicles with enhanced fuel efficiency. Because the projections incorporate travel cost/VMT elasticities, lower fuel efficiency would tend to reduce projected modal activity levels somewhat; in actuality, however, this tendency would be more than offset by increased energy consumption.

The three most significant differences between the current projections and those of previous OVERD baselines* concern light-duty fuel economy, truck stocks, and domestic air passenger travel.

1. Light-duty fuel economy. Unlike the two previous OVERD baselines, this baseline assumes a continued improvement in fuel economy throughout the projection period. This assumption is consistent with recent studies that indicate considerable potential for additional improvement in fuel economy -- even without major technological changes -- beyond the mandated 1985 Corporate Average Fuel Economy (CAFE) of 27.5 mi/gal.^{9,10,94,95} With technological changes, truly dramatic fuel-efficiency improvements have been claimed.^{10,12}

2. Truck stocks. Although trucks are used in virtually all economic sectors, a few key sectors generate a significant share of total truck ton-miles (TMT). As shown in Table 9, construction materials, wholesale and retail trade, and farm products are the major commodities moved by intercity truck. Together, these commodities account for nearly 40% of truck TMT. While the overall economic projections of the present effort do not differ greatly from those of the CSSP-80 baseline, projections for these and certain other key sectors are quite dissimilar. These sectoral projections are compared in Table 19. Particularly noteworthy are the construction, wholesale/retail trade, and utilities/services sectors, all of which tend to

*Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, referred to here as ANL-79, and Energy Savings Impacts of DOE's Conservation and Solar Programs, referred to here as CSSP-80.

Table 19 Economic Growth Rates of Major Truck-Using Sectors in ANL-81
and CSSP-80 Projections (Average Annual % Change over Period)

Sector	1980-1985		1985-1990		1990-2000		1980-2000	
	CSSP-80	ANL-81	CSSP-80	ANL-81	CSSP-80	ANL-81	CSSP-80	ANL-81
Construction	2.93	3.71	2.31	2.35	5.66	(0.65)	4.13	0.17
Wholesale and retail trade	3.77	2.07	3.88	1.89	2.65	1.04	3.24	1.51
Utilities and services	3.78	{2.15 ^a 3.82 ^b }	3.57	{1.94 ^a 2.71}	2.72	{1.98 ^a 1.64 ^b }	3.20	{2.01 ^a 2.45 ^b }
Agriculture	1.13	3.08	1.43	2.53	4.41	2.18	2.83	2.49
Manufacturing	3.15	5.62	1.78	2.81	2.66	3.09	2.56	3.65
For-hire trucking	4.14	c	4.74	c	4.41	c	2.83	c

^aFRATE communications sector.

^bFRATE business and personal services sector.

^cNo comparable sector in FRATE. Stocks and activity of for-hire trucks allocated to major commodities transported.

be quite vehicle-intensive. Seemingly small differences in economic activity projections thus could produce substantial differences in stock projections. Moreover, when the stock projections proceed from different base-year estimates, as they do in this case, the projections can differ even more. The CSSP-80 baseline, like that of its predecessor, ANL-79, estimates 1980 stock from the 1972 TIUS and post-1972 assumptions regarding stock growth in major sectors of truck use. By contrast, the ANL-81 baseline estimates 1980 stocks from the 1977 TIUS and post-1977 assumptions regarding stock growth in major use sectors. Because the 1977 TIUS reported lower-than-expected stock totals, and because truck sales were down for two of the three years immediately following 1977, 1980 stock estimates under ANL-81 are considerably smaller than those under CSSP-80.

3. Air passenger travel. The ANL-81 intercity travel-demand model (POINTS) is based on the premise of modal competition. Modal attributes, primarily travel times and costs, influence both the volume of travel generated and the distribution across available modes. In our baseline scenario, the travel network remains constant over time; thus, travel times also remain fixed. Travel costs, however, change markedly as jet-fuel prices rise more rapidly than either improvements in aircraft efficiency or increases in gasoline prices. (See Sec. 1.3.3 and Table 4.) The outstripping of efficiency improvements by jet-fuel prices results in absolute increases over time in the price of air travel, while the slower growth in gasoline relative to jet-fuel price results in relative increases in the cost of air travel vis-a-vis the costs of competing modes. Together, these cost effects produce much lower-than-historical projections of passenger-miles traveled (PMT) by air.

These differences are magnified still further when modal energy consumption is computed from the different projections of vehicle stock, energy intensity, and transportation activity. For all modes of transportation, the energy-consumption projections of ANL-81 are less than those under CSSP-80.

3.1.1 Passenger Travel

As discussed in Sec. 2, passenger-travel projections were developed separately for trips ≥ 100 mi one-way (intercity trips) and trips < 100 mi one-way (local trips). This distinction is significant because such travel characteristics as trip purposes, traffic conditions, and network efficiencies tend to distinguish local from long-distance travel. However, the selection of exactly 100 mi as the breakpoint between the two types of travel was based solely on the availability of suitable base data for calibrating the POINTS intercity model.

1. Automobile/light truck. For these modes, the 100-mi breakpoint also provided a means of distinguishing between the different fuel efficiencies inherent in local and long-distance driving cycles. Fuel economy for trips ≥ 100 mi was assumed to correspond to highway-cycle mi/gal,* while fuel economy across all travel distances (i.e., < 100 mi + ≥ 100 mi) was assumed to correspond to combined-cycle mi/gal. Fuel economy for travel < 100 mi was

*Calculated as the harmonic mean of highway mi/gal for autos and personal light trucks.

calculated as the residual term. All fuel-economy estimates were computed from the VMT and energy projections of the disaggregate categorical analysis that incorporated future vehicle-efficiency assumptions and ownership probabilities by vehicle type (from the stock model DVSAM) to calculate household VMT and energy consumption. Household-level totals were then expanded to national totals, using the future household weights computed as a function of future household demographic factors.

2. Bus. Bus travel was divided into three submodes, each of which was projected separately. Travel by school bus was projected as a function of school-age population; travel by transit bus was projected as a function of urban population; and intercity bus travel was projected as a function of travel times and costs of buses versus those of competing modes (POINTS model). School and transit bus travel were assumed to be local. Although intercity buses serve many localities <100 mi apart (and are therefore used for local travel according to our 100-mi breakpoint), such trips exhibit more long-distance than local characteristics -- on this basis we assumed all intercity bus travel to be long-distance.

3. Rail. Like intercity bus travel, intercity rail travel also includes a significant proportion of trips <100 mi. Again, however all such travel was assumed to be long-distance.

4. Air. All commercial air travel was assumed to be ≥100 mi. General aviation travel, projected by a separate model that considered competing air fares (among other variables), also was assumed to be long-distance.

The resulting projections of intercity and local passenger-miles are shown in Tables 20 and 21. Intercity travel grows considerably more slowly than local travel over the forecast period, probably because of its more discretionary nature.

Modal projections of total PMT and total passenger energy consumption are shown in Figs. 13 and 14, and Table 22.

3.1.2 Goods Movement

Intercity goods movement, expressed in ton-miles of travel (TMT), and local goods movement, expressed in local truck vehicle-miles of travel (VMT), were projected by means of the FRATE model. As with the passenger-travel projections, a distinction was made between intercity and local travel. Again, the network, traffic, and fuel-efficiency differences between local and intercity operations prompt such a distinction. Moreover, differences in the distribution of local and intercity trucks by size class and fuel type make the distinction even more relevant. A distance of 200 mi was set as the breakpoint between local and intercity truck areas of operation. For local trucks, only vehicle-miles were projected; for intercity trucks, both vehicle-miles and ton-miles were projected.

The projections of intercity ton-miles traveled and total energy consumption for local and intercity goods movement are shown in Tables 23 and 24 and Figs. 15 and 16. As can be seen in these tables and figures,

Table 20 ANL-81 Projections of Intercity Passenger-Miles of Travel
(Trips ≥ 100 mi), 1977-2000

Travel Mode	Passenger-Miles (10^9)					Average Annual % Change, 1977-2000
	1977	1980	1985	1990	2000	
Auto/light truck	237.06	239.94 ^a	240.26	261.59	278.47	0.7
Air, domestic ^b	162.10	203.17 ^c	191.36	198.33	227.57	1.5
Bus	25.70	27.70 ^c	29.29	31.80	37.15	1.6
Rail	4.42	4.85 ^c	4.40	4.01	3.24	(1.3)
Total domestic PMT	429.38	475.66	465.31	495.73	546.43	1.1
Air, international ^d	42.05	57.24 ^c	74.75	90.04	135.87	5.2
Total PMT	471.43	532.90	540.06	585.77	682.30	1.6

^aEstimated.

^bCommercial air carrier only.

^cActual.

^dU.S. carriers only.

Sources of historical data:

Auto/light truck -- U.S. Department of Commerce, Bureau of the Census, 1977 Census of Transportation, National Travel Survey, Washington, D.C. (1979). Includes pro-rated portion of PMT by "different means going and returning."

Air -- Civil Aeronautics Board, Air Carrier Traffic Statistics, Washington, D.C., various monthly issues.

Bus -- American Bus Assn., Bus Facts, Washington, D.C. (1981 Ed.).

Rail, 1977 data -- Assn. of American Railroads, Statistics of Railroads of Class I in the United States, years 1969 to 1979, Washington, D.C. (1980).

Rail, 1980 data -- Personal communication, Amtrak (July 1981).

Table 21 ANL-81 Projections of Local Passenger-Miles of Travel
(Trips <100 mi),^a 1977-2000

Travel Mode	Passenger-Miles (10 ⁹)					Average Annual % Change, 1977-2000
	1977	1980	1985	1990	2000	
Auto ^b	1804.88	1800.67 ^c	2056.18	2262.78	2478.09	1.39
Light truck ^b	308.84	301.69 ^c	341.65	418.90	472.48	1.87
Bus	73.42	73.94	78.42	82.62	91.07	0.94
Rail	15.94	17.04 ^c	17.42	17.86	18.32	0.61
Total	2203.08	1292.74	2493.67	2782.16	3059.96	1.45

^aExcludes motorcycles, mopeds, recreational boating.

^bAssumes average occupancies of 1.78 passenger-mi/vehicle-mi for autos and 1.73 passenger-mi/vehicle-mi for personal light trucks (1977 Nationwide Personal Transportation Study).

^cANL estimate.

Sources of historical data:

Auto/light truck -- U.S. Department of Transportation, Federal Highway Administration, 1977 Nationwide Personal Transportation Study, public use tape.

Bus, Transit -- American Public Transit Assn., Transit Fact Book, 1980-1981 Edition, Washington, D.C. (1981).

Bus, School -- ANL estimates based on U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, Washington, D.C. Annual average load assumed to be 18.2 passenger-mi/vehicle mi, National Safety Council, Accident Facts, Chicago (1978 Ed.).

Rail, Transit -- American Public Transit Assn., Transit Fact Book, 1980-1981 Edition, Washington, D.C. (1981).

Rail, Commuter -- Assn. of American Railroads, Statistics of Railroads of Class I in the United States, Years 1969 to 1979, Washington, D.C. (1980).

Fig. 13 Total Passenger-Miles of Travel, 1977-2000

Fig. 14 Energy Consumption for Total Passenger Transportation, 1977-2000

Table 22 ANL-81 Projections of Energy Consumption for Domestic Passenger Transportation, 1977-2000

Travel Mode	Energy Consumption (quads)					Average Annual % Change, 1977-2000
	1977 ^a	1980 ^a	1985	1990	2000	
Auto	10.037 ^a	9.743 ^a	8.723	7.875	6.698	(1.74)
Light truck	2.412 ^a	1.802 ^a	1.699	1.951	1.700	(1.51)
Bus	0.132	0.140	0.149	0.161	0.176	(1.50)
Rail ^b	0.062	0.065	0.069	0.069	0.069	0.13
Domestic air ^c	1.248	1.178	1.021	0.951	0.947	(1.19)
Other ^d	0.266	0.276	0.310	0.340	0.400	1.79
Total	14.172	13.204	11.971	11.347	9.990	(1.51)

^aCalculated from Tables 20 and 21 and from historical energy intensities.

^bIncludes transit and commuter rail.

^cIncludes general aviation. Excludes foreign carriers' fuel purchases in the U.S. and international operations of U.S.-flag carriers.

^dIncludes motorcycles, mopeds, and recreational vehicles other than light trucks.

Table 23 ANL-81 Projections of Domestic Ton-Miles of Travel, 1977-2000

Travel Mode	Ton-Miles (10 ⁹)					Average Annual % Change, 1977-2000
	1977	1980	1985	1990	2000	
Truck ^a	570.28	607.87	741.58	826.22	981.98	2.39
Rail	819.61	853.21	1077.14	1211.51	1521.78	2.73
Marine	585.71	601.99	711.29	780.55	934.76	2.05
Air	4.64	5.08	5.99	6.72	8.13	2.47
Pipeline ^b	869.60	929.99	1027.35	1073.59	1543.45	2.53
Total	2849.83	2998.14	3563.35	3898.59	4990.10	2.47

^aTrucks used in intercity travel.

^bIncludes oil, natural-gas, and coal-slurry pipelines.

Sources of historical data:

Truck -- U.S. Department of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey, Washington, D.C. (1981).

Other modes -- ANL commodity-specific estimates summed across all sectors.

Table 24 ANL-81 Projections of Energy Consumption for Domestic Freight Transportation, 1977-2000

Transport Mode	Energy Consumption (quads)						Average Annual % Change, 1977-2000
	1977	1980	1985	1990	1995	2000	
Intercity truck ^a	1.230	1.312	1.600	1.784	1.909	2.136	2.43
Local truck ^b	1.373	1.519	1.638	1.707	1.747	1.866	1.34
Rail	0.485	0.500	0.634	0.710	0.789	0.892	2.68
Marine	0.252	0.259	0.307	0.338	0.368	0.405	2.08
Air	0.032	0.035	0.043	0.048	0.053	0.059	2.70
Pipeline ^c	0.772	0.858	0.966	1.001	1.161	1.500	2.93
Total	4.144	4.482	5.060	5.463	5.823	6.833	2.20

^aTrucks used primarily in intercity travel (trips ≥ 200 mi).

^bTrucks used primarily in local travel (trips < 200 mi).

^cIncludes coal-slurry estimates that are exogenous to the FRATE projection procedure.

Fig. 15 Ton-Miles of Travel, 1977-2000 (excluding air freight)

ton-miles grow at a somewhat slower rate than does energy consumption in certain modes. This is largely due to a shift in economic activity from primary products to finished goods and services. The implications of this shift are most evident in marine and pipeline activity.

Marine ton-miles grow at a slow rate. Primary-goods sectors, the output of which are typically transported on inland and coastal waters, all reflect slow growth. The declining growth of crude and petroleum product output also lowers marine TMT growth. Energy consumption grows more rapidly than ton-miles because the most energy-efficient movements (i.e., of energy materials) experience the largest traffic losses.

