TRANSPORTATION ENERGY EFFICIENCY TRENDS, 1972-1992

David L. Greene

Center for Transportation Analysis
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Yuehui Fan

Oak Ridge Associated Universities
Oak Ridge, Tennessee

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ABSTRACT

The U.S. transportation sector, which remains 97% dependent on petroleum, used a record 22.8 quads of energy in 1993. Though growing much more slowly than the economy from 1975 to 1985, energy use for transportation is now growing at nearly the same rate as GDP. This report describes the analysis of trends in energy use and energy intensity in transportation into components due to, 1) growth in transportation activity, 2) changes in energy intensity, and 3) changes in the modal structure of transportation activities. Had passenger and freight movements in 1992 taken place at 1972 energy intensities and modal shares, 3.8 quads more energy would have been required. Energy intensity reductions would have saved 4.9 quads in 1992, had shifts to more energy intensive modes not tended to increase energy use. Passenger transport shows net efficiency gains while the freight sector as a whole does not, although poor data on freight activity casts doubt on the validity of the decomposition of freight energy intensity trends. An exception is rail freight, which would have used 75% more energy if 1992 movements had taken place at 1972 energy use per ton-mile. Air passenger travel achieved the greatest efficiency gains: at 1972 passenger mile efficiencies commercial air travel would have used twice as much energy as it actually did in 1992. Had the miles per gallon of highway passenger vehicles remained at 1972 levels, highway passenger travel would have used 6.6 quads more energy in 1992. Decreases in vehicle occupancy eroded 3.7 of the potential 6.6 quad savings. A detailed analysis of trends in new passenger car and light truck fuel economy from 1975 to 1993 shows that changes in the vehicle salesmix have had a relatively minor impact on fleet fuel economy. The shift from passenger cars to light trucks has tended to reduce overall light duty vehicle MPG by about 1 MPG, but sales shifts within the passenger car and light truck segments have more than offset this producing a net increase in MPG due to salesmix changes. Decreased vehicle weight has boosted fuel economy by 2 MPG, but increased performance has erased essentially all of that gain, with the result that almost all of increase in new vehicle MPG between 1975 and 1993 can be attributed to improved fuel economy technology. Essentially all (97%) of the 60% increase in new light duty vehicle MPG since 1975 had already been accomplished by 1985. The fact that fuel economy has not significantly changed for a decade, together with increasing traffic congestion and urbanization are probably responsible for the reported decline in in-use fleet fuel economy in 1992.

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TRANSPORTATION ENERGY EFFICIENCY TRENDS, 1972-1991

1. INTRODUCTION

The U.S. Transportation sector, which remains 97% dependent on petroleum, used a record high 22.8 quads of energy in 1993 (Figure 1). Though still growing more slowly than the economy as a whole, energy use in the transportation sector has accelerated over the past decade. Energy use in 1993 was up 2% over 1992, compared with average annual rates of just over 1.5% since 1982, and just over 1.0% since 1973 (U.S. DOE, EIA, 1994, Table 2.2). For twenty years prior to the oil price shock of 1973-74, transportation's energy use grew at about the same rate as GDP minus about one half percent. In 1979, growth of transportation energy use slowed dramatically relative to economic growth, and for nearly a decade from 1978 to 1986 transportation energy use grew at only half the rate of GDP. But by 1985 the gap in growth rates began to narrow. Although energy use today remains much lower than it would have been had no efficiency improvements been made, transportation energy use appears once again to be increasing at just slightly less than the rate of overall economic growth.

This paper describes a decomposition of trends in energy use in the transportation sector into components associated with, 1) the growth of transportation activities, 2) changes in energy intensity measured as energy use per dollar or per unit of activity such as passenger-mile or ton-mile, and 3) changes in the structure of transportation activities (e.g., the distribution of activity by mode).¹ For passenger travel by highway and air, the effects of trends in vehicle occupancy rates or load factors are also measured. The objective is to better understand when and how changes in transportation energy use came about as a guide to where energy use and energy conservation are headed. The Divisia decomposition method, a simple yet elegant means of breaking the trend into its components, is used throughout the energy analyses (Boyd, McDonald, Ross, and Hanson, 1987; Ross, 1989).

This paper is comprised of six sections.

¹We do not consider changes in circuitry, the ratio of actual distance traveled to the great circle distance between origin and destination.

Figure 1. U.S. Transportation Energy Use 1973-1993

U.S. DOE/EIA, (1993) AER table 1.5, (1994) MER table 2.5

First, the Divisia technique is briefly explained. A more detailed mathematical exposition is provided as an appendix.

Second, overall changes in transportation energy use are decomposed into intensity changes (energy use per dollar of transportation produced) and structural shifts (changes in shares of dollars of output between passenger and freight movements and across modes within the passenger and freight sectors), and overall growth in transportation activity.

Third, trends within the passenger mode are analyzed. At this level of the analysis, activity is measured by passenger-miles. Separate analyses of efficiency trends within highway and air transport are presented, introducing vehicle occupancy rates as a determinant of energy use per passenger mile.

Fourth, trends in freight energy use per ton-mile are analyzed, although severe data limitations cloud the interpretation of apparent trends.

Fifth, there is a separate analysis of light duty vehicle fuel economy trends from 1975-1993, using detailed fuel economy and sales data. Efficiency and market share effects are quantified for passenger cars and light trucks, and within the two vehicle classes by size class of vehicle. Next, effects of changes in performance and weight and fuel economy are quantified, so that changes in MPG of new light duty vehicles can be decomposed into performance, weight, technology, and sales shift components.

Sixth, energy use and efficiency trends since 1985 are described and contrasted with the trends of the 1972-1985 period.

This analysis differs from previous decompositions of transportation energy trends (U.S. DOE, 1989; Ross, 1989) in that we have attempted to use consistent activity measures to the maximum extent possible. Whereas we use passenger-miles to measure activity for all passenger modes and ton-miles for nearly all freight modes, Ross (1989) uses vehicle miles for automobiles and light trucks, and measures heavy truck activity in proportion to GNP. It is not that one approach is wrong and the other right, it is that they will give different answers. Available data suggest that there have been important trends in highway vehicle load factors. The advantage of our approach

is that it captures these trends. The disadvantage is that to do so it occasionally makes use of data whose validity may be questionable.

Available data on transportation activities are deficient in many areas, hindering the assessment of energy trends. In the freight sector, estimates of ton-miles transported are poorly known for all types of trucks but especially single-unit trucks. Ton-miles transported by pipelines, especially natural gas pipelines are not reported on an annual basis. Estimated energy efficiencies for domestic waterborne transport fluctuate widely for reasons that are not well understood and ton-miles and energy use in international shipping are poorly understood. On the passenger side, reasonable estimates of highway vehicle miles are available, but consistent estimates of vehicle occupancy rates (and thus passenger miles) are available only from infrequent surveys. Intervening years must be interpolated. The reader is urged to keep these serious data limitations in mind when interpreting the results of this analysis. Broad trends are likely to be meaningful, but numerical results involving suspect data, such as truck ton-miles, must be interpreted with caution.

In contrast to the relatively poor data on transportation activity levels, excellent, detailed data are available on the fuel economy and related characteristics of light duty vehicles (Murrell, Hellman, and Heavenrich, 1993). It is for this reason and because light duty vehicles account for 57% of transportation energy use (Davis and Strang, 1993) that trends in light duty vehicle fuel economy are the subject of more detailed analysis.

2. ANALYSIS OF ENERGY USE TRENDS BY DIVISIA DECOMPOSITION

The Divisia method is used in this study to analyze year-to-year changes in transportation energy use into energy intensity and structural change components. Divisia decomposition is a simple but elegant mathematical method for precisely analyzing any time trend that can be expressed as a product of several factors into its component parts (Boyd et al., 1987). Because energy use trends can generally be expressed as a product of elements such as energy use per unit of product, productivity per dollar, and total dollars of output, the Divisia technique is a fundamentally appropriate method for analyzing energy use trends. A brief description of the method is provided below. A more detailed mathematical explanation may be found in Appendix A.

In general, energy use (E) per unit of time (t) can be expressed as energy use per unit of activity (A) times the level of activity in time period t.

$$E_t = \left(\frac{E}{A}\right)_t \cdot A_t = e_t \cdot A_t \quad (1)$$

Here e is the measure of energy intensiveness, such as energy use per dollar, per passenger-mile, per ton-mile, etc. If the activity measured by A can be subdivided into meaningful categories, equation (1) can be written as a sum of energy uses.

$$E_t = \sum_{i=1}^n \left(\frac{E_u}{A_u}\right) \left(\frac{A_u}{A_t}\right) A_t \quad (2)$$

The Divisia method decomposes $e = E/A$ into changes in efficiency within subcategories and changes in the mix of activity among categories over time.

$$\Delta e_t = \sum_{i=1}^n \left[(e_t - e_{t-1})_i \frac{(s_t + s_{t-1})_i}{2} + (s_t - s_{t-1})_i \frac{(e_t + e_{t-1})_i}{2} \right] \quad (3)$$

Where $s_i = A_i/A$, is the activity share of subcategory i. In equation (3), the change in energy use from year t-1 to t is decomposed into two parts: 1) change in energy intensiveness, and 2) change in activity shares. For example, if passenger-miles per Btu improved for air and highway travel

this would show up in the first component as a decrease in energy intensiveness. If travel shifted from less energy intensive highway travel to air travel, this would show up as an increase in the second component.

If the year-to-year components of energy intensity changes estimated by the Divisia technique are added cumulatively over time, they produce an estimate of the cumulative effect of intensity or structural change that can be multiplied by the current activity level to obtain the cumulative change in energy use. By adding this estimate from actual energy use in the current year, one obtains an estimate of what energy use would have been for that year's activity level, but at the base year energy efficiency, and base year modal structure. We refer to that here as the "Trended Energy Use." The Trended Energy Use is exactly equal to the level of activity in a given year multiplied by the energy intensity of the base year. The difference between the Trended Energy Use and the actual energy use is the net effect of changes in the efficiency and structural components.

Both efficiency and structural component estimates depend on the categories into which transportation activities are divided. Thus, understanding how the sector has been structured for Divisia analysis is essential to understanding the meaning of the component estimates. The structure used for analyzing total transportation sector trends is illustrated in Figure 2. All transportation activity is divided into three parts: 1) Passenger, 2) Freight, and 3) Other. Also shown in Figure 2 are the elementary units in which activity data are available for the different modes. Reasonable estimates of passenger miles can be constructed for all passenger modes. Ton-mile estimates can be derived for all freight modes save international waterborne commerce, whose activity levels are measured in terms of ton-miles on U.S. territorial waters only. Air freight has not been included because the bulk of it is carried by commercial passenger flights, and a complete and consistent time series for all cargo flights is not readily available, but in any case, all cargo flights account for only a small fraction of a percent of transport energy use. Within the passenger sector, six modes are defined: three highway vehicle types, commercial and general aviation, and passenger rail. Within the freight mode highway freight is divided between larger single unit and combination trucks and domestic waterborne freight, rail and pipeline round out the sector. Military transportation and international waterborne freight energy use comprise a separate category. Energy use changes attributed to structural shifts include changes in the relative activity levels of these submodes shown in Figure 2.

For the overall analysis of transportation energy trends, activity is measured in dollars. While reasonable estimates of freight revenues are available, most passenger travel is produced by

FIGURE 2. STRUCTURE OF TRANSPORTATION SECTOR DECOMPOSITION

households and so comparable revenue estimates are not available. Instead, we have substituted estimates of dollar costs of personal vehicle travel, based on vehicle operating costs per mile. The values of modal activities are computed using 1987 as an index year, in much the same way price indices are constructed. For example, 1987 commercial air carrier revenues are divided by 1987 revenue passenger miles (RPM) to obtain a dollar yield per RPM for 1987. This value is then multiplied by RPMs in all years to obtain a series of dollar activity estimates indexed to 1987.²

For separate analyses of the freight or passenger modes, ton-miles and passenger miles, respectively, are used as activity measures. These may seem to be uniform measures for the respective modes but, in fact, a passenger mile by air is qualitatively different from a passenger-mile by car, the most obvious but not only difference being speed. The same holds for freight: tons of overnight mail do not equate to tons of coal shipped by rail or tons of oil by tanker. Thus, the analyst and reader must bear in mind that some of the changes that appear in a Divisia analysis of trends will be due to the changing nature of the phenomena being studied and others will be artifacts of definitions that equate ton-miles of potato chips to ton-miles of crushed rock. The freight mode has exactly the same structure as used in the total transportation sector analysis. The chief differences between the separate passenger and freight analyses and the overall transportation sector analysis is separation of passenger and freight efficiency trends and the use of passenger- and ton-miles rather than dollars to measure activity levels.

The six Divisia analyses are illustrated in Figure 3, which also shows the units in which activity is measured for each one. Splitting the transportation sector into passenger and freight allows us to see the differences between energy intensity trends in the two subsectors. Further analysis of highway, air, and rail modes make use of the load factor estimates available for these modes to distinguish between vehicle efficiency and vehicle occupancy effects on energy intensity.

²Using this indexing method means that productivity effects, defined as changes in physical output per dollar (e.g., ton-miles/\$), cannot be quantified since they will be zero by construction.

FIGURE 3. INDIVIDUAL DIVISIA ANALYSES OF ENERGY INTENSITY CHANGES

3. TRENDS IN TRANSPORTATION SECTORAL EFFICIENCY

The transportation sector would have used 3.8 quads more energy in 1992, had passenger and freight movements taken place at 1972 energy intensities per dollar and relative modal activity levels (Figure 4, Table 1). Had there also been no changes in the modal shares (using the structure defined in Figure 2), energy use would have been 4.9 quads higher than it was. Cumulative component changes are shown as "stacked" bars in the lower portion of the graph, with effects tending to reduce energy use shown as negative values. The difference between the solid energy use trend line and the dotted actual energy use line is the net effect, or sum, of the components.

Note that the stacked bars show cumulative effects, so that the fact that the bars remain at a roughly constant level from 1975 to 1979 implies that energy use per dollar was neither increasing nor decreasing. In the 1970s, efficiency and structural effects both tended to increase energy use. The decline in energy use in 1974-75 was therefore due solely to a decline in transportation activity. Starting in 1978, efficiency began improving, a trend that continued through 1992. At the same time, gradual structural shifts tended to increase energy use with a cumulative effect of one quad through 1990.

These trends are somewhat different from those reported in U.S. DOE (1989) for 1972-86 and also differ from Ross' (1989) calculations for the 1972-1985 period. The DOE analysis shows slightly increasing energy intensity up to 1975, but growing efficiency, or "conservation savings" thereafter. By 1986 the DOE study reports an almost 4 quad savings due to efficiency improvements, nearly all due to light duty vehicles and commercial aircraft. Ross' findings are similar, annual average growth rates in passenger- and ton-miles of traffic of 3.6% and 1.7%, but an overall growth rate of energy use of only 1% due to an average 2.4%/yr. decrease in energy intensity for passenger travel and 1.1%/yr. decrease for freight. In contrast, our analysis finds no net energy savings until after 1980 and no net savings for the freight modes, collectively.