Pipeline activity grows mainly as a result of traffic from coal-slurry lines that are projected to begin operation after 1990. The introduction of the more energy-intensive coal-slurry lines accounts for the disparity between TMT and energy-consumption rates.

Rail growth is influenced primarily by coal movements, which reflect a high growth rate (2.8%) to 2000. Because coal movements by rail are very energy-efficient, they lower the average energy intensity of rail TMT, and modal consumption grows more slowly than modal activity.

Fig. 16 Energy Consumption for Freight Transportation, 1977-2000

Air-cargo volume increases over time due to anticipated growth in the wholesale/retail trade and business/personal service sectors. The energy consumed moving cargoes by air grows at a rate comparable to air TMT.

As a result of significant efficiency improvements, truck energy consumption rises less rapidly than does truck activity. This is particularly evident with respect to local goods movement where technology shifts (i.e., from gasoline to diesel- and LPG-powered vehicles) produce a considerable improvement in fleet-average fuel efficiency.

Primarily because of truck efficiency improvements, the overall growth in total energy consumed for freight movement by all modes parallels the growth in freight ton-miles. This occurs despite faster growth in relatively less efficient air and truck modes. Were it not for the truck efficiency improvements assumed under the baseline scenario, freight energy consumption would grow at a more rapid pace than freight activity.

3.2 LIGHT DUTY VEHICLES

3.2.1 Vehicle Stocks

Table 25 presents the baseline projections of automobile and light truck stocks by type of ownership. Fleet autos include government vehicles. Figure 17 presents the distribution by size class of the automotive stock, and Table 26 compares this distribution with that of other researchers. As was shown in Sec. 1.3.1 (see also Table 7), the baseline automotive fleet is quite fuel-efficient across all three size classes. Hence, larger vehicles continue to compare reasonably well to smaller vehicles, and the size mix of the baseline fleet stays much more stable than in other studies.*

Dieselization assumptions also serve to maintain the shares held by larger vehicles. By the year 2000, somewhat less than 20% of the light duty fleet is assumed to use diesel fuel (see Table 27 and Fig. 18).

Table 26 and Fig. 19 also compare the present automotive stock projection against two previous OVERD stock projections, as well as against projections by other researchers.

Table 28 and Fig. 20 compare projections of light truck stock. Even in the base year there is little agreement among the various studies cited. This lack of agreement may be attributed to two factors: (1) in many states, registration data quantify only total truck registrations -- since the data do not distinguish between truck-size classes, there is no way of estimating the number of light trucks on the road; and (2) because the 1977 TIUS and 1977 NPTS do not agree with respect to the stock of personal light trucks, the largest single vehicle-use category, a control total cannot be built up from its component categories. As in the case of automobiles, the baseline stock estimates are late-in-the-year values, since they are based on NPTS, for which the sampling midpoint occurred late in the calendar year (i.e., Oct.-Nov. 1977).

3.2.2 Activity and Energy Consumption

Table 29 and Figs. 21 and 22 present projected light duty activity (in vehicle-miles) and energy consumption by local/long-distance travel categories. Total vehicle-miles traveled by automobiles and personal light trucks are shown. Nonpersonal light truck travel is excluded because of inconsistencies in the definition of "local" travel by these vehicles (i.e., all travel by vehicles normally used within 200 mi of their base of operations) as compared with that by personal vehicles (i.e., travel on trips of <100 mi).

As indicated in Table 29 and Fig. 21, local travel, both by auto and personal light truck, grows more rapidly over the projection period than

*It should also be noted that the baseline size classes are based on the EPA subcompact and minicompact (small), compact and intermediate (medium), and full-size (large) classes. Researchers who use alternative groupings (e.g., categorizing compact as "small") may have similar findings that appear inconsistent.

Table 25 ANL-81 Projections of Light Duty Stocks, 1977-2000

Type of Vehicle and Ownership	Stocks (10 ⁶)					Average Annual % Change, 1977-2000
	1977	1980	1985	1990	2000	
Automobile						
Household ^a	91.17	95.32	102.22	110.29	122.93	1.31
Fleet						
4-9 ^b	3.80	3.51	2.73	1.98	0.65	(7.39)
10+ ^b	6.61	7.20	8.25	9.65	12.41	2.78
Total	101.58	106.03	113.20	121.92	135.99	1.28
Light Truck						
Household ^a	19.11	19.90	21.22	25.16	28.64	1.77
Commercial ^c	6.84	7.60	8.89	10.02	11.66	2.35
Government ^a	1.10	1.15	1.20	1.30	1.40	1.05
Total	27.05	28.66	31.31	36.48	41.70	1.90
Total Light Duty	128.63	134.69	144.51	158.40	177.69	1.41

^aEstimated as of late in year shown.

^bEstimated as of Dec. 31 of year shown.

^cEstimated as of July 1 of year shown.

Sources of historical data:

Household autos/light trucks -- U.S. Department of Transportation, Federal Highways Administration, 1977 Nationwide Personal Transportation Study, public use tape.

Fleet autos -- Bobit Publishing Co., Automotive Fleet (April 1981).

Commercial light trucks -- U.S. Department of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey (1981).

Government light trucks -- U.S. General Services Administration, Federal Fleet Management Division, Federal Motor Vehicle Fleet Report (annual). State and local light truck fleet estimated by assuming that 80% of all trucks registered to such users are <10,000 lb gvw. U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, Washington, D.C. (annual).

Fig. 17 Automobile Stocks by Size Class

does intercity travel. This is attributed to the more discretionary nature of long-distance trips and to the increasing cost of travel. Increasing costs are particularly noteworthy through 1985 -- fleet improvement in fuel efficiency is not quite able to keep pace with rising fuel prices over this period. Light trucks are especially affected by rising fuel prices and less-than-comparable fleet fuel-efficiency improvements. Between 1980 and 1985 the fuel efficiency of the light truck fleet improves much less rapidly than that of the automotive fleet, relying primarily on dieselization to achieve significant improvement in fuel efficiency. Consequently, light truck stocks and VMT rise quite slowly over this period. Not until 1990 do personal light trucks compete with some success against automobiles, thereby increasing their numbers and causing a spurt in light truck VMT. Because fuel-efficiency improvements do not keep pace with VMT growth, the energy consumption of light trucks peaks around 1990.

Automobile VMT follows a somewhat different pattern, because VMT grows more steadily and energy consumption declines more steadily throughout the projection period. As seen in Table 30, fleet-average fuel economy improves significantly, reaching nearly 29 mi/gal by year 2000.

Table 30 also shows the projected activity levels, energy consumption and fuel economy of small, medium, and large automobiles over the period. By year 2000, significant diesel penetration occurs in all size classes,

Table 26 Comparison of Projections: Automobile Stocks and Shares by Size Class

Source of Projection	Value					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Stock (10 ⁶)						
ANL-81 ^a	106.0	113.2	121.9	N/A	136.0	1.3
ANL-79	104.6	114.0	121.4	128.8	135.5	1.3
CSSP-80	103.5	113.5	124.5	N/A	147.4	1.8
NEPP-81	104.0	108.0	117.0	N/A	131.0	1.2
OPPE-81	103.3	110.9	121.1	133.5	146.6	1.8
EEA-7/81	104.0	109.1	118.9	127.0	133.0	1.2
DRI-Summer/81	107.2	114.1	124.5	133.3	139.4	1.3
Share of Total (% small/medium/large) ^b						
ANL-81 ^c	27/34/39	26/46/28	28/44/27	N/A	34/40/26	-
ANL-79	N/A	38/25/37	40/25/35	40/25/35	40/25/35	-
CSSP-80	24/46/29	29/49/21	32/50/18	N/A	33/48/20	-

^aEstimate as of late (i.e., Oct.-Nov.) in year shown.

^bMay not add to 100% due to rounding.

^c1978.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

Table 27 Comparison of Projections: Shares of Light Duty Vehicle Stocks or Sales by Engine Technology

Source of Projection	Share of Total (% Otto/Diesel/Other)					Comments
	1980	1985	1990	1995	2000	
Automobile						
ANL-81 ^a	99.3/0.7/0	96.0/4.0/0	90.4/9.5/0.1	N/A	82.4/17.4/0.2	"Other" = EV
CSSP-80 ^b	100/0/0	85/15/0	85/15/0	85/15/0	85/15/0	
EEA-7/81 ^a	99/1/0	94/6/0	83/17/0	76/24/0	73/27/0	
Light Truck						
ANL-81 ^a	100/0/0	97/3/0	90/10/0	N/A	80/20/0	Diesel shares assumed, EVs not considered
CSSP-80 ^b	100/0/0	85/15/0	85/15/0	85/15/0	85/15/0	
EEA-7/81 ^a	100/0/0	96/4/0	88/12/0	81/19/0	77/23/0	

^aShare of stocks.

^bShare of new sales.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

Fig. 18 Automobile and Light Truck Stocks by Engine Technology

including small autos. This occurs as a result of the assumption that, after 1990, a small fuel-efficient diesel automobile will be available. Because this vehicle responds well to consumer preference for small vehicles, the small diesel captures a significant share of the automotive market and thus accounts for a sizable share of VMT by the year 2000.* It should be noted that this market penetration occurs despite relatively high diesel fuel prices.

Tables 31 and 32 and Figs. 23 and 24 compare the ANL-81 baseline projections of auto and light truck VMT and VMT/vehicle with those developed by other researchers. As the tables show, all the projections of VMT/vehicle are reasonably similar, while those of VMT are quite different. In ANL-81, vehicle-miles of auto travel increase at a fairly slow rate over the period.

*In the stock model, the small diesel share was held to a maximum of 8% of the combined auto and van stock to account for a probable constraint on diesel vehicle supply. Were it not for this stock constraint, the diesel share of small auto VMT would have been higher.

Fig. 19 Projections of Automobile Stocks

Although the growth rate of light truck VMT rises considerably faster, it still falls short of the rates projected for light trucks in these other studies. The relatively low VMT growth rates in ANL-81 may be attributed to our different assumptions regarding future fuel prices and relative fuel economies of autos and light trucks. The recent downturn in light truck sales is interpreted as a reaction to their lower fuel economy relative to automobiles, as opposed to a temporary slowdown of a long-term trend. Thus, the slower growth shown in ANL-81 appears quite reasonable.

Tables 33 and 34 and Figs. 25 and 26 compare projections of light duty energy consumption and fleet-average fuel economy from several different sources. Because of post-1990 improvements in fuel economy, the baseline projections (ANL-81) show a continuing increase in fuel economy to year 2000, as well as a continuing decline in fuel consumption. Overall, light truck consumption under the baseline scenario is less than that projected by most other sources due to these assumed fuel-economy improvements, as well as the above-discussed differences in projected stocks and VMT.

Table 28 Comparison of Projections: Light Truck Stocks^a

Source of Projection	Stocks (10 ⁶)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81	28.7	31.3	36.5	N/A	41.7	1.9
ANL-79	26.4	33.5	37.2	40.8	43.2	2.5
CSSP-80	25.4	34.9	42.1	N/A	58.5	4.3
NEPP-81	28	32	38	N/A	47	2.6
OPPE-81	24.8	28.7	32.9	36.8	42.1	2.7
DRI-Summer/81	30.1	31.6	34.3	37.9	42.3	1.7
EEA-7/81	29.1	34.9	40.1	44.4	49.7	2.7

^aIncludes all trucks <10,000 lb gvwt.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

Fig. 20 Projections of Total Light Truck Stocks

3.3 HEAVY DUTY TRUCKS

3.3.1 Vehicle Stocks

Table 35 shows projected truck stocks by size class, fuel type, and type of travel (see also Figs. 27 and 28). Under the baseline scenario, total vehicle stocks grow by 59% between 1980 and 2000. While stocks used for intercity travel reflect the largest increase (69%), stocks used for local travel also grow substantially (49%). By year 2000, 62% of all heavy duty truck stocks are diesel, and more than half are used for intercity operations. In 1977, only 27% were diesel, and 48% were used for intercity travel.

Table 36 and Fig. 29 compare the new stock projections of ANL-81 with recent forecasts by EEA and DRI as well as with two previous OVERD baselines (ANL-79 and CSSP-80). The most striking feature of this comparison is the similarity between the ANL-79 and CSSP-80 base-year stock totals and their marked dissimilarity to more recent efforts. Both ANL-79 and CSSP-80 used the Transportation Energy Conservation (TEC) model for their truck-stock projections.⁹⁶ The TEC model forecasts future stocks as a function of future economic activity in key truck-using economic sectors and of historical ratios between sectoral output and truck stocks. Because the 1977 TIUS was not available at the time of these analyses, 1977 and 1980 stocks were projected

Table 29 ANL-81 Projections of Auto and Personal Light Truck
VMT and Energy Consumption, 1977-2000

VMT and Energy Use by Trip Length and Type of Vehicle	Historical		Projected		
	1977	1980 ^a	1985	1990	2000
Local (<100 mi)					
Automobile					
VMT (10 ⁶)	1013.977	1011.273	1155.16	1271.225	1392.187
Gal gasoline (10 ⁶)	74.722	72.580	65.165	58.705	49.618
Quads	9.340	9.079	8.182	7.387	6.286
Light truck					
VMT (10 ⁶)	178.518	174.387	197.486	242.138	273.108
Gal gasoline (10 ⁶)	17.816	13.053	12.642	14.500	12.649
Quads	2.227	1.632	1.583	1.824	1.600
Total					
VMT (10 ⁶)	1192.495	1185.659	1352.647	1513.363	1665.295
Gal gasoline (10 ⁶)	92.538	85.633	77.806	73.205	62.267
Quads	11.567	10.696	9.765	9.211	7.886
Inter-city (>100 mi)					
Automobile					
VMT (10 ⁶)	105.681	103.381	107.912	114.857	123.558
Gal gasoline (10 ⁶)	5.571	5.332	4.399	3.847	3.245
Quads	0.696	0.667	0.541	0.488	0.412
Light truck					
VMT (10 ⁶)	19.085	22.905	18.542	22.822	23.005
Gal gasoline (10 ⁶)	1.477	1.337	0.924	1.032	0.790
Quads	0.185	0.167	0.116	0.127	0.100
Total					
VMT (10 ⁶)	124.766	126.286	126.454	137.679	146.563
Gal gasoline (10 ⁶)	7.048	6.669	5.323	4.879	4.035
Quads	0.881	0.846	0.651	0.614	0.512
Total travel					
Automobile					
VMT (10 ⁶)	1119.657	1114.655	1263.072	1386.083	1515.745
Gal gasoline (10 ⁶)	80.293	77.912	69.563	62.552	52.863
Quads	10.036	9.746	8.723	7.875	6.698
Light truck					
VMT (10 ⁶)	197.603	197.292	216.029	264.961	296.113
Gal gasoline (10 ⁶)	19.293	14.390	13.566	15.532	13.475
Quads	2.412	1.800	1.699	1.951	1.700
Total					
VMT (10 ⁶)	1317.261	1311.947	1479.101	1651.044	1811.858
Gal gasoline (10 ⁶)	99.586	92.302	83.129	78.084	66.338
Quads	12.448	11.542	10.422	9.826	8.398

^aEstimated.