The reason why previous studies have found earlier and larger energy efficiency savings than we have is because they measured energy intensities for passenger cars, light trucks, and heavy trucks on a per vehicle-mile basis. We measure passenger car and light truck activity in passenger-miles and heavy truck activity in ton-miles. Because the best available data indicate significant declines in vehicle occupancy rates and in truck load factors, particularly during the 1970s, our analysis indicates less reduction in energy intensities.

FIGURE 4. TRANSPORTATION ENERGY USE, 1972-1992
EFFICIENCY AND MODAL STRUCTURE EFFECTS

Table 1. Changes in Transportation Energy Use, 1972-1992
Efficiency and Sectoral Structure Effects

YEAR	Actual Energy Use (Quads)	Trended Energy Use (Quads)	Components of Energy Savings (Quads)			Activity in 1987 Indexed \$s (billion)
			Total	Efficiency	Structure	
1972	18.0	18.0	0.00	0.00	0.00	679
1973	18.8	18.5	0.28	0.13	0.14	697
1974	18.0	17.9	0.07	0.02	0.05	674
1975	18.2	17.8	0.46	0.23	0.23	670
1976	19.2	18.6	0.67	0.42	0.25	701
1977	20.0	19.4	0.67	0.49	0.17	731
1978	20.9	20.4	0.50	0.25	0.25	771
1979	21.0	20.5	0.48	0.21	0.26	775
1980	20.2	20.0	0.13	-0.22	0.35	756
1981	19.9	19.9	-0.03	-0.45	0.42	751
1982	19.3	20.0	-0.62	-1.01	0.39	754
1983	19.5	20.8	-1.34	-1.59	0.25	785
1984	20.0	21.8	-1.77	-2.04	0.27	822
1985	20.5	22.2	-1.68	-2.05	0.37	835
1986	21.3	22.9	-1.66	-1.99	0.33	864
1987	21.7	23.8	-2.15	-2.61	0.46	898
1988	22.3	24.7	-2.37	-3.00	0.63	931
1989	22.7	25.2	-2.42	-3.23	0.81	948
1990	22.7	25.6	-2.91	-3.84	0.93	964
1991	22.1	25.9	-3.75	-4.63	0.88	976
1992	22.6	26.3	-3.75	-4.85	1.06	993

4. PASSENGER TRAVEL ENERGY EFFICIENCY TRENDS

Significant improvements in transportation energy efficiency have been made in passenger travel. Had there been no changes in vehicle efficiencies, vehicle occupancies, and the modal shares of passenger travel, 19.4 quads would have been required for the over 4 trillion passenger miles traveled in 1992 (Figure 5, Table 2), a 23% increase over actual energy use. In fact, vehicle occupancy rates have declined significantly since 1972, and modal shifts have on net favored less energy efficient modes. If these factors had remained constant at 1972 levels but highway vehicle and aircraft fuel economy had improved as they did, passenger travel would have required only 11.5 quads of energy in 1992, almost 30% less than actual energy use and 40% less than if none of these changes had occurred.

As Figure 5 shows, efficiency initially declined through 1977. By 1978 this trend began to reverse and efficiency improvements added continually to energy savings through 1992. Structural shifts and vehicle occupancy rates seem to have gradually and continuously added to energy use in passenger transport. Since load factors on commercial aircraft have been improving over this period, the increase in energy use due to structural change must be entirely attributable to shifts to more energy intensive vehicle types and/or the general decline in automobile and light truck occupancy rates (Table 3). The rapid growth of air travel increased its share of passenger miles from 5.6% in 1972 to 12.3% in 1992. The increasing popularity of light trucks for passenger travel boosted their share of passenger miles from 11.6% in 1972 to 20.4% by 1992. Declines in the shares of rail and bus had a relatively minor impact.

By far the most dramatic energy efficiency gains have been achieved by commercial air travel. Energy use for air travel would have been more than twice what it was in 1992 had there been no reductions in energy use per seat-mile (Figure 6, Table 4). Almost three-fourths of the gain in passenger-miles per gallon can be attributed to delivering more seat miles per gallon, the remaining one fourth being due to an increase in the average number of passengers per seat. Contrary to the trend for highway travel, aircraft load factors improved through 1979 and then worsened suddenly in 1980, perhaps as an immediate impact of airline deregulation. In subsequent years aircraft occupancy regained lost ground and by 1989 contributed half a quad to air travel energy savings.

**FIGURE 5. PASSENGER TRANSPORTATION ENERGY USE
1972-92, EFFICIENCY AND MODAL STRUCTURE EFFECTS**

Table 2. Passenger Transportation Energy Use, 1972-1992
Efficiency and Modal Structure Effects

YEAR	Actual Energy Use (Quads)	Trended Energy Use (Quads)	Components of Energy Savings (Quads)			Passenger-Miles (billion)
			Total	Efficiency	Structure	
1972	13.1	13.1	0.00	0.00	0.00	2,717
1973	13.7	13.5	0.25	0.14	0.11	2,784
1974	13.1	12.9	0.19	0.06	0.13	2,671
1975	13.5	13.1	0.38	0.22	0.16	2,704
1976	14.2	13.6	0.61	0.40	0.21	2,810
1977	14.6	13.9	0.69	0.42	0.27	2,875
1978	15.1	14.5	0.54	0.17	0.37	3,007
1979	14.7	14.4	0.30	-0.12	0.42	2,986
1980	13.9	14.3	-0.43	-0.83	0.41	2,958
1981	13.7	14.4	-0.65	-1.05	0.40	2,970
1982	13.6	14.7	-1.05	-1.48	0.42	3,031
1983	13.8	15.1	-1.31	-1.79	0.48	3,119
1984	14.1	15.7	-1.54	-2.06	0.52	3,228
1985	14.4	16.1	-1.67	-2.26	0.60	3,324
1986	15.0	16.7	-1.70	-2.29	0.59	3,444
1987	15.2	17.3	-2.05	-2.78	0.73	3,577
1988	15.5	18.1	-2.58	-3.34	0.76	3,746
1989	15.7	18.5	-2.84	-3.65	0.81	3,833
1990	15.8	18.8	-3.03	-3.90	0.87	3,897
1991	15.4	18.9	-3.52	-4.37	0.85	3,911
1992	15.9	19.4	-3.52	-4.38	0.86	4,021

Table 3. Vehicle Occupancy Rates and Load Factors, 1972-1991

	1972	1975	1977	1980	1983	1985	1990	1991
Passenger (passenger-miles/vehicle-miles)								
Passenger Car	2.07		1.86		1.76		1.62	1.61
Light Truck	2.02		1.81		1.71		1.72	1.72
Air	65.2		85.2		101.0		100.0	99.5
Bus	18.3		18.6		15.9		15.3	15.4
Rail	26.7		26.9		25.5		23.4	22.9
Freight (ton-miles/vehicle-miles)								
Combination Trucks	11.5	9.7		8.1		7.7	7.6	7.8
Rail	25.9	27.4		31.8		35.9	40.9	42.1

**FIGURE 6. AIR PASSENGER ENERGY USE, 1972-1992
SEAT-MILE EFFICIENCY AND LOAD FACTOR EFFECTS**

Table 4. Air Passenger Energy Use Trends, 1972-1992
Seat-Mile Efficiency and Load Factor Effects

YEAR	Actual Energy Use (Quads)	Trended Energy Use (Quads)	Components of Energy Savings (Quads)			Passenger-Miles (billion)
			Total	Tech. Imp.	Load Effect	
1972	1.4	1.4	0.00	0.00	0.00	152
1973	1.4	1.6	-0.13	-0.10	-0.03	174
1974	1.3	1.6	-0.28	-0.20	-0.08	174
1975	1.3	1.6	-0.28	-0.23	-0.05	173
1976	1.3	1.7	-0.41	-0.30	-0.10	192
1977	1.4	1.9	-0.47	-0.35	-0.12	206
1978	1.4	2.1	-0.70	-0.44	-0.27	237
1979	1.5	2.4	-0.90	-0.57	-0.33	270
1980	1.5	2.4	-0.92	-0.69	-0.24	268
1981	1.4	2.4	-0.92	-0.69	-0.22	260
1982	1.4	2.5	-1.05	-0.81	-0.24	272
1983	1.4	2.7	-1.22	-0.92	-0.30	295
1984	1.6	2.9	-1.27	-0.98	-0.29	320
1985	1.7	3.2	-1.46	-1.08	-0.38	351
1986	1.9	3.4	-1.57	-1.20	-0.37	379
1987	2.0	3.8	-1.82	-1.36	-0.46	418
1988	2.1	4.0	-1.90	-1.40	-0.50	438
1989	2.1	4.0	-1.95	-1.41	-0.54	447
1990	2.2	4.3	-2.07	-1.53	-0.54	472
1991	2.1	4.2	-2.11	-1.58	-0.53	463
1992	2.1	4.5	-2.30	-1.70	-0.60	493

The 3.5 trillion passenger miles traveled by highway in 1992 would have required an additional 6.6 quads of energy had vehicle fuel economy remained constant at 1972 levels (Figure 7, Table 5). During the 1970s vehicle-mile energy efficiency decreased in 1973, and then began continuous improvement. Illustrating the gradual process of turnover of the vehicle stock, replacing older low Figure 7. Highway Passenger Energy Use, 1972-1992, Efficiency, Occupancy and Vehicle Type Effects fuel economy vehicles with newer more efficient ones, the improvement is gradual. As we will see in Section 6, new light duty vehicle fuel economy has not improved appreciably since 1982. Since the average vehicle life expectancy is now about 12 years, we should expect fleet efficiency improvements to be slowing to a stop soon. This appears to have begun, since the efficiency gain in 1992 is the smallest since 1976. The gains in vehicle efficiency, however, were more than cut in half by falling vehicle occupancy rates and to a lesser extent by shifts to vehicle types with lower fuel economy. Decreases in the number of passengers per vehicle mile added 3.5 quads to total energy use, while vehicle type shifts added 0.5 quads. The effect of the increasing light truck market share on efficiency is small but evident at the very beginning of the period and persists in spite of the fuel price shocks of 1973-74 and 1979-80. Decreasing vehicle occupancy rates appear to have been the most important factor in eroding the gains due to vehicle efficiency improvements. Caution must be exercised in interpreting this result, however, since the data on highway vehicle occupancy rates is rather weak. The best data come from surveys such as the Nationwide Personal Transportation Survey, rather than from direct observation of highway vehicles.³

³Occupancy rates are occasionally estimated from direct observation of vehicles, but this is not done on a systematic basis for the entire country. Thus, such data provide essentially anecdotal support to the survey data.

**FIGURE 7. HIGHWAY PASSENGER ENERGY USE, 1972-1992
EFFICIENCY, OCCUPANCY AND VEHICLE TYPE EFFECTS**

Table 5. Highway Passenger Energy Use Trends, 1972-1992
Efficiency, Occupancy and Vehicle Type Effects

YEAR	Actual Energy Use (Quads)	Trended Energy Use (Quads)	Components of Energy Savings (Quads)				Passenger-Miles (billion)
			Total	Efficiency	Occupancy	Structure	
1972	11.6	11.6	0.00	0.00	0.00	0.00	2,534
1973	12.1	11.8	0.32	0.04	0.24	0.04	2,577
1974	11.7	11.3	0.38	-0.14	0.48	0.04	2,463
1975	12.0	11.4	0.56	-0.26	0.74	0.07	2,497
1976	12.7	11.8	0.86	-0.27	1.04	0.09	2,584
1977	13.0	12.1	0.94	-0.53	1.35	0.12	2,635
1978	13.4	12.5	0.92	-0.78	1.52	0.17	2,734
1979	13.0	12.3	0.72	-1.07	1.60	0.19	2,677
1980	12.2	12.1	0.02	-1.86	1.70	0.18	2,652
1981	12.1	12.2	-0.18	-2.18	1.83	0.18	2,674
1982	12.0	12.5	-0.51	-2.69	1.98	0.20	2,725
1983	12.1	12.8	-0.64	-3.03	2.14	0.24	2,790
1984	12.3	13.2	-0.91	-3.48	2.30	0.26	2,884
1985	12.5	13.4	-0.96	-3.74	2.45	0.33	2,938
1986	12.9	13.9	-0.98	-3.91	2.62	0.31	3,029
1987	13.1	14.3	-1.21	-4.46	2.83	0.42	3,123
1988	13.3	15.0	-1.71	-5.21	3.06	0.44	3,272
1989	13.4	15.3	-1.93	-5.65	3.24	0.48	3,347
1990	13.4	15.5	-2.09	-6.01	3.39	0.52	3,387
1991	13.1	15.6	-2.49	-6.53	3.53	0.51	3,410
1992	13.6	16.0	-2.38	-6.60	3.72	0.50	3,491

5. FREIGHT ENERGY EFFICIENCY TRENDS

The picture for the freight sector is entirely different, although the reader is once again warned that the quality of data on freight activities is poor, and could be misleading. However, Divisia analysis of the available data suggest that had ton-mile energy efficiencies and the distribution of traffic by mode remained at their 1972 levels, freight transport in the U.S. in 1992 would have required 0.1 quads more energy than was actually used (Figure 8, Table 6). The small impact of changes in the modal structure of freight transport is not surprising given that the modal shares of ton miles in 1992 were almost identical to those in 1972. Rail carried an estimated 28% of ton-miles in 1972 and 29% in 1991. Combination trucks increased their share from 17% to 20%. Changes in the energy intensity of ton-mile movements tended to increase energy use slightly as efficiency gains by the rail mode were offset by apparent increases in the energy use per ton-mile by intercity trucks. Rail freight Btu per ton-mile has declined from 706 in 1972 to just over 399 in 1992. The energy intensiveness of domestic waterborne commerce shows a more erratic but still overall downward trend. Truck transport efficiency is commonly measured in terms of Btu per vehicle mile (or MPG), and these statistics show a very slight downward trend for heavy trucks. The truck statistics are poor, however, and could easily be misleading.

The factor responsible for the apparent overall decline in freight energy efficiency is a decline in tons per truck (truck load factors). This is precisely what the available published data indicate. These data, however, are rough estimates and could be subject to substantial error.⁴ What little other evidence there is on truck load factors, however, tends to corroborate the conclusion of decreasing heavy truck load factors. The Census of Transportation Truck Inventory and Use Survey (TIUS) indicates the average load carried by combination trucks declined from 17.7 tons in 1982 to 15.9 tons in 1987.⁵ This is all the more surprising because the Surface Transportation Assistance Act of 1982 permitted larger and heavier trucks, including double trailers, to operate nationwide over a specified network for the first time. Other things equal, this should have increased the average tons carried per truck. The available data suggest, however, that other

⁴This is not intended to be a criticism of the data source or its methods. It is simply a result of the fact that highway freight movements have not been systematically measured for over a decade. At this point, even the best estimates will only be educated guesses.