Sources of historical data:

VMT by trip length -- U.S. Department of Transportation, Federal Highway Administration, 1977 Nationwide Personal Transportation Study, public use tape.

Total gallons -- Calculated from VMT, assuming fleet-average mi/gal as shown in Table 30.

Gallons by trip length -- Calculated from VMT, assuming fleet average mi/gal of 13.6 and 10.0 for local auto and light truck travel, respectively, and 19.0 and 17.1 for long-distance auto and light truck.

Quads -- Calculated from gallons, assuming 100% gasoline VMT in 1977, 99.3% gasoline VMT in 1980.

Fig. 21 Light Duty Vehicle-Miles, by Trip Length

from a 1972 base. The resulting estimates fall reasonably close to reported Class 7 and 8 stocks, but they are well above total stocks in Classes 3 through 8.

Table 19 showed the growth rates for key truck-dependent sectors under the CSSP-80 and ANL-81 baseline scenarios. As a result of significant differences in many of these growth rates, truck stocks grow somewhat slower in ANL-81 than in CSSP-80. Coupled with the above-noted discrepancy in base-year stocks, this results in significantly elevated stock projections under CSSP-80 as compared with ANL-81. Moreover, because stock projections are linked to transportation activity and energy projections, the high stock projections under CSSP-80 produce high activity and energy projections as well.

3.3.2 Activity

Over the projection period, truck activity, measured in vehicle-miles of travel (VMT), rises by 68%. As with vehicle stocks, the largest increases occur in intercity operations. These results may be seen in Table 37 and Fig. 30.

Intercity truck ton-miles of travel (TMT) grow by a comparable margin between 1980 and 2000. Table 38 presents these results by truck size class.

Fig. 22 Light Duty Energy Consumption, by Trip Length

Tables 39 and 40 and Figs. 31 and 32 compare the current report's baseline projections of truck VMT and VMT/vehicle against those of other efforts. While VMT rises more rapidly than do stocks over the projection period, it fails to match the comparable levels projected under ANL-79 and CSSP-80.* Although the ANL-81 VMT projection exceeds the EEA projection for all years shown, it grows at a slower rate, a fact directly attributable to the relatively modest economics of the baseline scenario and the constant mode splits within commodity sectors. VMT/vehicle grows marginally over the projection period.

3.3.3 Energy Consumption

Overall, the energy consumed by commercial trucks is projected to rise by 41% (1.7%/yr) between 1980 and 2000 (see Table 41 and Fig. 33). This relatively modest growth is a direct result of significant improvements in energy intensity, particularly among local trucks. While the fuel consumed by intercity trucks grows by 63% over the period, consumption by local trucks

*Originally, the CSSP-80 study's VMT projection was considerably higher (U.S. DOE Office of Planning and Evaluation, Conservation and Solar Strategy Paper, June 1980). When the truck projections were revised in late 1980, VMT per vehicle was reduced substantially to the CCSP-80 values shown in Table 40. Hence, VMT is not nearly as high under CSSP-80 as under ANL-79.

Table 30 ANL-81 Projections of VMT and Energy Use by
Type of Light Duty Vehicle -- 1977-2000

VMT and Energy Use by Type of Vehicle	Historical		Projected		
	1977	1980 ^a	1985	1990	2000
Auto (multipurpose)					
Small ICE ^b					
VMT (10 ⁹)	263.119	312.738	357.241	415.665	540.551
Diesel VMT (%)	-	-	-	0.1	23.9
Gal gasoline (10 ⁹)	14.447	17.168	16.283	15.185	12.694
Gal diesel (10 ⁹)	-	-	-	0.582	2.637
Quads petroleum	1.806	2.146	2.035	1.979	1.952
Average mi/gal	18.20	18.22	21.94	26.36	35.25
Medium ICE ^b					
VMT (10 ⁹)	352.692	381.594	578.572	615.650	610.209
Diesel VMT (%)	-	2.0	5.5	10.7	13.2
Gal gasoline (10 ⁹)	23.941	25.591	30.857	26.116	19.944
Gal diesel (10 ⁹)	-	0.289	1.258	2.066	2.329
Quads petroleum	2.992	3.239	4.031	3.553	2.816
Average mi/gal	14.73	14.74	18.01	21.84	27.40
Large ICE ^b					
VMT (10 ⁹)	503.846	420.321	327.258	353.614	363.427
Diesel VMT (%)	-	-	5.9	11.6	14.3
Gal gasoline (10 ⁹)	41.912	34.864	20.404	17.323	13.750
Gal diesel (10 ⁹)	-	-	0.762	1.280	1.508
Quads petroleum	5.238	4.361	2.656	2.343	1.928
Average mi/gal	12.02	12.06	15.46	19.01	23.82
Electric					
VMT	-	-	-	1.109	1.558
Quads electricity	-	-	-	0.0017	0.0018
Total					
VMT (10 ⁹)	1119.657	1114.655	1263.072	1386.083	1515.745
Diesel VMT (%)	-	0.7	4.1	9.1	17.3
Elec. VMT (%)	-	-	-	0.08	0.10
Gal gasoline (10 ⁹)	80.300	77.623	67.543	58.624	46.389
Gal diesel (10 ⁹)	-	0.289	2.020	3.928	6.474
Quads petroleum	10.037	9.746	8.723	7.875	6.698
Average mi/gal, ICE	13.94	14.31	18.16	22.14	28.64
Quads electricity	-	-	-	0.0017	0.0018
Light Truck					
Personal					
VMT (10 ⁹)	197.603	197.292	216.029	264.961	296.113
Diesel VMT (%)	-	0.2	3.0	8.0	15.0
Gal gasoline (10 ⁹)	19.297	14.372	13.334	14.81	11.980
Gal diesel (10 ⁹)	-	0.016	0.232	0.722	1.495
Quads	2.412	1.802	1.699	1.951	1.700
Average mi/gal	10.24	13.71	15.92	17.05	21.97
Commercial and Government					
VMT (10 ⁹)	69.846	77.171	90.548	104.851	127.138
Diesel VMT (%)	-	0.6	4.6	13.2	25.9
Gal gasoline (10 ⁹)	6.821	7.250	7.136	6.558	5.900
Gal diesel (10 ⁹)	-	0.029	0.226	0.649	1.373
Quads	0.853	0.910	0.923	0.910	0.928
Average mi/gal	10.24	10.60	12.30	14.55	17.48
Total					
VMT (10 ⁹)	267.448	274.463	306.577	369.812	423.251
Diesel VMT (%)	-	0.3	3.5	9.5	18.2
Gal gasoline (10 ⁹)	26.118	21.622	20.470	21.368	17.880
Gal diesel (10 ⁹)	-	0.045	0.458	1.371	2.868
Quads	3.265	2.712	2.622	2.861	2.628
Average mi/gal	10.24	12.67	14.65	16.26	20.40

Table 30 (Cont'd)

VMT and Energy Use by Type of Vehicle	Historical		Projected		
	1977	1980 ^a	1985	1990	2000
Subtotal: Auto and Personal Light Truck					
VMT (10 ⁹)	1317.261	1311.947	1479.101	1651.044	1811.858
Gal gasoline (10 ⁹)	99.597	91.995	80.877	73.434	58.369
Gal diesel (10 ⁹)	-	0.305	2.252	4.650	7.969
Quads	12.449	11.545	10.422	9.826	8.398
Total: Light Duty Vehicle					
VMT (10 ⁹)	1387.107	1389.118	1569.649	1755.895	1938.996
Gal gasoline (10 ⁹)	106.418	99.245	88.013	79.992	64.269
Gal diesel (10 ⁹)	-	0.334	2.478	5.299	9.342
Quads	13.302	12.455	11.345	10.738	9.328

^aANL estimate.^bInternal combustion engine.

Sources of historical data:

Auto VMT by size class and personal light truck VMT -- U.S. Department of Transportation, Federal Highway Administration, 1977 Nationwide Personal Transportation Study, public use tape.

Commercial light truck VMT -- U.S. Department of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey, Washington, D.C. (1980).

Government light truck VMT -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979). Totals include federal civilian VMT as reported by the General Services Administration as well as approximately 80% of the state and local truck VMT.

Automotive energy -- Calculated from VMT and assuming fleet-average mi/gal of 13.94. U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 1977, Washington, D.C. (1978).

Light truck energy -- Calculated from VMT, assuming fleet-average mi/gal of 10.24, an ANL estimate based on Energy and Environmental Analysis, The Highway Fuel Consumption Model, Fourth Quarterly Report, Washington, D.C. (1981); and William F. Gay, National Transportation Statistics, U.S. Department of Transportation, Transportation Systems Center (Sept. 1980).

grows by only 23%. Local trucking operations benefit not only from increased dieselization and the penetration of various fuel-saving devices into the new fleet, but also from a "trickle down" effect as more efficient intercity vehicles eventually enter the local fleet.*

Within the two areas of operation, there are also significant differences in energy growth rates by vehicle size. In local trucking operations, the energy consumed by heavier trucks grows most rapidly, as truckers shift to larger vehicles. Intercity operations reflect a slightly different pattern, with fuel efficiency tending to improve somewhat faster in the smaller sizes (from the combination of improved fuel efficiency and increased dieselization) -- but with VMT growing at fairly uniform rates across all three sizes. As a result, the energy consumed by heavier trucks grows at a slightly faster rate than does total energy consumed by all commercial trucks.

*A third factor explaining the much slower growth of energy consumption by local trucks is the slower growth in local truck VMT (see the preceding discussion). Note that all these VMT and energy-consumption growth rates exclude personal trucks.

Table 31 Comparison of Projections: Vehicle-Miles Traveled by Type of Light Duty Vehicle

Source of Projection by Vehicle Type	VMT (10 ⁹)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Automobile						
ANL-81	1115	1263	1386	N/A	1516	1.5
ANL-79	N/A	1364	1518	1666	1815	2.2
CSSP-80	1207	1297	1437	N/A	1693	1.8
EIA-81	1130	N/A	N/A	1596	N/A	2.3
EIA-80	1194 ^a	1184	1364	1474	N/A	1.2
NEPP-81	1097	1224	1371	N/A	1601	1.9
OPPE-81	1229	1343	1509	1680	1878	2.1
EEA-7/81	1097	1207	1315	1398	1454	1.4
DRI-Summer/81	1126	1272	1397	1503	1637	1.9
TSC/EIA-81	1112	1210	1356	1501	1564	1.7
Light Truck ^b						
ANL-81	274	307	370	N/A	423	2.2
ANL-79	N/A	395	460	528	584	2.6
CSSP-80	297	377	454	N/A	473	3.9
EIA-80 ^c	281 ^c	314	366	415	N/A	2.3
NEPP-81	244	311	375	N/A	482	3.5
OPPE-81	294	326	369	413	473	2.4
EEA-7/81	263	338	406	451	505	3.3
TSC/EIA-81	275	293	311	333	367	1.5

^a1978

^b<10,000 lb gw.

^cIncludes motorcycles.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

EIA-81 -- U.S. Department of Energy, Energy Information Administration, 1981 Annual Report to Congress, Volume 3: Energy Projections, Washington, D.C., DOE/EIA-0173(81)/3 (Feb. 1982).

TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).

EIA-80 -- U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Volume 3: Forecasts, Washington, D.C., DOE/EIA-0173(80)/3 (March 1981).

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to the National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

Table 32 Comparison of Projections: Annual VMT Per Vehicle

Source of Projection by Vehicle Type	Annual VMT/Vehicle (10 ³)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Automobile						
ANL-81	10.5	11.2	11.4	N/A	11.2	0.3
ANL-79	N/A	12.0	12.5	12.9	13.4	0.9
CSSP-80	11.7	11.5	11.5	11.5	11.5	(0.1)
NEPP-81	10.5	11.3	11.7	N/A	12.3	0.8
OPPE-81	11.9	12.1	12.5	12.6	12.8	0.4
EEA-7/81	10.5	11.2	11.2	11.2	11.1	0.3
DRI-Summer/81	10.5	11.1	11.2	11.3	4.7	0.5
Light Truck ^a						
ANL-81	9.6	9.8	10.1	N/A	10.1	0.3
ANL-79	N/A	11.8	12.4	12.9	13.5	0.9
CSSP-80	11.7	11.4	10.8	N/A	10.9	(0.4)
NEPP-81	8.7	9.7	9.9	N/A	10.2	0.8
OPPE-81	11.9	11.5	11.5	11.9	12.1	0.1
EEA-7/81	9.3	9.8	9.8	9.7	9.6	0.3

^a<10,000 lb gvw.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1981).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

Fig. 23 Projections of Light Duty Vehicle-Miles Traveled

Table 42 and Fig. 34 compare the projection of heavy truck energy use with the previous OVERD baselines and the recent EEA projection. Because of the above-discussed differences in projected stocks and VMT, the new baseline is significantly lower than its predecessors. But Table 42 also shows the new baseline is fairly similar to the EEA projection.

3.4 BUSES

3.4.1 School Bus

Table 43 shows projected school bus stocks, activity, and energy consumption through year 2000. Total stocks grow by 36% over the period. Most of this growth occurs in diesel stocks, which increase from an insignificant share in 1980 to more than a third of the fleet in 2000. This is a result of the dieselization assumptions in the baseline scenario.

Fig. 24 Projections of Light Duty Vehicle-Miles Traveled per Vehicle

The diesel share of school bus vehicle-miles (VMT) grows still faster over this period, rising from 2% in 1980 to 46% in 2000. This occurs because of the higher utilization (i.e., VMT/vehicle) assumptions for diesel vehicles. Diesel technology is assumed to be most attractive for vehicles with the greatest utilization. As fuel prices rise and the most intensively used vehicles are replaced with diesels, diesels may be expected to begin replacing vehicles that are less intensively used. Thus, the average utilization of all diesel school buses will decline over time.

Between 1980 and 2000, school bus energy consumption rises by 22%. In year 2000, 40% of the fuel consumed is diesel.

Table 33 Comparison of Projections: Energy Consumption
by Type of Light Duty Vehicle

Source of Projection by Vehicle Type	Energy Consumption (quads)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Automobile						
ANL-81	9.75	8.72	7.88	N/A	6.70	(1.9)
ANL-79	N/A	9.2	8.8	9.3	10.1	(0.3)
CSSP-80	9.0	7.7	7.1	N/A	7.7	(0.8)
NEPP-81	9.1	8.0	7.0	N/A	6.9	(1.4)
OPPE-81	9.71	8.89	8.05	8.16	9.14	(0.3)
TSC/EIA-81	8.73	7.34	6.45	5.84	5.57	(2.3)
EEA-7/81	9.38	7.65	6.38	5.97	6.18	(2.1)
DRI-Summer/81	8.92	7.74	7.23	6.95	6.86	(1.3)
Light Truck ^a						
ANL-81	2.71	2.62	2.86	N/A	2.63	(0.2)
ANL-79	N/A	3.17	3.28	3.64	3.89	2.3
CSSP-80	2.7	3.0	3.3	N/A	4.1	2.1
NEPP-81	2.5	2.8	3.0	N/A	3.1	1.1
OPPE-81	2.72	2.73	2.89	3.12	3.69	1.5
TSC/EIA-81	2.43	2.23	2.00	1.75	1.73	(1.7)
EEA-7/81	3.34	3.33	3.06	2.97	3.19	(0.2)

^a<10,000 lb gvwt.

- Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).
- CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.
- NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).
- OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).
- TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).
- EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).
- DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

Table 34 Comparison of Projections: Fleet-Average On-the-Road Fuel Economy by Type of Light Duty Vehicle

Source of Projection by Vehicle Type	Fuel Economy (mi/gal)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Automobile						
ANL-81 ^a	14.3	18.2	22.1	N/A	28.6	3.5
ANL-79	N/A	18.5	21.5	22.5	22.5	1.9
CSSP-80	16.7	21.0	25.3	27.1	27.4	2.5
NEPP-81	15.1	19.3	24.8	N/A	29.7	3.4
EIA-81	15.3	N/A	N/A	26.8	N/A	3.8
EIA-80	14.3 ^b	18.4	22.3	25.5	N/A	3.5
OPPE-81	15.8	19.7	24.7	27.5	28.6	3.0
TSC/EIA-81	15.9	20.6	25.9	31.2	34.7	4.0
EEA-7/81	15.1	20.5	28.1	33.3	34.9	4.3
	20.4 ^c	28.6 ^c	35.1 ^c	35.1 ^c	35.1 ^c	2.7 ^c
DRI-Summer/81	15.8	20.6	24.3	27.3	30.1	3.3
	18.4 ^c	24.1 ^c	25.9 ^c	27.9 ^c	29.6 ^c	2.5 ^c
Mellon-81 ^d	20.7 ^c	32.2 ^c	37.9	41.8 ^c	46.6 ^c	4.1
Light Truck						
ANL-81 ^e	12.7	14.6	16.3	N/A	20.4	2.4
ANL-79	N/A	15.6	17.3	18.2	19.1	2.0
CSSP-80	13.7	15.6	17.7	18.9	19.3	1.7
	14.4 ^c	17.7 ^c	20.2 ^c	20.2 ^c	20.2 ^c	1.7 ^c
NEPP-81	12.1	14.1	16.9	N/A	19.9	2.5
EIA-80 ^f	10.1 ^b	12.5	14.1	15.7	N/A	2.6
OPPE-81	13.5	15.8	17.1	18.2	18.6	1.6
TSC/EIA-81	14.1	16.4	19.4	23.7	26.6	3.2
EEA-7/81	10.6	13.1	16.6	19.5	21.0	3.5
DRI-Summer/81	10.9	12.4	14.1	15.5	16.8	2.2
Mellon-81 ^g	15.4 ^c	19.4 ^c	21.1 ^c	22.2 ^c	23.5 ^c	2.1 ^h

^aExcludes electric vehicles.

^b1978.

^cNew vehicles..

^dEPA test, no mix shift. Domestic and import fuel economy assumed comparable.

^ePersonal light trucks only.

^fSingle-unit trucks.

^gDomestic only; imports achieve better fuel economy. EPA test mpg.

^h1985-2000.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EIA-81 -- U.S. Department of Energy, Energy Information Administration, 1981 Annual Report to Congress, Volume 3: Energy Projections, Washington, D.C., DOE/EIA-0173(81)/3 (Feb. 1982).

TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).

EIA-80 -- U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Volume 3: Forecasts, Washington, D.C., DOE/EIA-0173(80)/3 (March 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

Mellon-81 -- R. Shackson and H.J. Leach, Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete with OPEC Oil, The Energy Productivity Center, Mellon Institute, Arlington, Va. (Aug. 1980).

Fig. 25 Projections of Energy Consumption by Light Duty Vehicles

3.4.2 Transit Bus

Between 1980 and 2000, transit stocks and activity rise by 30%. These parameters grow at a comparable rate because vehicle utilization (vehicle-miles/vehicle) and average load (passenger-miles/vehicle-mile) are assumed to remain constant over time. Since fuel efficiency is assumed to decline from its estimated 1980 level of approximately 3.6 mi/gal to 3.3 mi/gal by 1985, the energy consumed by transit buses is projected to increase by 42% over the period (see Table 44).

3.4.3 Intercity Bus

As stated previously, passenger-miles of travel by intercity buses were projected as part of the POINTS intercity passenger model. Table 45 shows that between 1977 and 2000, bus PMT and VMT rise by 43% and 36%, respectively. VMT rises at a somewhat slower rate than PMT because load factors (passenger-miles/vehicle-mile) are assumed to increase over time. Vehicle stocks grow as

Fig. 26 Projections of Fuel Economy of Light Duty Vehicles

a result of increased VMT, which is assumed to reach a steady annual value of 55-57,000 mi/vehicle.

Between 1977 and 2000, intercity bus PMT increases more rapidly than intercity auto and rail PMT, and about as rapidly as domestic air PMT. This is attributable to the fuel-cost assumptions of the baseline scenario. In 1980, fuel represented approximately 9% of the operating cost of intercity buses.⁶⁶ Assuming that all other cost elements (such as labor, capital, and maintenance) increase with inflation and intercity buses become 10% more fuel-efficient, real bus fares (as measured by yield or revenue per revenue passenger-mile) may be expected to rise to 112% of their 1977 levels by the year 2000. This is in marked contrast to auto and rail costs. Because fuel represents nearly 70% of out-of-pocket costs for autos,⁸⁴ rising fuel prices are projected to increase auto travel costs in year 2000 to 135% of their 1977 levels.* Rail travel costs may be expected to increase comparably. While fuel accounts for a minor portion of rail costs (as with buses, it

*This increase occurs despite significant fuel economy improvements.

Table 35 ANL-81 Projections of Heavy Duty Truck Stocks by Travel Distance, Fuel Type, and Size Class -- 1977-2000^a (10³)

Truck Size by Travel Distance and Type of Fuel	Historical		Projected			
	1977	1980 ^b	1985	1990	1995	2000
Local (<200 mi) ^c						
Gasoline						
Medium	1059.54	1173.45	1300.95	1264.11	1169.83	1158.75
Heavy	586.95	641.06	679.67	641.98	570.60	542.27
Heavy-Heavy	419.12	228.75	152.97	69.58	27.00	7.59
Total	2065.61	2043.26	2133.59	1975.67	1767.43	1708.61
Diesel						
Medium	13.96	15.46	84.51	294.60	510.96	663.18
Heavy	25.09	35.16	106.08	241.07	380.40	488.66
Heavy-Heavy	331.99	606.10	827.63	1034.80	1147.06	1257.15
Total	371.04	656.72	1018.22	1570.47	2038.42	2408.99
Total						
Medium	1073.50	1188.91	1385.46	1558.71	1680.79	1821.93
Heavy	612.04	676.22	785.75	883.05	951.00	1030.93
Heavy-Heavy	751.11	834.85	980.60	1104.38	1174.06	1264.74
Total	2436.65	2699.98	3151.81	3546.14	3805.85	4117.60
Intercity (>200 mi)						
Gasoline						
Medium	772.53	911.93	1123.30	1119.83	1002.01	1008.02
Heavy	529.87	613.79	729.47	711.87	608.47	586.99
Heavy-Heavy	30.49	17.39	12.58	5.84	3.03	0.00
Total	1332.89	1543.11	1865.35	1837.54	1613.51	1595.01
Diesel						
Medium	11.77	13.89	73.33	264.38	439.73	379.41
Heavy	82.70	104.09	205.75	373.30	516.25	651.39
Heavy-Heavy	793.59	948.86	1245.24	1433.42	1509.66	1665.55
Total	888.06	1066.84	1526.52	2091.10	2465.64	2896.35
Total						
Medium	784.30	925.82	1198.83	1384.21	1441.74	1587.43
Heavy	612.57	717.88	935.22	1085.17	1124.72	1238.38
Heavy-Heavy	824.08	966.25	1257.82	1459.26	1512.69	1665.55
Total	2220.95	2609.95	3391.82	3928.64	4079.15	4491.36
Total						
Gasoline						
Medium	1832.07	2085.38	2424.25	2383.94	2171.84	2166.77
Heavy	1116.82	1254.85	1409.14	1353.85	1179.07	1129.26
Heavy-Heavy	449.61	246.14	165.55	75.42	30.03	7.59
Total	3398.50	3586.37	3998.94	3813.21	3380.94	3303.62
Diesel						
Medium	25.73	29.35	160.04	558.98	950.69	1242.59
Heavy	107.79	139.25	311.83	614.37	896.65	1140.05
Heavy-Heavy	1125.58	1554.96	2072.87	2488.22	2656.72	2922.70
Total	1259.10	1723.56	2544.74	3661.57	4504.06	5305.34
Total						
Medium	1857.80	2114.73	2584.29	2942.92	3122.53	3409.36
Heavy	1224.61	1394.10	1720.97	1968.22	2075.72	2269.31
Heavy-Heavy	1575.19	1801.10	2238.42	2563.64	2686.75	2930.29
Total	4657.60	5309.93	6543.68	7474.78	7885.00	8608.96

^aExcludes commercial and government light trucks (See Table 25).

^bEstimated.

^cExcludes government and military heavy trucks.

Source of historical data: U.S. Department of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey, Washington, D.C. (1981).

Fig. 27 Heavy Duty Truck Stocks by Size Class

represents <10%), Amtrak's stated policy of recovering a larger share of operating expenses from passenger revenues may be expected to result in steadily increasing fares (see Sec. 3.5.1). As a consequence of auto and rail cost increases, buses attract a larger portion of those travelers whose value of time (i.e., time-value of money) is on the low end of the distribution.

3.5 RAIL

3.5.1 Rail Passenger

As shown in Table 46, rail passenger activity is projected to decline between 1980 and 2000. This is a direct result of Amtrak's stated policy of increasing the percentage of operating expenses recovered from passenger revenues.

Because automobile costs rise more slowly than rail fares, rail steadily loses passenger traffic. As the values in Table 46 indicate, rail PMT declines by 9% between 1980 and 1985, by another 9% between 1985 and 1990, and by 19% between 1990 and 2000. Overall, the rate of traffic decline is on the order of 2%/yr throughout the projection period.

Fig. 28 Heavy Duty Truck Stocks by Travel Distance and Engine Technology

3.5.2 Rail Freight

Table 47 lists the major commodities moved by rail, along with statistics on their 1980 activity levels. Coal dominates current rail freight activity and will probably continue to do so because this sector is expected to grow nearly as fast as most of the other sectors shown in the table. According to the DRI economic forecast, coal output is expected to grow some 70% over the next 20 years. Because most of this growth is likely to come from western lignites with relatively long average lengths of haul, the impact on rail ton-miles may be expected to be still greater.

The other bulk commodity sectors shown on Table 47 may be expected to continue to rely on rail service. The mode split for manufactured commodity sectors, however, is more problematical. As stated previously, commodity mode splits are held constant in the baseline scenario. While this is not necessary from the standpoint of the model, it is a convenience that was adopted because the results of the 1977 Commodity Transportation Survey were not available at the time of this writing. Thus, 1963-1972 trends in mode split by manufactured commodity sectors could not be confirmed in a post-1973 environment (actually, post-1979 would be preferable). Between 1963 and 1972, a growing proportion of manufactured-product hauls was shifted from rail to truck. Typically characterized by short distances and low volume, these hauls

Table 36 Comparison of Projections: Heavy Duty Truck Stocks

Source of Projection, Two Categories	Stocks (10 ⁶)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
Total Heavy Duty Truck ^a						
ANL-81	5.31 ^b	6.54	7.47	7.89	8.61	2.4
ANL-79	N/A	8.25	9.28	10.55	10.76	2.0
CSSP-80 ^c	7.16	8.12	9.16	N/A	12.68	2.9
NEPP-81	4.5	4.3	4.5	N/A	5.2	0.8
EEA-7/81	4.45	4.37	4.61	4.68	4.97	0.6
DRI-Summer/81	4.7	4.9	5.0	5.1	5.5	0.5
Heavy-Heavy Truck Only ^d						
ANL-81	1.80 ^b	2.24	2.56	2.69	2.93	2.5
ANL-79	N/A	2.15	2.55	3.22	3.22	2.6
CSSP-80	N/A	N/A	N/A	N/A	N/A	N/A
OPPE-81	1.66	2.01	2.42	2.90	3.49	3.8
EEA-7/81	1.88	2.32	2.96	3.31	3.75	3.5

^aClasses 3 through 8.^bEstimated.^cCalculated from heavy truck VMT and VMT/vehicle.^dClasses 7 and 8.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

OPPE-81 -- R.W. Barnes et al., unpublished information, Oak Ridge National Laboratory (Feb. 1982).

Fig. 29 Projections of Heavy Duty Truck Stocks

of manufactured goods are among the more energy-intensive rail movements. In fact, for such commodities as basic textiles, apparel, rubber and plastic products, and communications and electrical products, rail energy intensities are comparable to truck energy intensities. Shifts from rail to truck are thus not necessarily energy-inefficient.

Since the baseline scenario does not permit mode shifts over time, these movements continue to utilize rail. Moreover, because manufactured-commodity sectors grow faster than bulk-commodity sectors, their continued rail utilization offsets the modal-efficiency improvement from increased coal traffic. Thus, rail energy intensity remains quite stable under the baseline scenario.

Table 48 presents the resulting projections of rail freight ton-miles and energy consumption. Tables 49 and 50 and Figs. 35 and 36 compare these projections with the results of other studies.

Table 37 ANL-81 Projections of Commercial Truck Vehicle-Miles
by Type of Travel and Size Class, 1977-2000 (10⁹)

Truck Size Class by Type of Travel	Historical		Projected			
	1977	1980 ^a	1985	1990	1995	2000
Local						
Light ^b	60.56	67.36	79.89	92.82	102.62	113.15
Medium	8.28	9.18	10.94	13.05	14.79	16.43
Heavy	5.24	5.83	7.14	8.70	10.04	11.31
Heavy-Heavy	11.52	15.45	19.43	23.03	25.00	27.17
Total ^c	85.60	97.81	117.39	137.59	152.45	168.06
Intercity						
Medium	17.02	20.09	26.02	30.04	31.29	34.46
Heavy	14.33	16.79	21.88	25.38	26.31	28.97
Heavy-Heavy	50.51	59.23	77.10	89.45	92.72	102.09
Total ^c	81.86	96.11	125.00	144.87	150.32	165.52
Total						
Light ^b	60.56	67.36	79.89	92.82	102.62	113.15
Medium	25.30	29.27	36.96	43.09	46.08	50.89
Heavy	19.57	22.62	29.02	34.08	36.35	40.28
Heavy-Heavy	62.03	73.68	96.53	112.48	117.72	129.26
Total ^c	167.46	193.94	242.39	282.47	302.77	333.58

^aEstimated.