⁵The TIUS data also suggest a decline in tons carried per heavy single unit truck. Because this "trend" is based on only two data points, and because single unit trucks are often not carrying freight at all, we have assumed a constant load factor of 4.84 ton-miles per truck-mile for single unit trucks.

**FIGURE 8. FREIGHT ENERGY USE, 1972-1992
EFFICIENCY AND MODAL STRUCTURE EFFECTS**

Table 6. Freight Transportation Energy Use, 1972-1992, Efficiency and Modal Structure Effects

YEAR	Actual Energy Use (Quads)	Trended Energy Use (Quads)	Components of Energy Savings (Quads)			Ton-Miles (billion)
			Total	Efficiency	Structure	
1972	3.7	3.7	0.00	0.00	0.00	2,871
1973	3.8	3.9	-0.02	-0.05	0.03	3,019
1974	3.7	3.8	-0.14	-0.17	0.02	2,986
1975	3.5	3.6	-0.05	-0.11	0.06	2,812
1976	3.7	3.8	-0.12	-0.23	0.11	2,968
1977	3.9	4.0	-0.09	-0.27	0.18	3,099
1978	4.2	4.4	-0.25	-0.32	0.07	3,471
1979	4.4	4.6	-0.12	-0.15	0.03	3,571
1980	4.3	4.6	-0.25	-0.08	-0.17	3,568
1981	4.3	4.5	-0.14	0.08	-0.22	3,507
1982	4.1	4.2	-0.11	-0.03	-0.08	3,312
1983	4.2	4.4	-0.17	-0.20	0.04	3,412
1984	4.5	4.5	-0.01	-0.10	0.09	3,563
1985	4.7	4.5	0.20	0.06	0.14	3,511
1986	4.7	4.5	0.24	0.01	0.23	3,511
1987	4.9	4.7	0.19	-0.04	0.23	3,670
1988	5.1	4.8	0.21	-0.07	0.28	3,795
1989	5.1	4.8	0.34	-0.04	0.39	3,764
1990	5.2	4.9	0.31	-0.11	0.41	3,805
1991	5.0	4.9	0.15	-0.33	0.48	3,812
1992	5.1	5.0	0.11	-0.44	0.55	3,920

factors, perhaps the changing composition and delivery requirements of freight, and greater movements with part loads or empty back hauls, more than offset the potential for larger trucks to increase truck load factors. Because trucks are on average far more energy intensive per ton-mile than the other modes, these apparent changes in truck ton-mile efficiencies offset changes in the other modes.

The Divisia analysis of rail freight movements, in contrast, shows enormous efficiency gains, almost entirely due to increased carloads (ton-miles per railroad car-mile). If the 1992 rail ton-miles had been moved at 1972 energy intensities, 75% more energy would have been required (Figure 9, Table 7). Nearly all (85%) of .33 quad savings was achieved by increasing railroad car load factors from about 25 tons per car in 1972 to about 40 in 1992. More than any other mode, the rail mode has succeeded in reducing energy intensity by improving the efficiency of its operations.

FIGURE 9. RAIL FREIGHT ENERGY USE, 1972-1992
EFFICIENCY AND LOAD FACTOR EFFECTS

Table 7. Rail Freight Transportation Energy Use, 1972-1992
Efficiency and Load Factor Effects

YEAR	Actual Energy Use (Quads)	Trended Energy Use (Quads)	Components of Energy Savings (Quads)			Ton-Miles (billion)
			Total	Efficiency	Load Effect	
1972	0.6	0.6	0.00	0.00	0.00	777
1973	0.6	0.6	-0.04	0.00	-0.04	852
1974	0.6	0.6	-0.03	0.01	-0.04	851
1975	0.5	0.5	-0.02	0.01	-0.03	754
1976	0.5	0.6	-0.02	0.02	-0.04	794
1977	0.6	0.6	-0.03	0.03	-0.06	826
1978	0.6	0.6	-0.06	0.02	-0.08	858
1979	0.6	0.6	-0.08	0.03	-0.12	914
1980	0.5	0.7	-0.10	0.02	-0.12	919
1981	0.5	0.6	-0.12	0.02	-0.14	910
1982	0.4	0.6	-0.13	0.01	-0.13	798
1983	0.4	0.6	-0.15	-0.01	-0.15	828
1984	0.5	0.7	-0.18	-0.01	-0.18	922
1985	0.4	0.6	-0.19	-0.02	-0.17	877
1986	0.4	0.6	-0.20	-0.03	-0.17	868
1987	0.4	0.7	-0.25	-0.04	-0.20	944
1988	0.4	0.7	-0.27	-0.04	-0.23	996
1989	0.4	0.7	-0.28	-0.04	-0.24	1,014
1990	0.4	0.7	-0.30	-0.05	-0.26	1,034
1991	0.4	0.7	-0.33	-0.07	-0.27	1,039
1992	0.4	0.8	-0.33	-0.05	-0.28	1,067

6. LIGHT DUTY VEHICLE FUEL ECONOMY TRENDS⁶

The fuel economy of new passenger cars and light trucks improved dramatically in the decade following the oil price shock of 1973-74. Those gains were not reversed by the collapse of world oil prices in 1986 which returned motor fuel prices to near pre-1973 levels. Both passenger car and light truck miles per gallon (MPG) remained just above the levels required by federal Automotive Fuel Economy Standards despite falling gasoline prices and waning interest on the part of car buyers in miles per gallon. Over the past two decades important changes have taken place in the market mix of light duty vehicles. Light truck sales boomed while demand for passenger cars became sluggish. Sales by size of vehicle and market segment have waxed and waned in complex patterns. During the decade of the 1980s, vehicle performance increased dramatically while fuel economy remained constant. Trends toward lighter vehicles, established in the 1970s were reversed, completely in the case of light trucks and partially for passenger cars. How all of these trends affected overall light duty vehicle fuel economy is the subject of this section.

The Divisia analysis shows that sales shifts among vehicle size classes and even between passenger cars and light trucks are a relatively minor factor in overall light duty vehicle fuel economy. The key to past increases in light-duty vehicle fuel economy has been the improvement in miles per gallon of all types of vehicles, large and small, car and truck. Analysis of the effects of performance and weight on fuel economy reveals the importance of technological gains. If neither weight nor horsepower-to-weight ratios had changed since 1975, the average fuel economy of light-duty vehicles would be the same as it is today, 25 MPG. In other words, vehicle technology has been improved to the extent that the same size and weight vehicle that got 15 MPG in 1975 would get 25 MPG using today's technology. Weight reductions have boosted fuel economy by about 2 MPG, while performance increases have cost about 2 MPG.

6.1 CHANGES IN THE VEHICLE SALES MIX

From 15.3 miles per gallon (MPG) in 1975, the fuel economy of new light-duty vehicles increased to a peak of 25.9 MPG in 1987, and stands at 25.0 MPG today (Figure 10). Essentially all (97%)

⁶All of the data used in the analysis of passenger car and light truck fuel economy are from the Environmental Protection Agency's database of light duty vehicle fuel economy (Murrell, Hellman, and Heavenrich, 1993).

**FIGURE 10. NEW LIGHT-DUTY VEHICLE FUEL ECONOMY
EFFECT OF THE CAR/TRUCK SALESMIX, 1975-1993**

of the 60% fuel economy gain had been achieved by 1982. Neither passenger car nor light truck fuel economy has improved significantly for more than a decade.

Since 1975, light truck sales have nearly doubled due to the growing popularity of minivans and sport utility vehicles, while passenger car sales have fluctuated in the vicinity of 10 million units annually. As a result, the market share of light trucks increased from 19.4% to 34.2% (Figure 11). Because light truck MPG averages only about 75% of passenger car MPG, the market shift to light trucks might have been expected to have a seriously detrimental effect on overall fuel economy. To the contrary, the Divisia analysis reveals that the shift to light trucks reduced overall light-duty vehicle MPG by less than 1 MPG, or just under 4%. There are two reasons for this somewhat unexpected result. First, both passenger car and light truck MPG increased significantly over the period. Second, because average fuel economy is a weighted harmonic rather than a simple arithmetic mean, changes in market shares have less impact than one's intuition suggests.⁷

It is a popular misconception that fuel economy increased because consumers decided to buy smaller cars. The salesmix among car size classes is nearly the same today as in 1975 and as a result has been a minor factor in fuel economy trends (Figure 12). In part, the confusion stems from how one measures size. The weight and exterior dimensions of passenger cars have decreased. The interior dimensions which determine the room available for driver and passengers, have not. This analysis of salesmix shifts is based on EPA data, in which cars are classified by interior volume. Below, we separately assess the effect of weight reduction on fuel economy.

The increased market share of light trucks eroded about ten percent of the increase in light duty fuel economy that would have occurred had the car-truck shares remained constant and all else equal. This seems to suggest that market sales shifts have worked against the fuel economy gains made by cars and light trucks in response to fuel economy standards. A closer look at the effect of all salesmix shifts on fuel economy reveals a different picture. **Within** the car and light truck markets the sales shift effects appear quite different. For passenger cars, sales shifts had a minor, slightly positive effect on MPG, a fraction of an MPG out of a 12 MPG gain (Figure 13). For light trucks, sales shifts had a much larger beneficial impact on MPG, about 2 MPG out of 7 MPG (Figure 14). Thus, although the shift to light trucks tended to **decrease** the fuel economy of the

⁷Consider a simple example to illustrate how our intuition about weighted averages can be misleading. Suppose passenger cars have 70% of the market and get 20 MPG while light trucks have 30% and get only 15 MPG. The weighted harmonic average fleet MPG is 18.18. Now if the light truck share increases by 20 percentage points to 50%, the harmonic mean MPG decreases to 17.14 MPG, less than a 6% decline. What confuses our intuition is that a relative 40% increase in market share, causes only a 6% decrease in MPG.

**FIGURE 11. LIGHT-DUTY VEHICLE MARKET SHARES
1975-1993**

**FIGURE 12. MARKET SHARES OF PASSENGER CARS
BY SIZE CLASS, 1975-1993**

**FIGURE 13. NEW PASSENGER CAR FUEL ECONOMY
EFFECTS OF SIZE CLASS MARKET SHARES, 1975-1993**

**FIGURE 14. NEW LIGHT TRUCK FUEL ECONOMY
EFFECT OF TRUCK TYPE MARKET SHARES, 1975-1993**

light duty fleet, the shift within the light truck segment tended to **increase** it (Figure 15). The **net** result of sales shifts among classes of cars and trucks and between cars and trucks has been to increase light duty vehicle fuel economy. Figure 16 illustrates the cumulative effects in terms of fuel consumption rates (gallons per mile) of each of the three components: shifts among 1) size classes of light trucks, 2) size classes of passenger cars, and between 3) passenger cars and light trucks. Initially, salesmix shifts increase fuel consumption rates (decrease average MPG). This is reversed in 1979 and from then on the **net** effect of salesmix shifts (shown by the black bars) is to reduce fuel consumption (increase MPG). Beginning in 1981, increasing sales of light trucks begin to reduce the car-truck salesmix component until the effect becomes an increase in fuel consumption of about 0.0015 gal.mi.⁸

The effect of salesmix shifts within the light truck component, however, more than offsets the car-truck salesmix shift, with the result that the overall net effect of salesmix shifts is -0.001 gal/mi, about a half an MPG **increase** in fuel economy (Figure 16). Overall, however, the net effect of all salesmix shifts together has been to increase fuel economy. At the same time that sales were shifting to light trucks, the nature of the light truck was being redefined, primarily by the emergence of passenger-car like minivans and sport utility vehicles. Because the distinction between passenger cars and light trucks is blurry at best, and because most cars and trucks most of the time are used for transporting people, looking at the car/truck sales split is seeing only part of the picture. Looking at the whole light duty vehicle salesmix effect, we see that it had a positive effect on MPG over the 1975-1993 period.

6.2 CHANGES IN PERFORMANCE AND WEIGHT, 1975-1993

Since 1975, passenger cars have become lighter but also more powerful and the effects of those two factors on fuel economy has been to cancel each other. The average passenger car is 800 lbs. lighter today than in 1975 (Figure 17). Light truck horsepower has also increased but like most dieters, light trucks have regained all of the weight they lost during the 1980s. Measured in terms of the ratio of horsepower to weight, performance is up 30% for passenger cars and 15% for light trucks (Figure 18). Zero-to-sixty miles per hour acceleration times are down 20% for cars and

⁸The use of gallons per mile rather than miles per gallon makes it possible to "add up" the market share-weighted effects. Thus, the **within** passenger car and **within** light truck components are weighted by the passenger car and light truck market shares in Figure 15. For comparison, a 25 MPG vehicle consumes 0.04 gal/mi of gasoline. A +0.001 gal/mi change is an increase of 2.5% in fuel consumption, or a decrease of 0.6 MPG.

**FIGURE 15. LIGHT-TRUCK MARKET SHARES
1975-1993**

**FIGURE 16. EFFECTS OF SALESMIX SHIFTS ON
LIGHT-DUTY VEHICLE FUEL USE PER MILE, 1975-1993**

**FIGURE 17. PASSENGER CAR AND LIGHT TRUCK WEIGHT
1975-1993**

**FIGURE 18. PASSENGER CAR AND LIGHT TRUCK
PERFORMANCE, 1975-1993**

more than 10% for light trucks over 1975 levels. These trends have important implications for fuel economy since, holding technology constant, weight (or mass) is the most important determinant of vehicle energy use and power is second (Smith, 1981; Greene, 1992). In the late 1970s, fuel economy gains were accompanied by stripping 1,000 lbs. from passenger cars, and about 300 lbs. from light trucks. In the latter half of the 1980s and early 1990s MPG gains were maintained in the face of rising weights and performance levels.

To analyze the effects of weight and power on MPG, a constant elasticity method is used in place of the Divisia method. The constant weight and performance MPG (mpg_y) in any year, y , is computed from the actual fuel economy (MPG_y) by the following formula,

$$mpg_y = MPG_y \left(\frac{W_y}{W_o} \right)^\alpha \left(\frac{P_y}{P_o} \right)^\beta \quad (4)$$

where W is weight and P performance in years y and o , and α and β are the constant elasticity parameters. The elasticity values used are $\alpha = -0.66$ (U.S. Congress, OTA, 1991, p. 112) and $\beta = -0.34$ (DeCicco and Ross, 1993).⁹

If the weight of light duty vehicles had not been decreased, all else constant, passenger cars would be getting about 24 MPG instead of 28 (Figure 19). The gap between actual and weight-adjusted MPG has narrowed slightly from a peak of just over 5 MPG in 1988 to just under 4 MPG in 1993, due to a 200 lb. increase in the average weight of passenger cars. Clearly, the "downweighting" of the passenger car fleet continues to be a major factor in maintaining passenger car efficiency gains. Performance increases, on the other hand, have cost cars more than 2.5 MPG. At 1975 performance levels, the 1993 new car fleet would have averaged 30.6 MPG instead of 28.0. Had there been no changes in performance or weight, the 4,000+ pound "gas guzzlers" of 1975 vintage, using today's fuel economy technology, would still get 26.4 MPG as compared with 15.8 in 1975. The curve labeled "Constant Weight and HP/LB" in Figure 19 is a reasonable representation of the progress of fuel economy technology. Interestingly, this curve trends upward at an almost constant rate of 0.6 MPG/yr., and has continued its upward climb despite the leveling off of actual new car MPG.