^bThese commercial light trucks also appear in a composite use class in Table 30.

^cMay not add due to rounding.

Source of historical data: U.S. Department of Congress, Bureau of the Census, 1977 Truck Inventory and Use Survey, Washington, D.C. (1981).

3.6 MARINE

3.6.1 Waterborne Freight

Energy commodities represent the vast majority of domestic waterborne freight, accounting for nearly two-thirds of all maritime ton-miles of travel. This may be seen in Table 51, which lists the major commodities moved in domestic waterborne commerce, their 1980 TMT, and their shares of total marine TMT. Clearly, petroleum products dominate maritime movements. In the DRI forecast, petroleum products experience little economic growth over the projection period. This in turn affects projections of maritime activity and energy consumption.

Fig. 30 Heavy Duty Truck VMT by Size Class and Fuel Type

Table 38 ANL-81 Projections of Intercity Truck Ton-Miles by Size Class, 1977-2000 (10⁹)

Size Class	1977	1980 ^a	1985	1990	1995	2000
Medium (Class 3)	22.81	24.32	29.66	33.05	35.67	39.28
Heavy (Classes 4-6)	114.06	121.57	148.32	165.24	178.37	196.40
Heavy-Heavy (Classes 7,8)	433.41	461.98	563.60	627.93	677.81	746.30
Total	570.28	607.87	741.58	862.22	891.85	981.98

^aEstimated.

Source of historical data: U.S. Department of Commerce, Bureau of the Census, 1977 Truck Inventory and Use Survey, Washington, D.C. (1981).

Table 39 Comparison of Projections: Heavy Duty Truck^a
Vehicle-Miles of Travel

Source of Projection	VMT (10 ⁹)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81	126.6	162.5	189.6	200.1	220.4	2.8
ANL-79	N/A	259.8	301.1	342.6	390.2	4.2
CSSP-80	135.2	153.4	172.9	N/A	239.5	2.9
NEPP-81	90	108	126	N/A	155	2.8
EIA-80 ^b	67	80	95	109	N/A	3.1
EEA-7/81	89.5	109.75	133.48	150.42	176.83	3.5
DRI-Summer/81 ^c	370.6	395.6	419.8	449.1	494.6	1.5

^aClasses 3-8.

^bCombination trucks.

^cVMT projected for all trucks, including light trucks.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981)
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NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EIA-80 -- U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Volume 3: Forecasts, Washington, D.C., DOE/EIA-0173(80)/3 (March 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

DRI-Summer/81 -- Data Resources, Inc., Energy Review, Lexington, Mass. (June 1981).

Table 40 Comparison of Projections: Heavy Duty Truck^a
Vehicle-Miles Per Vehicle

Source of Projection	VMT/Vehicle (10 ³)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81	23.84	24.83	25.37	25.38	25.60	0.4
ANL-79	N/A	31.49	32.44	32.47	36.27	1.2
CSSP-80	18.90	18.89	18.89	18.88	18.89	0
NEPP-81	20.0	25.1	28.0	N/A	29.8	2.0
EEA-1/81	20.12	25.29	29.93	32.21	34.14	2.7
OPPE-81 ^b	37.35	35.92	34.82	33.75	33.92	(0.5)

^aClasses 3-8.

^bDiesel classes 7 and 8 only.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

Fig. 31 Projections of Heavy Duty Truck Vehicle-Miles Traveled

Within the FRATE model, commodity-sector projections of aggregate maritime activity (in ton-miles) are disaggregated by vessel type and area of operation. Three operating areas are specified internally in FRATE: inland waterway, Great Lakes, and coastal.* Within each of these operating areas are predominant vessel types, or submodes, each of which has specialized functions and, consequently, unique energy intensities.** The inland waterways fleet consists largely of barges lashed to tug-towboats, while the Great Lakes fleet includes dry bulk vessels, tankers, and tug-towboats. The coastal fleet is predominantly tug-towboats and tankers. Although various other vessels are utilized in each area of operation, most maritime activity is confined to the vessels listed above, and hence they are the only marine submodes specified in the FRATE model.

*A fourth area, foreign trade, is estimated exogenously based on overall projections of economic growth under the baseline scenario. Foreign trade is not included in the FRATE model because of generally unreliable ton-mile data, wide variations in average length of haul by commodity sector, and the lack of any "driver" for projecting the volume and composition of imports.

**For example, the energy intensities of tug-towboats in coastal versus inland operations have been estimated at 278 and 481 Btu/TMT, respectively. Likewise, Great Lakes tankers are known to be less energy-efficient than their generally larger counterparts in coastal operations.⁹²

Fig. 32 Projections of Heavy Duty Truck Vehicle-Miles Per Vehicle

Table 52 shows projected ton-miles by area of operation and vessel type. Under the baseline scenario, all areas of operation and vessel types are assumed to maintain a constant share of maritime activity. Thus, coastal movements, which constituted more than 57% of domestic maritime activity in the base year, maintain that share throughout the projection period; likewise, inland and Great Lakes movements maintain 9% and 34% shares, respectively.

Table 53 presents projections of total energy consumption by vessels engaged in domestic trade, as well as U.S. fuel purchases by vessels engaged in foreign trade. For domestic trade, it is disaggregated by area of operation and vessel type; for foreign trade, consumption is disaggregated by U.S. flag and foreign flag. Fuel purchased abroad by U.S. flag vessels is not projected. However, it may be estimated as approximately 1.38 times U.S. consumption.⁹⁷ Again, the distribution across areas of operation and vessel types is held constant in the baseline scenario.

3.6.2 Recreational Boating

The energy consumed by recreational boating is projected to grow at an average annual rate of 2.4%, from approximately 0.18 quads in 1980 to 0.29 quads in year 2000. This is somewhat faster than anticipated growth in future

Table 41 ANL-81 Projections of Commercial Truck Energy Consumption by Size Class and Type of Travel, 1977-2000 (quads)

Truck Size Class by Type of Travel	Historical		Projected			
	1977 ^a	1980 ^a	1985	1990	1995	2000
Local						
Light ^b	0.760	0.821	0.840	0.823	0.814	0.853
Medium	0.132	0.135	0.150	0.167	0.179	0.196
Heavy	0.118	0.121	0.138	0.156	0.170	0.188
Heavy-Heavy	0.362	0.441	0.510	0.561	0.584	0.628
Total ^c	1.373	1.519	1.638	1.707	1.747	1.866
Intercity						
Medium	0.239	0.260	0.323	0.375	0.416	0.473
Heavy	0.323	0.351	0.446	0.520	0.575	0.656
Heavy-Heavy	0.669	0.701	0.832	0.889	0.918	1.008
Total ^c	1.230	1.312	1.600	1.784	1.909	2.136
Total						
Light	0.760	0.821	0.840	0.823	0.814	0.853
Medium	0.371	0.395	0.473	0.542	0.595	0.669
Heavy	0.441	0.472	0.584	0.676	0.745	0.844
Heavy-Heavy	1.031	1.142	1.342	1.450	1.502	1.636
Total ^c	2.603	2.830	3.239	3.491	3.656	4.003

^aCalculated from historic activity levels (See Tables 37 and 38) and energy intensity.

^bCommercial use only.

^cMay not add due to rounding.

stocks, because stock growth was assumed to be concentrated in larger, relatively less energy-efficient engine sizes. Recent trends in the recreational boating industry support this assumption. While unit sales have remained fairly static over the past several years, stocks have been growing, particularly in the larger engine sizes. Due to fairly low scrappage, this trend may be expected to continue.

3.6.3 Total Maritime Energy Consumption

Table 54 and Fig. 37 compare the new projections of total marine energy consumption (i.e., domestic waterborne freight plus recreational boating) with the previous baseline projections. The new projections are somewhat lower than the earlier projections, primarily as a result of reduced growth in petroleum-product shipments (see above discussion) and generally more modest economic assumptions.

Fig. 33 Heavy Duty Truck Energy Use by Size Class and Fuel Type

3.7 AIR

3.7.1 Air Freight

Commodities transported by air are typically time-sensitive and of high value. In 1980, more than 70% of air ton-miles came from three sectors: wholesale/retail trade, business/personal services, and postal services. Postal shipments generally are transported in the lower hold, or belly, of passenger aircraft, while shipments from the business/personal services and wholesale/retail trade sectors often move on all-cargo aircraft.

Because of major differences in energy intensities between passenger aircraft carrying belly cargo and all-cargo aircraft, air freight is divided into belly-cargo and all-cargo submodes within FRATE. Commodity-sector energy intensities are assigned on the basis of this submodal split. Thus, commodity sectors that rely exclusively on all-cargo aircraft could be assigned energy intensities of more than 26,000 Btu/TMT, while those completely dependent on belly cargo could have energy intensities of as low as 3300 Btu/TMT.*40

*This large disparity between all-cargo and belly-cargo energy intensities is due to the incremental nature of the latter estimate. Since belly cargo is ancillary to passenger operations, its energy intensity is calculated on the basis of the incremental fuel consumption attributable to its added weight.

Table 42 Comparison of Projections: Heavy Duty Truck^a
Energy Use

Source of Projection	Energy Use (quads)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81	2.01	2.40	2.67	2.84	3.15	2.3
ANL-79 ^b	4.26	5.02	5.61	6.12	6.77	2.7
CSSP-80	3.3	3.6	3.7	N/A	4.8	1.9
NEPP-81	2.3	2.4	2.5	N/A	3.0	1.3
EEA-7/81	2.33	2.49	2.76	2.75	2.95	1.2
OPPE-81 ^c	2.62 ^d	2.96	3.15	3.48	3.93	2.0
TSC/EIA-81	2.31	2.56	2.65	2.80	2.98	1.3

^aClasses 3-8.

^bAssumes constant fuel efficiency, 1975-2000.

^cDiesel classes 7 and 8 only.

^d1980 estimate includes diesel use by light duty vehicles.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Base-line, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

NEPP-81 -- U.S. Department of Energy, Office of Policy Planning and Analysis, Energy Projection to the Year 2000, a supplement to The National Energy Policy Plan, Washington, D.C., DOE/PE-0029 (July 1981).

EEA-7/81 -- Energy and Environmental Analysis, Inc., The Highway Fuel Consumption Model, Fourth Quarterly Report, Arlington, Va. (July 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).

Fig. 34 Projections of Energy Consumption by Heavy Duty Trucks

Table 55 shows projected air cargo ton-miles and energy consumption by all-cargo and belly freight submodes. In the baseline scenario, the sub-modal split and energy intensities are held constant over the projection period.

3.7.2 Air Passenger

3.7.2.1 Domestic Air Carriers

Projections of passenger-miles of travel by domestic air carriers are based on the output of the POINTS model. As stated previously, total air PMT was estimated by computing percentage changes in inter-SMSA passenger-miles of travel (by air) between the base-year estimate and each POINTS forecast. These "growth factors" were applied to base-year air PMTs. The results are displayed in Table 56.

When the POINTS forecast of commercial aviation revenue passenger-miles (RPMs) is compared to historic trends and other forecasts such as those illustrated in Fig. 38, a fundamental difference becomes evident. All other major forecasts show RPMs growing at an accelerated rate through year 2000, a rate comparable to observed growth between 1960 and the late

Table 43 ANL-81 Projections of School Bus^a Stocks, Activity, and Energy Consumption -- 1980-2000

Stock, VMT, Fuel Economy, Energy Use	1980	1985	1990	2000
Stock (10³)				
Gasoline	405.9	405.0	364.1	318.5
Diesel	5.4	26.4	84.9	182.3
Total	411.3	431.4	449.0	500.8
Vehicle miles/vehicle				
Gasoline	7154	6990	6587	6105
Diesel	10678	10433	9831	9113
Total	7200	7200	7200	7200
Total vehicle miles (10⁶)				
Gasoline	2903.3	2831.5	2398.3	1944.5
Diesel	58.2	274.6	834.3	1661.2
Total	2961.5	3106.1	3232.6	3605.7
Miles/gallon				
Gasoline	7.4	7.4	7.4	7.4
Diesel	10.4	10.4	10.4	10.4
Total	7.4	7.6	8.0	8.5
Energy consumption (quads)				
Gasoline	0.050	0.048	0.041	0.033
Diesel	0.001	0.004	0.011	0.022
Total	0.051	0.052	0.052	0.055

^aIncludes other nonrevenue buses.

Source of historical data: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 1980, Washington, D.C. (1981).

1970s. While RPMs also grow under the POINTS forecast, they do so at a much decelerated rate compared to the other forecasts.*

A view of the historic trend in yield (revenue/revenue passenger-mile) helps to explain some of these differences. Yield, measured in constant dollars, is a reasonably good index of changes in the real cost of air travel to the air traveler. In the early 1960s, following the introduction and diffusion of turbofan jet technology, yield dropped dramatically. Beginning in the late 1960s its rate of decline slowed somewhat until 1978, when a combination of events, including deregulation, resulted in strong competition

*Moreover, most forecasts imply a 150% increase in RPMs per capita between 1980 and 2000. By contrast, the POINTS forecast estimates an increase of only 14%.

Table 44 ANL-81 Projections of Transit Bus Stocks, Activity, and Energy Consumption -- 1980-2000

Stock, VMT, Energy Use	1980	1985	1990	2000
Stock (10^3) ^a	59.4	66.3	72.0	77.1
Vehicle miles/vehicle (10^3)	28.2	29.5	29.5	29.5
Vehicle miles (10^6)	1677.2	1955.8	2125.3	2273.2
Average load (PMT/VMT)	13.8	14.3	14.8	14.8
Passenger miles (10^9)	23.21	28.0	31.5	33.6
Miles/gallon	3.6	3.3	3.3	3.3
Energy consumption (quads) ^b	0.065	0.082	0.089	0.096

^aIncludes all types of buses and vans operated by transit systems.

^bAll fuel assumed to be diesel.

Source of historical data: American Public Transit Assn.: Transit Fact Book, 1980-1981 Ed., Washington, D.C. (1981).

Table 45 ANL-81 Projections of Intercity Bus Stocks, Activity, and Energy Consumption -- 1977-2000

Stock, VMT, Energy Use	1977	1980	1985	1990	2000
Stock (10^3)	20.2	21.0	20.6-21.8	22.4-23.7	26.3-27.5
Vehicle miles/vehicle (10^3)	54.6	56.0	56.0	55-57	55-57
Vehicle-miles (10^6)	1102	1175	1220	1305	1515
Passenger-miles (10^9)	25.7	27.7	29.3	31.8	37.2
Energy intensity					
Btu/PMT	980	963	917	876	876
Mi/gal	6.1	5.9	6.2	6.5	6.5
Energy consumption (quads)	0.025	0.027	0.027	0.028	0.033

Source of historical data: American Bus Assn., Bus Facts, Washington, D.C., 1981 Ed.