⁹DeCicco and Ross (1993) cite a value for the elasticity of miles per gallon with respect to 0-60 mph acceleration time of 0.44. Based on Murrell, Hellman, and Heavenrich (1993), we estimate an elasticity of acceleration time with respect to the ratio of horsepower to weight of -0.77. This implies an elasticity of MPG with respect to hp/wt of -0.34.

**FIGURE 19. EFFECTS OF WEIGHT AND HORSEPOWER
ON PASSENGER CAR FUEL ECONOMY, 1975-1993**

Weight has had a negligible effect on light truck MPG because light trucks today weigh almost exactly what they did in 1975. The effect of increased horsepower has been to reduce light truck fuel economy by 1 MPG. Technological improvements as represented by the "Constant 1975 Weight and HP/LB" curve (Figure 20) do not show the same steady rate of advance as for passenger cars. This may be due in part to the more dramatic changes in the market shares of truck types, but clearly there is more to it than the composition of truck sales. The curve suggests that fuel economy technology has been applied in a very different manner in the light truck market.

Overall, weight reduction has raised light-duty vehicle MPG by about 2, and performance increases have reduced light-duty vehicle MPG by about 2. Had neither changed since 1975, the average MPG of passenger cars and light trucks would be only 0.3 MPG lower than the actual 1993 value.

**FIGURE 20. EFFECTS OF WEIGHT AND HORSEPOWER
ON LIGHT TRUCK FUEL ECONOMY, 1975-1993**

7. TRANSPORTATION ENERGY TRENDS SINCE 1985

The decade from 1975 to 1985 saw a reversal of trends in the energy efficiency of U.S. transportation from ever increasing energy intensiveness to increasing energy efficiency. Total energy use in 1985 was only slightly greater than it had been ten years earlier, and was actually lower than in 1978 and 1979. In the short space of twelve years, new car fuel economy had roughly doubled, and the in-use fuel economy for passenger cars and light trucks was climbing as a result. Commercial air passenger transport and rail freight had accomplished even more impressive gains. Efficiency improvements appeared to be holding energy use in check, and official projections called for continuing gains on the efficiency front.

From the perspective of 1994, one sees continued growth in energy savings due to efficiency improvements but there are also some signs that things may be about to change. According to the Federal Highway Administration, the in-use fuel economy of passenger cars and light trucks **declined** in 1994, for the first time in 20 years. Though contrary to nearly all past fuel economy predictions, in hindsight, this is no surprise since the fuel economy of new light duty vehicles is no higher today than it was twelve years ago. Fuel economy gains from the replacement of older, low fuel economy vehicles with newer, more efficient ones have been largely played out. The counter-effects of increasing urbanization and traffic congestion now appear to be causing in-use fuel economy to decline.¹⁰ Although the data for heavy trucks are less reliable, they too show a decline in miles per gallon in 1992. The past gains for rail freight, based heavily on load factor improvements, appear to have slowed considerably. And although load factor improvements for air transport seem to be stalled, technological and aircraft size-based efficiency gains continue.

The causes of the change in transportation energy use trends since 1985 are not difficult to find. From a high of nearly \$45 (1987 \$) per barrel in 1981, crude oil prices declined to \$28/barrel in 1985, then crashed to \$15/barrel in 1986. Since then, the price of a barrel of crude has fluctuated between \$10 and \$20. Prices of transportation fuels have reflected the trends in the cost of crude. Combined with the technologically-based energy efficiency improvements these price declines have put the cost of energy per unit of transportation service below pre-1973 levels. Energy prices and

¹⁰Congestion in the 50 largest U.S. cities increased by 15% from 1982 to 1990 (Schrank, Turner, and Lomax, 1993). The percent of vehicle travel on urban streets and highways increased from 55.6% in 1980 to 60.7% in 1992 (U.S. DOT, TSC, 1992, p. 20; U.S. DOT, FHWA, 1992, table VM-1). Westbrook and Patterson (1989) projected that for these and other reasons, realized fuel economy would decline at a rate of just over 0.5% per year through 2010 due to adverse operating conditions.

energy costs are not signalling the market that efficiency improvements are needed. At the same time, there have been no new regulatory initiatives to raise energy efficiency and the fuel economy standards already in place have been held at or near 1985 levels. Advances in technology and operations have produced continued energy efficiency gains in some areas, most notably air passenger travel and rail freight. However, in the case of light duty vehicles technological advances have been exchanged for increased amenities or improved performance rather than energy efficiency, or have been overshadowed by the effects of traffic congestion on operating efficiency.

From the perspective of 1994, transportation energy trends appear altogether different. Energy use is on the rise, roughly in proportion to the growth of the economy. Energy efficiency, though up slightly in some areas is down in others, and the rate of improvement appears to be slowing. If oil prices remain at current levels and no other significant actions are taken, there is little reason to expect these trends to change.

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APPENDIX A

TRANSPORTATION SECTOR METHODOLOGY

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A.1 INTRODUCTION

This appendix describes a methodology for analyzing the energy conservation gains achieved by the U.S. transportation sector over the two decades from 1972 to 1992. The objective of energy use trend decomposition is to separate changes in energy use due to changes in the types of transportation activities accomplished from changes in the energy intensiveness (or energy efficiency) of those activities in order to quantify and explain the energy conservation (energy efficiency) gains that have been achieved and to understand how other trends affecting energy use either reinforce or offset the conservation gains.

The method described here draws heavily on previous work on the subject of decomposing energy trends, and proposes some modifications to achieve consistency between aggregate national and detailed sectoral decompositions.¹¹ The basis of the analytical method is the simple, yet elegant Divisia decomposition method (Boyd et al., 1987). One reason for using the Divisia method is that this study is part of a larger analysis of all sectors which relies on the same technique. More importantly, the Divisia method provides an accurate decomposition of any time trend that can be expressed as a product of component elements. Since energy use trends can generally be expressed as a product of elements such as vehicle miles, miles per gallon, vehicle occupancy factors, etc., the Divisia index is a fundamentally appropriate decomposition technique.

¹¹The approach proposed here is based on the method proposed by Belzer (1989) and U.S. DOE (1989). It also draws on previous work by Ross (1989), Klan (1989), Boyd et al. (1987; 1988), and for the passenger car mode McNutt and Difiglio (1982), and in the commercial air model, Smith (1981) and Greene (1992).