Table 46 ANL-81 Projections of Intercity Rail Passenger Activity and Energy Consumption, 1977-2000

Activity, Energy Consumption	1977	1980 ^a	1985	1990	2000
Passenger-miles (10 ⁹)	4.42	4.85	4.40	4.01	3.24
Btu/passenger-mile	3369	3308	3137	2967	2967
Energy consumption (quads)	0.015	0.016	0.014	0.012	0.010

^aANL estimate.

Sources of historical data:

Passenger-miles -- Assn. of American Railroads, Statistics of Railroads of Class I in the United States, Years 1969 to 1979, Washington, D.C. (1980).

Energy consumption and intensity -- G. Kulp et al., Transportation Energy Conservation Data Book, Oak Ridge National Laboratory, Oak Ridge, Tenn., Ed. 4 (1980).

Table 47 ANL-81 Estimates of Major Commodities Moved by Rail, 1980

Commodity Sector	Ton-Miles (10 ⁹)	% of Total
Coal	160.035	18.8
Farm products	109.722	12.9
Lumber and wood products	93.263	10.9
Canned, frozen foods	64.910	7.6
Paper products	56.758	6.7
Chemicals	54.505	6.4
Stone, clay, and glass	39.759	4.7
Metal mining products	36.782	4.3
Nonmetal mining products	33.955	4.0
Total	649.689	76.3

Sources:

Mode shares -- U.S. Department of Commerce, Bureau of the Census, 1972 Commodity Transportation Survey, Washington, D.C. (1976).

Ton-miles -- ANL estimates.

Table 48 ANL Projections of Rail Freight Activity and Energy Consumption, 1977-2000

TMT, Energy Use	1977 ^a	1980 ^a	1985	1990	2000
Ton-miles (10 ⁹)	819.606	853.205	1077.137	1211.506	1521.781
Btu/ton-mile	592	586	589	586	586
Energy consumption (quads)	0.485	0.500	0.634	0.710	0.892

^aANL commodity-level estimates summed across all sectors.

Table 49 Comparison of Projections: Rail Ton-Miles

Source of Projection	Ton-Miles (10 ⁹)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81	853	1077	1212	1347	1522	2.9
ANL-79	N/A	1091	1237	1380	1550	3.1
CSSP-80	N/A	1024	1173	N/A	1491	2.7
EIA-80	868 ^a	975	1070	1146	N/A	1.6
OPPE-81	919	1062	1196	1345	1532	2.6
TSC/EIA-81	895	1045	1200	1333	1471	2.5

^a1978.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

EIA-80 -- U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Volume 3: Forecasts, Washington, D.C., DOE/EIA-0173(80)/3 (March 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).

Table 50 Comparison of Projections: Rail^a Energy Use

Source of Projection	Energy Use (quads)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81	0.50	0.63	0.71	0.79	0.89	2.9
ANL-79	0.63	0.72	0.80	0.89	0.98	1.9
CSSP-80	N/A	0.65	0.72	0.78	0.89	2.2
EIA-80	0.58 ^b	0.61	0.67	0.72	N/A	1.3
OPPE-81	0.57	0.63	0.69	0.76	0.84	2.0
TSC/EIA-81	0.59	0.66	0.74	0.80	0.86	1.2

^aFreight only.^b1978.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al. Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

EIA-80 -- U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Volume 3: Forecasts, Washington, D.C., DOE/EIA-0173(80)/3 (March 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).

Fig. 35 Projections of Rail Freight Ton-Miles

and a sharp reduction in yield. This latter trend continued through 1979 despite higher operating costs brought on by a rapid increase in jet-fuel prices. A widespread discount campaign by major airlines fostered the 1979 decline in yield.* In 1980 real yield remained nearly constant. By the first quarter of 1981, however, yield had increased sharply, rising 21.7% in current dollars above the first quarter of 1980 and producing the largest single increase shown in Fig. 38.⁹⁸ This increase is consistent with the projected cost factors presented earlier in Table 13.

As shown in Fig. 38, the POINTS input assumed that real yield would increase over time. The rate of increase was computed as a function of projected increases in jet-fuel prices, modified by assumed aircraft-efficiency improvements and capital expenses. Jet-fuel prices were assumed to rise substantially over the forecast period (see Table 4). Capital expenses also were assumed to increase significantly as air carriers gradually retire their largely depreciated 1960- and 1970-vintage fleet and replace it with such new-generation aircraft as the B757 and B767. The growth rate for capital expenses was based on projections through 1990 developed by industry sources. Beyond 1990 capital expenses were assumed to remain constant in real terms. All other cost elements (such as labor and maintenance) were assumed to rise with inflation.

*While yield was down, RPMs reached record levels, partly as a result of discount fares and coupons and partly as a result of auto travelers shifting to air travel because of gasoline shortages.

Fig. 36 Projections of Rail Energy Consumption

Table 51 ANL-81 Estimates of Major Commodities Moved in Domestic Waterborne Commerce, 1980

Commodity Sector	Ton-Miles (10 ⁹)	% of Total
Petroleum products	257.562	42.8
Metal mining	72.901	12.1
Crude oil	72.104	12.0
Coal mining	51.417	8.5
Nonmetal mining	32.655	5.4
Farm products	30.443	5.1
Subtotal	517.082	85.9

Sources:

Mode shares -- U.S. Department of the Census, 1972 Commodity Transportation Survey, Washington, D.C. (1976).

Ton-miles -- ANL estimates.

Table 52 ANL-81 Projections of Domestic Marine Ton-Miles by Area of Operation and Vessel Type (10⁹)

Vessel Type by Area of Operation	Historical		Projected			
	1977 ^b	1980 ^b	1985	1990	1995	2000
Inland waterway ^a	197.97	203.47	240.42	263.83	287.12	315.95
Great Lakes						
Dry bulk	47.75	49.07	57.98	63.63	69.25	76.20
Tanker	1.76	1.81	2.14	2.34	2.55	2.81
Tug-tow	1.45	1.49	1.76	1.94	2.11	2.32
Total	50.96	52.37	61.88	67.91	73.91	81.33
Coastal						
Tanker	246.59	253.45	299.46	328.63	357.64	393.55
Tug-tow	90.19	92.70	109.53	120.19	130.81	143.94
Total	336.78	346.15	408.99	448.82	488.45	537.49
Total	585.71	601.99	711.29	780.55	849.47	934.76

^aTug-tow only.

^bANL commodity-level estimates summed across sectors.

The resulting increase in real yield is quite different from the historic trend, and this difference helps account for the shape of the POINTS forecast curve. Because trends in yield and air-travel demand tend to be inversely related, the other forecasts must assume declining real yield over the projection period. It appears most unlikely that this assumption will be borne out, however, given the outlook for air-carrier operating costs, particularly through 1990.

Although the POINTS model was calibrated with cross-sectional data at only one point in time (1977), the POINTS forecast implies that future demand for domestic air travel will respond as a typical technology-substitution curve and take the curve's familiar S shape. The high RPMs recorded for 1978, 1979, and 1980 (relative to the POINTS forecast) represent an artificial technological "improvement" (intense marketing and price competition) -- which could not be sustained in the long run because of low associated profit. Therefore, in the POINTS forecasts, these three data points are aberrant. Nevertheless, a simple experiment was devised to test the ability of the POINTS model to simulate some of the unusual conditions that resulted in these demands. In an effort to replicate the peak demand of 1979, a 15% reduction in the real cost of air travel (from 1977 values) and a 50% increase

Table 53 ANL-81 Projections of Marine Energy Consumption by Area of Freight Operation and Vessel Type, 1977-2000 (10¹² Btu)

Vessel Type by Area of Operation	Historical		Projected			
	1977 ^a	1980 ^a	1985	1990	1995	2000
Inland waterway ^b	95.22	97.87	115.64	126.90	138.11	151.97
Great Lakes						
Dry bulk	25.93	26.65	31.49	34.55	37.60	41.38
Tanker	1.15	1.18	1.39	1.53	1.66	1.83
Tug-tow	0.44	0.45	0.54	0.59	0.64	0.71
Total	27.52	28.28	33.42	36.67	39.90	43.92
Coastal						
Tanker	87.54	89.97	106.31	116.66	126.96	139.71
Tug-tow	25.07	25.77	30.45	33.41	36.36	40.02
Other	17.00	17.00	21.00	24.00	27.00	29.00
Total	129.61	132.74	157.76	174.07	190.32	208.73
Total domestic	252.35	258.89	306.82	337.64	368.33	404.62
Foreign trade ^c						
U.S. flag	117.37	126.76	147.53	167.14	186.27	207.39
Foreign flag	734.73	793.51	923.56	1046.26	1166.02	1298.27
Total	852.10	920.27	1071.09	1213.39	1352.29	1505.66

^aANL commodity-level estimates summed across sectors and distributed to area of operation and vessel type.

^bTug-tow.

^cU.S. fuel only.

in out-of-pocket auto costs* were put into the model. The result was a 17.7% increase in air RPMs (over 1977 levels) as compared to the 23.8% observed increase. This shortfall may be attributed to the 1979 fuel shortage, which was not simulated in the test run. Nonetheless, the POINTS estimate is in the range of the other forecasts of 1979 demand shown on Fig. 38. This lends further support to the lower-than-historic POINTS forecast.

The projections of domestic PMT by commercial air carriers show an increase at roughly twice the rate of population growth between 1977 and 2000 (1.5% versus 0.8%). This produces the above-mentioned 14% increase in air PMT per capita.

*This increase is based solely on the rate at which retail gasoline prices rose between 1977 and 1979. It does not include the opportunity costs associated with waiting in gas lines nor the intangible "cost" of uncertain fuel availability.

Table 54 Comparison of Projections: Marine Energy Use

Source of Projection	Energy Use (quads)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81 ^a	0.44	0.53	0.59	0.65	0.73	2.6
ANL-79 ^a	0.58	0.70	0.77	0.84	0.93	2.4
CSSP-80 ^a	0.37	0.43	0.51	0.60	0.72	3.4
OPPE-81 ^a	0.69	0.80	0.94	1.10	1.30	3.2
EIA-80 ^b	1.20 ^c	1.36	1.31	1.31	N/A	0.5
TSC/EIA-81	0.36 ^d	0.40	0.42	0.44	0.47	1.3

^aDomestic trade and recreational boating.

^bTotal fuels purchased in the U.S.

^c 1978.

^dFuel oil only.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

CSSP-80 -- D. Greene et al., Energy Savings Impacts of DOE's Conservation and Solar Programs, Oak Ridge National Laboratory, Oak Ridge, Tenn., ORNL/TM-7690-V2 (May 1981) -- updated in part with unpublished information from Oak Ridge National Laboratory.

EIA-80 -- U.S. Department of Energy, Energy Information Administration, 1980 Annual Report to Congress, Volume 3: Forecasts, Washington, D.C., DOE/EIA-0173(80)/3 (March 1981).

OPPE-81 -- R.W. Barnes et al., Oak Ridge National Laboratory, unpublished information (Feb. 1982).

TSC/EIA-81 -- J.K. Pollard et al., Transportation Energy Outlook: 1985-2000, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Mass., DOT-TSC-RS-112-SS-81-6 (Sept. 1981).

Fig. 37 Projections of Marine Energy Consumption

Table 55 ANL-81 Projections of Domestic Air Cargo Ton-Miles and Energy Consumption by Type of Operation, 1977-2000

TMT and Energy Consumption by Submode	Historical ^a		Projected			
	1977	1980	1985	1990	1995	2000
Ton-miles (10 ⁹)						
All-cargo	0.67	0.77	0.91	1.02	1.12	1.24
Belly-cargo	3.97	4.31	5.08	5.70	6.26	6.89
Total	4.64	5.08	5.99	6.72	7.38	8.13
Energy consumption (10 ¹² Btu)						
All-cargo	17.95	19.14	21.76	23.51	25.79	28.41
Belly-cargo	13.11	16.08	20.00	22.66	25.56	28.15
Total	31.06	35.22	41.76	46.17	51.35	56.56

^aANL commodity-specific estimates summed across all sectors.

Table 56 ANL-81 Projections of Commercial Aviation Passenger Travel and Energy Consumption, 1977-2000

PMT and Energy Consumption, by Type of Operation	1977	1980	1985	1990	2000
PMT (10 ⁹)					
Domestic	162.17	203.20	191.36	198.33	227.57
International ^a	42.05	57.24	74.75	90.04	135.87
Total	204.22	260.44	266.11	288.37	363.44
Energy consumption (quads)					
Domestic	1.100	1.039	0.833	0.724	0.629
International ^b	0.158	0.161	0.179	0.182	0.207
General aviation ^c	0.148	0.139	0.188	0.227	0.318
Total	1.406	1.339	1.200	1.133	1.543

^aU.S. carriers only.

^bU.S. fuel purchased by U.S. carriers only. Includes belly freight. Total consumption by U.S. flag carriers may be estimated by assuming quantities shown represent 55% of total.

^cIncludes commuter air carriers.

Sources of historical data:

PMT -- Civil Aeronautics Board, Air Carrier Traffic Statistics, Washington, D.C., monthly; and Transportation Assn. of America, Transportation Facts and Trends, Washington, D.C., Quarterly Supplement (April 1981).

Energy consumption -- G. Kulp et al., Transportation Energy Conservation Data Book, Oak Ridge National Laboratory (1980); and Civil Aeronautics Board, Air Carrier Traffic Statistics, Washington, D.C., monthly.

3.7.2.2 International

Table 56 also presented PMT and energy-consumption forecasts of U.S. flag air carriers' international operations. Only fuel purchases in the U.S. are shown. Total consumption may be estimated from 1980 data, which indicate that U.S. purchases represent approximately 55% of total consumption for these operations.

As Table 56 shows, international air travel is projected to grow substantially between 1980 and 2000, at an average annual rate of 4.4%. The faster growth projected for international than for domestic air travel is attributable to generally more optimistic economic forecasts for the major U.S. trading partners (principally Japan and West Germany) and the consideration of relatively lower yield "discount" fares in the international

Fig. 38 Projections of Airline Revenue Passenger-Miles and Yield

projection. As stated in Sec. 2.5.2, international yield was assumed to respond less readily to cost increases because of greater competition from budget airlines and historically larger profit margins on which to absorb such increases.

The energy consumed by U.S. carriers' international operations rises much more slowly than activity in the baseline projection. Energy use grows by only 1.3% as a result of significant improvements in aircraft energy efficiency. Under the baseline scenario, comparable efficiency improvements are assumed for aircraft in domestic and international operations.

3.7.2.3 General Aviation

The projected energy consumption of general aviation and commuter air carriers were also shown in Table 56. Because of a lack of data on commuter air carriers' energy consumption, base-year consumption estimates that combined commuter carriers with general aviation were used. This base was projected using the growth rates derived from the general-aviation model. Between 1980 and 2000 the energy consumption of this aviation fleet is projected to rise more rapidly than that of the other aviation categories. This is largely attributable to the energy-intensity assumptions of the baseline scenario. While the NASA program includes development of an advanced turbo-prop and attendant fuel savings of 15-20%, it is unlikely that this new design can reverse the historical trend toward increasing energy intensity in the general aviation fleet. Thus, general aviation energy intensity was held constant in the baseline scenario, and projected increases in general aviation activity were translated directly into projected increases in energy consumption.

3.8 PIPELINE

Pipeline activity was projected by the FRATE model as a function of anticipated growth in the crude oil, petroleum products, and natural gas sectors. The three principal assumptions of the DRI forecast that directly influence FRATE results are as follows:

- Decontrol of natural gas prices between 1983 and 1987.*
- Fairly stable natural gas supplies. Declining production in the lower 48 states is offset by increased supplies from Canadian, Mexican, and Alaskan sources (these latter rising from <5% of total supply in 1980 to >17% in 2000); by LNG imports (rising from 0.5% to 6% of total supply); and by increased production of synthetic natural gas (rising from 0.6% to 4% of total supply).
- Modest increases in domestic crude oil supplies as newly discovered and unconventional sources make up for declining production from lower-48 and Alaskan wells.

Table 57 presents 1980 estimates of ton-miles of crude oil, petroleum products, and natural gas moved by pipeline.**

Table 58 shows the FRATE projections of pipeline energy consumption. Because energy intensities are assumed to remain constant under the baseline scenario, the increase in energy consumption over the projection period corresponds to the increase in pipeline activity over that period. As Table 58 indicates, the energy consumed by crude oil and natural gas lines grows at the same rate (on the order of 1.2%/yr over the period), while consumption by petroleum product lines grows somewhat more slowly (0.7%/year).

Currently, coal-slurry movements account for an insignificant portion of ton-miles generated by the coal sector. For that reason, coal-slurry activity is not calculated endogenously within FRATE. The projection shown in Table 58 is based on a previous ANL analysis, which utilized pipeline construction schedules to estimate

Table 57 ANL-81 Estimates of Pipeline Activity by Type of Line, 1980

Type of Line	Ton-Miles (10 ⁹)
Crude oil	299.25
Petroleum products	282.28
Natural gas	347.15
Total	928.68

Sources:

Mode Shares -- U.S. Department of Commerce, Bureau of the Census, 1972 Commodity Transportation Survey, Washington, D.C. (1981).

Ton-miles -- ANL estimates.

*Oil decontrol, as a result of the January 28, 1981, oil decontrol order, is also included in the forecast.

**Natural gas movements generally are expressed solely in volumetric units. Historic data on natural gas production was converted to ton-miles by assuming a conversion factor of 44,870 ft³ = 1 ton and also assuming an average length of haul comparable to that of petroleum products.

Table 58 ANL-81 Projections of Pipeline Energy Consumption
by Type of Line, 1977-2000 (quads)

Type of Line	1977 ^a	1980 ^a	1985	1990	1995	2000
Crude oil	0.066	0.075	0.085	0.087	0.091	0.097
Petroleum products	0.089	0.085	0.096	0.101	0.105	0.111
Natural gas	0.613	0.694	0.787	0.810	0.847	0.899
Coal slurry	0.004	0.004	0.004	0.004	0.118	0.393
Total	0.772	0.858	0.972	1.002	1.161	1.5

^aANL commodity-specific estimates summed across all sectors.

coal-slurry activity to year 2000.² Since many construction schedules have been delayed due to continuing legal and institutional difficulties involving eminent domain and general right-of-way acquisition, slurry pipeline developers have revised their expectations.⁹⁹ The new projections reflect these later completion dates.

The sole existing coal-slurry line, the Black Mesa, is quite energy-intensive. As additional slurry pipelines are built, the average length of haul will increase; energy intensity should then decline considerably. In our baseline projections, coal-slurry energy intensity was assumed to decline from 2990 Btu/TMT in 1977 to 1995 Btu/TMT in year 2000.

Table 59 compares the new baseline projections of pipeline energy consumption with previous projections. Consumption grows more rapidly in ANL-81, largely as a result of new coal-slurry activity incrementing stable to moderate increases in oil and gas activity. With decontrol, oil and gas pipeline activity remains considerably higher than in the earlier efforts.

Table 59 Comparison of Projections: Pipeline Energy Use

Source of Projection	Energy Use (quads)					Average Annual % Change, 1980-2000
	1980	1985	1990	1995	2000	
ANL-81 ^a	0.86	0.97	1.00	1.16	1.50	2.8
ANL-79	0.91	0.97	1.22	1.21	1.20	1.4
CSSP-80	0.86	1.11	1.32	1.35	1.35	2.3
OPPE-81	0.75	0.77	0.81	0.79	0.79	0.3
TSC/EIA-81	0.62	0.57	0.63	0.62	0.61	0

^aIncludes coal slurry.

Sources: ANL-79 -- R. Knorr and M. Millar, Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline, Argonne National Laboratory, Argonne, Ill., ANL/CNSV-4 (Aug. 1979).

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4 SENSITIVITY TO ALTERNATIVE ECONOMIC AND FUEL-PRICE ASSUMPTIONS

4.1 ALTERNATIVE SCENARIOS

The ANL-81 baseline scenario is a relatively surprise-free, business-as-usual future. It is a starting point for examining conservation programs and for viewing other potential futures. Although we judged these alternative futures as relatively less likely than the baseline to occur, it is useful to characterize them in terms of scenarios. Their energy implications may be assessed, enabling conservation programs to be evaluated against a range of future eventualities. Such strategic planning is a useful tool for program planning and management -- it not only identifies those factors that enhance or limit program performance, but it also highlights new opportunities and suggests potential modifications to program direction or scope.

Future work at the CTR will focus on projecting transport activity and energy demand under a range of alternative scenarios. Though quite different from one another, each of the scenarios will represent a highly plausible, internally consistent future with an associated set of likely vehicle technologies, vehicle-purchase behaviors, and fuel demands. The scenarios and their associated projections will be described in a series of technical memoranda to be published in 1983.

4.2 ALTERNATIVE FUEL PRICES

A single baseline scenario was defined for the current effort. In order to test the effect of higher fuel price assumptions, a variation on that baseline was defined, and a full set of projections was developed for that case. Termed the constrained-growth case, this variation is not a full-blown scenario: only a few of its parameters differ from the baseline. The main difference between the two is in world oil price; however, because of that parameter's effect on inflation and economic growth, as well as on petroleum product prices, changes in the three latter parameters also had to be made.

The PESSIMLONG2006 solution to the DRI macro model was selected to represent the higher fuel-price case. Table 60 contrasts the key parameters of that case with the baseline scenario. Because the constrained-growth case carries higher world oil prices through to economic activity, it affects the volume of transportation demand, the distribution of that demand across modes, and modal energy consumption. These effects may be seen in Tables 61 and 62.

Tables 63 and 64 detail light and heavy duty vehicle-miles and energy consumption by size class. Because the freight side is more closely tied to economic activity, there is considerably more variation in heavy duty VMT and energy consumption across the two projections. While higher fuel prices induce some shift from relatively less fuel-efficient light trucks to automobiles, as well as an overall decline in light duty VMT, the passenger side is relatively insensitive to price increases on the order of those modeled. This is to be expected, given the low price elasticities of demand (i.e., VMT) observed historically and assumed for this analysis, and also given the relatively small fuel-price variation between the baseline scenario and the constrained-growth case (see Table 60).

Table 60 Key Parameters, Baseline versus Constrained-Growth Case

Parameter	Baseline			Constrained Growth			Average Annual % Change, 1980-2000	
	1985	1990	2000	1985	1990	2000	Baseline	Constrained Growth
Real GNP (% change) ^a	3.2	2.7	2.2	2.3	2.0	1.8	2.6	2.0
Real disposable personal income (% change) ^a	2.9	2.7	2.2	2.3	1.8	2.0	2.5	2.0
Consumer price index (% change) ^a	8.5	8.1	7.1	12.2	11.4	9.0	7.7	10.4
Unemployment rate ^b	6.4	6.0	5.9	6.6	6.2	5.8	-	0
World oil price (1980 \$/bbl)	36.3	43.0	57.1	43.6	52.8	75.8	2.6	4.1
Retail gasoline price (1980 \$/gal)	1.35	1.58	2.01	1.58	1.82	2.41	2.5	3.5
Retail diesel price (1980 \$/gal)	1.24	1.49	1.95	1.50	1.75	2.39	3.2	4.3
Jet-fuel price (1980 \$/gal)	1.08	1.33	1.80	1.32	1.58	2.23	3.1	4.3
Average electricity rate (1980 ¢/kWh)	4.9	4.9	4.9	4.9	4.9	4.9	0	0

^a1980-85, 1985-90, 1990-2000.^bRate for year shown.

Table 61 Passenger-Miles of Travel and Energy Consumption by Mode,
Baseline Scenario versus Constrained-Growth Case

PMT and Energy Consumption by Mode	Projection						Average Annual %, Change, 1980-2000	
	Baseline			Constrained Growth			Baseline	Constrained Growth
	1985	1990	2000	1985	1990	2000		
Passenger-miles ^a (10 ⁹)								
Local travel								
Auto ^b	2056.18	2262.78	2478.09	2013.81	2281.93	2495.83	1.61	1.65
Light truck ^b	341.65	418.90	472.48	329.26	355.72	444.95	2.27	1.96
Bus	78.42	82.62	91.07	78.42	82.62	91.07	1.05	1.05
Rail	17.42	17.86	18.32	17.42	17.86	18.32	0.36	0.36
Total local PMT	2493.67	2782.16	3059.96	2438.91	2738.13	3050.17	1.68	1.66
Intercity travel								
Auto/light truck	240.26	261.59	278.47	232.99	256.72	274.06	0.75	0.67
Air ^c	191.36	198.33	227.57	190.23	196.83	225.90	0.57	0.53
Bus	29.29	31.80	37.15	27.77	31.10	36.78	1.48	1.43
Rail	4.40	4.01	3.24	5.12	4.18	3.18	(1.52)	(1.61)
Subtotal	465.31	495.73	546.43	456.11	488.83	539.92	0.70	0.64
International air ^d	74.75	90.04	135.87	68.23	79.59	108.42	4.42	3.25
Total intercity PMT	540.06	585.77	682.30	524.34	568.42	648.34	1.24	0.99
Energy (quads)								
Auto	8.723	7.875	6.698	7.867	7.683	6.698	(1.86)	(1.86)
Light truck	1.699	1.951	1.700	1.637	1.893	1.598	(0.29)	(0.60)
Bus	0.149	0.161	0.176	0.147	0.160	0.175	1.15	1.12
Rail ^d	0.069	0.069	0.069	0.071	0.068	0.068	0.30	0.23
Domestic air	1.021	0.951	0.947	1.000	0.904	0.858	(1.09)	(1.57)
Other ^e	0.310	0.340	0.400	0.310	0.340	0.400	2.06	2.06
Subtotal	11.971	11.347	9.990	11.031	11.048	9.797	(1.38)	(1.48)
International air	0.179	0.182	0.207	0.164	0.160	0.165	1.26	0.12
Total passenger energy	12.150	11.529	10.197	11.195	11.208	9.962	(1.34)	(1.46)

^aExcludes motorcycles, mopeds, recreational boating, general aviation.

^bAssumes average occupancies of 1.78 passenger-mi/vehicle-mi for autos and 1.73 passenger-mi/vehicle-mi for light trucks.

^cCommercial aviation only.

^dTransit and commuter rail assumed constant across both projections.

^eMotorcycles, mopeds, recreational boating, and general aviation.

Table 62 Domestic Freight Ton-Miles of Travel and Energy Consumption
by Mode, Baseline versus Constrained-Growth Case

TMT and Energy Consumption by Mode	Projection						Average Annual %, Change, 1980-2000	
	Baseline			Constrained Growth			Baseline	Constrained Growth
	1985	1990	2000	1985	1990	2000		
Ton-miles (10 ⁹)								
Intercity truck ^a	741.58	826.22	981.98	709.73	772.00	880.82	2.43	1.87
Rail	1077.14	1211.51	1521.78	1026.02	1127.61	1354.96	2.94	2.34
Marine	711.29	780.55	934.76	686.31	736.02	847.12	2.22	1.72
Air	5.99	6.72	8.13	5.76	6.31	7.40	2.38	1.90
Pipeline ^b	1052.66	1090.25	1402.82	1040.56	1067.62	1319.61	2.08	1.76
Total TMT	3589.66	3878.56	4849.47	3468.38	3709.56	4409.90	2.43	1.95
Energy (quads)								
Intercity truck	1.526	1.724	1.962	1.532	1.667	1.797	2.04	1.59
Local truck	1.584	1.642	1.819	1.586	1.614	1.724	0.91	0.63
Rail	0.600	0.697	0.882	0.602	0.659	0.790	2.88	2.31
Marine	0.269	0.296	0.355	0.276	0.296	0.340	0.98	0.76
Air	0.039	0.045	0.054	0.039	0.042	0.053	2.19	2.10
Pipeline ^b	0.962	1.016	1.471	0.968	0.995	1.435	2.73	2.60
Total domestic	4.980	5.420	6.543	5.003	5.273	6.136	1.87	1.55
Intl. shipping ^c	1.071	1.213	1.506	1.029	1.136	1.358	2.49	1.96
Total freight energy	6.051	6.633	8.049	6.032	6.409	7.494	1.98	1.62

^aTon-miles not projected for local trucking.

^bIncludes coal slurry.

^cIncludes foreign flag carriers.

Table 63 Light-Duty Vehicle-Miles of Travel and Energy Consumption by Vehicle Size Class, Baseline versus Constrained-Growth Case

VMT and Energy Use by Vehicle Type	Baseline			Constrained Growth		
	1985	1990	2000	1985	1990	2000
Auto (multipurpose)						
Small						
VMT (10 ⁹)	357.24	415.66	540.55	364.60	433.62	545.13
Diesel VMT (%)	-	0.1	23.9	-	5.0	23.7
Gal gasoline (10 ⁹)	16.28	15.18	12.69	15.48	15.36	12.83
Gal diesel (10 ⁹)	-	0.58	0.64	-	0.68	2.64
Quads	2.035	1.979	1.952	1.934	2.014	1.969
Average mi/gal	21.9	26.36	35.25	23.56	27.04	35.25
Medium						
VMT (10 ⁹)	578.57	615.65	610.21	567.61	620.59	614.10
Diesel VMT (%)	5.5	10.7	13.2	6.2	12.0	15.8
Gal gasoline (10 ⁹)	30.86	26.12	19.94	28.01	25.32	19.47
Gal diesel (10 ⁹)	1.26	20.66	2.33	1.10	2.33	2.80
Quads	4.03	3.553	2.816	3.654	3.487	2.823
Average mi/gal	18.01	21.84	27.40	19.50	22.45	27.57
Large						
VMT (10 ⁹)	327.26	353.61	363.43	303.99	340.03	361.70
Diesel VMT (%)	5.9	11.6	14.3	6.6	12.9	17.1
Gal gasoline (10 ⁹)	20.40	17.32	13.75	17.53	15.91	13.25
Gal diesel (10 ⁹)	0.76	1.28	1.51	0.63	1.37	1.78
Quads petroleum	2.66	2.343	1.928	2.278	2.179	1.904
Average mi/gal	15.46	19.01	23.82	16.74	19.68	24.05
Total						
VMT (10 ⁹)	1263.07	1386.08	1515.74	1236.20	1395.79	1522.83
Diesel VMT (%)	4.1	9.1	17.3	4.5	10.1	18.9
Gal gasoline (10 ⁹)	67.54	58.62	46.39	61.02	56.59	45.56
Gal diesel (10 ⁹)	2.02	3.93	6.47	1.73	4.38	7.23
Quads petroleum	8.723	7.875	6.698	7.866	7.683	6.698
Average mi/gal	18.16	22.14	28.64	19.70	22.87	28.82
% electricity, VMT	-	0.08	0.10	-	0.11	0.12
Quads electricity	-	0.0017	0.0018	-	0.0023	0.0022
Light Trucks						
Personal						
VMT (10 ⁹)	216.02	264.96	296.11	208.10	261.87	280.76
Diesel VMT (%)	3	8	15	3	10	20
Gal gasoline (10 ⁹)	13.33	14.81	11.98	12.85	14.15	10.73
Gal diesel (10 ⁹)	0.23	0.22	1.49	0.22	0.89	1.85
Quads	1.699	1.951	1.700	1.637	1.893	1.598
Average mi/gal	15.92	17.05	21.97	15.92	17.40	22.31
Commercial and government						
VMT (10 ⁹)	88.06	101.59	124.52	88.05	99.99	118.93
Diesel VMT (%)	4.6	20.8	25.9	4.6	20.8	25.9
Gal gasoline (10 ⁹)	53.42	4.89	4.15	0.53	4.76	4.21
Gal diesel (10 ⁹)	0.15	0.72	1.06	0.15	0.71	1.02
Quads	0.688	0.711	0.666	0.688	0.693	0.667
Average mi/gal	16.78	18.11	23.87	12.94	18.29	22.76
Total light truck						
VMT (10 ⁹)	304.09	366.55	420.63	296.15	361.85	399.69
Diesel VMT (%)	3.5	11.5	18.2	3.5	13.0	21.7
Gal gasoline (10 ⁹)	18.68	19.70	16.13	18.19	18.91	14.94
Gal diesel (10 ⁹)	0.38	1.44	2.56	0.37	1.60	2.86
Quads	2.387	2.662	2.366	2.325	2.586	2.265
Average mi/gal	15.96	17.34	22.50	15.95	17.64	22.45

Table 63 (Cont'd)

VMT and Energy Use by Vehicle Type	Baseline			Constrained Growth		
	1985	1990	2000	1985	1990	2000
Subtotal: Auto and Personal Light Truck						
VMT (10 ⁹)	1479.10	1651.04	1811.86	1444.30	1657.66	1803.59
Gal gasoline (10 ⁹)	80.88	73.43	58.37	73.87	70.74	56.28
Gal diesel (10 ⁹)	2.25	4.65	7.97	1.95	5.27	17.96
Quads	10.422	9.826	8.398	9.503	9.576	8.296
Total: Light Duty Vehicle						
VMT (10 ⁹)	1567.17	1752.64	1936.37	1532.35	1757.65	192.25
Gal gasoline (10 ⁹)	86.22	78.32	62.52	79.21	75.50	6.05
Gal diesel (10 ⁹)	2.40	5.37	9.03	2.09	0.60	18.98
Quads	11.110	10.537	9.064	10.191	10.269	8.963

Table 64 Vehicle-Miles Traveled, Fuel Consumption, and Fuel Economy by Truck Size -- Baseline versus Constrained-Growth Case

VMT, Fuel Consumption, and Fuel Economy by Size	Baseline			Constrained Growth		
	1985	1990	2000	1985	1990	2000
Medium truck						
VMT (10 ⁹)	38.33	47.95	64.58	36.81	44.95	54.70
Gal gasoline (10 ⁹)	3.42	3.16	2.80	3.28	2.96	2.42
Gal diesel (10 ⁹)	0.33	1.06	2.30	0.31	1.00	1.97
Quads	0.473	0.542	0.669	0.454	0.508	0.577
Average mi/gal	10.24	11.37	12.66	10.23	11.36	12.44
Heavy truck						
VMT (10 ⁹)	34.92	41.90	57.22	31.94	41.51	48.46
Gal gasoline (10 ⁹)	3.50	2.96	2.41	3.15	2.77	2.06
Gal diesel (10 ⁹)	1.25	2.21	3.91	1.20	2.36	3.40
Quads	0.611	0.677	0.844	0.560	0.634	0.729
Average mi/gal	7.35	8.10	9.05	7.34	8.08	8.88
Heavy-heavy truck						
VMT (10 ⁹)	51.23	59.59	70.77	49.23	55.90	61.01
Gal gasoline (10 ⁹)	0.52	0.22	0.02	0.50	0.21	0.01
Gal diesel (10 ⁹)	9.20	10.25	11.78	8.84	9.61	10.26
Quads	1.342	1.449	1.636	1.289	1.359	1.449
Average mi/gal	5.27	5.69	6.00	5.27	5.69	5.94
Total truck						
VMT (10 ⁹)	124.48	149.44	192.58	117.97	142.36	164.18
Gal gasoline (10 ⁹)	7.44	6.34	5.23	6.94	5.94	4.50
Gal diesel (10 ⁹)	10.78	13.52	18.00	10.36	12.97	15.63
Quads	2.394	2.667	3.149	2.304	2.50	2.75
Average mi/gal	6.83	7.53	8.29	6.82	7.53	8.16

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APPENDIX A
MATERIALS COMPOSITION
OF NEW VEHICLES,
1990 and 2000

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Table A.1 Materials Composition of New Vehicles
(% by Weight): 1990

Engine Technology	Engine Material(s) ^a	%	Body Material(s)	%
All Otto-cycle	Mild and specialty steels	16.9	Mild and specialty steels	62.0
	Cast iron	32.8	Cast iron	4.0
	Nodular iron	6.7		
	Malleable iron	2.2		
	Copper	3.3	Copper	1.2
	Aluminum	28.0	Aluminum	5.4
	Lead	4.2	Lead	0.3
	Rubber	1.2	Rubber	8.0
	Plastic	2.2	Plastic	10.0
	H ₂ SO ₄	1.9	Glass	4.0
	Ceramics	0.2	Sound-deadener	3.0
	Miscellaneous	0.4	Miscellaneous	2.1
All diesel	Mild and specialty steels	32.9	Mild and specialty steels	62.0
	Cast iron	24.2	Cast iron	4.0
	Nodular iron	22.8		
	Malleable iron	2.0		
	Copper	1.4	Copper	1.2
	Aluminum	4.4	Aluminum	5.4
	Lead	4.6	Lead	0.3
	Rubber	0.2	Rubber	8.0
	Plastic	0.8	Plastic	10.0
	H ₂ SO ₄	1.7	Glass	4.0
	Miscellaneous	5.0	Sound-deadener	3.0
			Miscellaneous	2.1
Electric vehicle	Mild and specialty steels	1.0	Mild and specialty steels	62.0
	Malleable iron	47.0	Cast iron	4.0
	Copper	34.0	Copper	1.2
	Aluminum	9.0	Aluminum	5.4
	Silicon	1.5	Lead	0.3
	Miscellaneous	7.5	Rubber	8.0
			Plastic	10.0
			Glass	4.0
			Sound-deadener	3.0
			Miscellaneous	2.1
Lead/acid EV propulsion battery materials	Lead	60.5	N/A	
	Rubber	1.44		
	Plastic	5.4		
	Glass	0.21		
	H ₂ SO ₄	29.63		
	Miscellaneous	2.82		
Nickel/zinc EV propulsion battery materials	Copper	0.72	N/A	
	Zinc	17.7		
	Nickel	29.7		
	Cobalt	1.6		
	Plastic	7.2		
	Potassium hydroxide	33.7		
	Miscellaneous	9.38		

^aUsed for drivetrain, charger, and controller in electric vehicles and for drivetrain in heat-engine vehicles.

Table A.2 Materials Composition of New Vehicles
(% by weight): 2000

Engine Technology	Engine Material(s) ^a	%	Body Material(s)	%
All Otto-cycle	Mild and specialty steels	18.6	Mild and specialty steels	56.0
	Cast iron	7.2	Cast iron	4.0
	Nodular iron	7.4		
	Malleable iron	2.5		
	Copper	3.6	Copper	1.2
	Aluminum	28.8	Aluminum	9.0
	Lead	4.6	Lead	0.3
	Rubber	0.2	Rubber	10.0
	Plastic	2.4	Plastic	12.0
	H ₂ SO ₄	2.1	Carbon/graphite	1.2
	Ceramics	0.2	Glass	3.0
	Magnesium	20.7	Sound-deadener	3.0
	Miscellaneous	1.7	Miscellaneous	0.3
All diesel	Mild and specialty steels	30.9	Mild and specialty steels	56.0
	Cast iron	26.3	Cast iron	4.0
	Nodular iron	11.1		
	Malleable iron	2.6		
	Copper	1.7	Copper	1.2
	Aluminum	6.1	Aluminum	9.0
	Lead	4.7	Lead	0.3
	Rubber	0.2	Rubber	10.0
	Plastic	1.1	Plastic	12.0
	H ₂ SO ₄	1.7	Carbon/graphite	1.2
	Ceramics	11.1	Glass	3.0
	Miscellaneous	2.5	Sound-deadener	3.0
			Miscellaneous	0.3
Electric vehicle	Mild and specialty steels	1.0	Mild and specialty steels	56.0
	Malleable iron	46.0	Cast iron	4.0
	Copper	37.0	Copper	1.2
	Aluminum	9.0	Aluminum	9.0
	Silicon	1.5	Lead	0.3
	Miscellaneous	5.5	Rubber	10.0
			Plastic	12.0
			Carbon/graphite	1.2
			Glass	3.0
			Sound-deadener	3.0
Lead/acid EV propulsion battery materials			Miscellaneous	0.3
	Lead	60.5	N/A	
	Rubber	1.4		
	Plastic	5.4		
	Glass	0.2		
Nickel/zinc EV propulsion battery materials	H ₂ SO ₄	29.6		
	Miscellaneous	2.8		
	Copper	0.7	N/A	
	Zinc	17.7		
	Nickel	29.7		
	Cobalt	1.6		
	Plastic	7.2		
	Potassium hydroxide	33.7		
	Miscellaneous	9.4		

^aUsed for drivetrain, charger, and controller in electric vehicles and for drivetrain in heat-engine vehicles.

APPENDIX B

BASE-YEAR ENERGY INTENSITIES

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Table B.1 Base-Year Modal Energy Intensities by
Commodity Sector (Btu/TMT)

Code ^a	Commodity Sector	Truck	Rail	Water	Air	Pipe
1	Farm products	2038	531	481	3300	0
2	Forestry, fishery products	2134	545	370	3300	0
3	Metal mining	2134	522	511	0	0
4	Coal mining	2134	489	481	0	0
5	Nonmetal mining	2134	528	511	0	250
6	Crude oil	2134	665	408	0	0
7	Construction	2388	525	370	3300	0
8	Meat and dairy products	1986	701	370	3300	0
9	Canned, frozen, and other foods	1986	701	370	3300	0
10	Candy, cookies, beverages, tobacco	1986	701	370	3300	0
11	Basic textiles and leather	2245	1009	370	26859	0
12	Apparel and related products	2245	1009	370	26859	0
13	Paper products	2055	685	370	3300	0
14	Industrial chemicals and synthetics	2134	540	334	3300	0
15	Drugs, paints, other chemicals	2134	540	334	3300	0
16	Petroleum products	2235	526	408	3300	300
17	Rubber and misc. plastic products	2388	525	370	3300	0
18	Lumber and wood products	2398	620	481	3300	0
19	Furniture and fixtures	2398	620	370	3300	0
20	Stone, clay, and glass products	2388	525	481	3300	0
21	Iron and steel products	1968	534	481	3300	0
22	Primary nonferrous metal products	1968	534	370	3300	0
23	Fabricated metal products	2118	761	370	26859	0
24	Metal cans and miscellaneous	2118	761	370	3300	0
25	Industrial machinery	1933	990	370	3300	0
26	Other machinery	1933	990	370	26859	0
27	Communications equipment	1974	1273	370	26859	0
28	Electrical products	1974	1273	370	26859	0
29	Motor vehicles and equipment	2355	979	370	3300	0
30	Transportation equipment	2355	979	370	3300	0
31	Instruments, cameras, etc.	2388	525	370	26859	0
32	Wholesale and retail trade	2134	554	370	3300	0
33	Business and personal services	2134	554	370	3300	0
34	Communications	2134	554	370	3300	0
35	Other	2134	554	370	3300	0
36	Postal services	2134	554	370	3300	0
37	Natural gas	0	0	0	0	2000

^aCommodity classification code used to identify economic sector in FRATE model.

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Heat Content of Various Fuels^a

Fuel	Heat Content
Fuel oil	
Crude	138,100 Btu/gal
Residual	149,700 Btu/gal
Distillate	138,700 Btu/gal
Automotive gasoline	125,000 Btu/gal
AVGAS	124,000 Btu/gal
Jet fuel (kerosene)	135,000 Btu/gal
Jet fuel (naphtha)	127,500 Btu/gal
Diesel oil (32)	138,700 Btu/gal
Coal product	
Crude light oil	130,000 Btu/gal
Crude coal tar	150,000 Btu/gal
Crude petroleum	138,100 Btu/gal
Ethane	73,390 Btu/gal
Still gas	142,286 Btu/gal
Natural gas	
Liquid	95,800 Btu/gal
Wet	1,095 Btu/ft ³
Dry	1,021 Btu/ft ³
Coal	
Anthracite	25.4 · 10 ⁶ Btu/short ton
Bituminous	26.2 · 10 ⁶ Btu/short ton
Lignite	13.4 · 10 ⁶ Btu/short ton
Electrical generation and distribution efficiency	30%
Lubricants	144,405 Btu/gal
Waxes	155,643 Btu/gal
Petroleum coke	143,423 Btu/gal
Asphalt and road oil	158,000 Btu/gal
Natural gasoline and cycle products	110,000 Btu/gal

^a1 Btu/gal = 278.7 J/L = 2.787 · 10⁵ J/m³

1 Btu/short ton = 942 J/metric ton