A.2 SECTORAL ACTIVITY MEASURES AND AGGREGATION

Adding together the components of Divisia analyses of different sectors calls for a consistent measure of activity. As will be shown below, a consistent activity measure is not a requirement for decomposing changes in energy intensiveness. Rather, its value lies in preserving the meaning of changes across sectors. For example, in the transport sector, one may analyze automobile efficiency improvements in terms of energy use per passenger mile and heavy truck efficiency improvements in terms of energy use per ton mile. Adding together the automobile and heavy truck efficiency changes defined in this way results in a hybrid measure of total efficiency change but one that has some meaning. The problem of interpretation increases when adding up transportation efficiency changes with those of other sectors defined in terms of energy use per dollar of output. To obtain a overall measure of energy efficiency change for transport that is consistent with those used in other sectors, one must use the common numeraire of dollars of revenue for both the passenger and freight modes.

Recognizing the importance of this problem for applying the Divisia technique to transportation, Belzer (1989) proposed converting freight ton-miles into passenger mile equivalents on the basis of equivalent energy use in a base year. This is a reasonable approach, but still results in inconsistent treatment of transportation vis a vis other sectors. We have chosen to measure activity using either the market value of a unit of activity or the estimated cost of production. Cost of production is used for transportation services not directly purchased in the marketplace, such as household vehicle travel, and for which there is therefore no market price.¹²

For some modes and vehicle types, measures of the value of output are readily available in the form of total revenues (e.g., commercial air carriers). We have not attempted to adjust revenue estimates for subsidies, profits, or losses. For other modes, individuals produce transportation services using their own labor time, fuel, and capital inputs (vehicles). We propose to estimate the value of these services by the cost of producing them. The most important case is that of light duty vehicles. Annual estimates of per mile vehicle operating costs (including capital depreciation, maintenance, fuel, insurance, etc.) are available and have been used to estimate the total cost of highway passenger travel (Smith, 1993).

¹²Another example is military transportation.

For the sake of consistency with the other sectors, we use Belzer's (1989) approach of valuing transportation activity at 1987 prices and costs. That is, we divide 1987 modal revenues (costs) by a physical activity measure (e.g., ton-miles, passenger-miles) and use the resulting price index to value the physical activity of all other years. This has the advantage of eliminating price fluctuations (e.g., in fuel prices) from the Divisia decomposition and the disadvantage of also eliminating productivity changes, since output per dollar becomes constant by assumption.¹³ In effect, the dollar activity measure computed in this way is a weighted sum of the physical activity measures, the 1987 dollars per unit being the weights.

Aggregating activities at the sectoral level based on dollars does not prevent us from analyzing efficiency changes at lower levels based on more intuitive measures of activity. Passenger miles, vehicle miles, or ton miles may all be used for mode-vehicle type analyses. Only the total sectoral trends need be analyzed on the basis of the common unit of dollars.

A.3 MATHEMATICAL EXPOSITION OF THE DIVISIA METHOD

In this section the Divisia method is derived, a categorization of the transportation sector is presented, and the Divisia equations used in specific sectoral and modal decompositions are developed.

Changes over time in any variable that can be expressed as a product of components can be analyzed in terms of changes in its component parts by means of the Divisia technique. In particular, energy use (E) per unit of time (t) can be generally expressed as a product of energy intensity (energy use per unit of activity or output of an activity requiring the energy) and the level of activity (A) per unit of time,

$$E = \left(\frac{E}{A} \right) A = e A \quad (\text{A.1})$$

¹³We did carry out the Divisia analysis with and without the price index assumption (see data appendix), which showed that apparent productivity changes are in fact dominated by short-term swings in input prices which tend to obscure long-term productivity trends. Although this may be resolvable by using input factor price indices to adjust cost and revenue estimates, this was beyond the scope of this study.

where e is energy intensiveness measured in terms of energy use per unit of activity (e.g., gallons per vehicle miles, Btu per ton mile, etc.).

When activity A can be broken down into meaningful subcategories (i), the identity represented by equation (A.1) can be expanded as a sum of identities for each subcategory.

$$E = \sum_{i=1}^n \left(\frac{E_i}{A_i} \right) \left(\frac{A_i}{A} \right) A \quad (\text{A.2})$$

The Divisia method decomposes energy intensity ($e = E/A$) into its changes over time. Consider change in energy intensity over time as expressed by the derivative of e with respect to t ,

$$\frac{de}{dt} = \sum_{i=1}^n \left(\frac{de_i}{dt} s_i + \frac{ds_i}{dt} e_i \right) \quad (\text{A.3})$$

where $s_i = A_i/A$, is the activity share of subcategory i . Dividing (A.3) by $e = \sum_i e_i s_i$, and noting that the relative change in e is, $(de/dt) \cdot (1/e) = d\ln\{e\}/dt$, we obtain,

$$\frac{d\ln(e)}{dt} = \sum_{i=1}^n \left(\frac{d\ln(e_i)}{dt} \frac{e_i s_i}{e} + \frac{d\ln(s_i)}{dt} \frac{e_i s_i}{e} \right) \quad (\text{A.4})$$

It is useful to define $w_i = e_i s_i / e = E_i / E$, as the energy share of activity i (note that A 's cancel out), so that the relative change in e has been decomposed in (A.4) into energy-shares-weighted relative changes in the energy intensities of its components (i) and their activity shares.

Equation A.4 defines the Divisia decomposition for continuous variables. Since we use annual data, we must approximate the continuous case by means of year-to-year changes. If the time interval is one year, $dt = 1$, and equation (A.4) in discrete form is,

$$\ln(e_t) - \ln(e_{t-1}) = \sum_{i=1}^n \left[\{ \ln(e_{it}) - \ln(e_{it-1}) \} \bar{w}_{it} + \{ \ln(s_{it}) - \ln(s_{it-1}) \} \bar{w}_{it} \right] \quad (\text{A.5})$$

where we define the energy share to be the average energy share of the years t and $t-1$.

$$\bar{w}_{it} = \frac{w_{it} + w_{it-1}}{2} \quad (\text{A.6})$$

Use of the midpoint of the two year's energy shares greatly improves the accuracy of the discrete approximation to the continuous decomposition. This same midpoint approximation is used throughout, whenever we use the Divisia analysis with discrete data.

Note that since $(e_{it}/e) = w_i$ is the energy use share of activity i , it is not always necessary to know the activity share (s_i) of i in order to estimate the efficiency change component for i . This property of the Divisia method is useful when activity levels are not known but independent estimates of energy intensiveness are available. One can first compute the efficiency change components using energy shares (rather than activity shares), add them and subtract the sum from the total energy intensity change, de/dt . The remainder is the sum of the share change component, computed without actually knowing the activity shares. Although this works in the case of incommensurate units the results must be interpreted carefully because of the different definitions of energy intensiveness. For example, one could measure the energy intensity of both passenger and freight in terms of energy use per dollar of revenue. The efficiency and shares components using this commensurate measure of energy intensiveness will, in general, be different from those computed based on the incommensurate measures of ton-miles and passenger-miles. Wherever possible, we use commensurate measures in this report.

An important and useful feature of the Divisia method is that the identity (A.2) can be expanded by using any meaningful multiplicative factors. A useful factor for passenger travel is average load factor (f_i) defined as the total passenger miles for subcategory i divided by total vehicle miles for vehicles of subcategory i (PM_i/VM_i). If A is defined in terms of passenger miles, f_i converts to vehicle miles. Equation (A.2) can then be written as,

$$E = \sum_{i=1}^n \left(\frac{E_i}{PM_i} \right) f_i \left(\frac{VM_i}{VM} \right) VM \quad (A.7)$$

The Divisia technique can be applied to equation (A.7) in a straightforward manner. Load factor (or any other multiplicative factor) is treated exactly as energy intensity or subcategory energy shares: the relative change is weighted by the category's energy share (w_i).

$$\frac{d\ln(e)}{dt} = \sum_{i=1}^n \left(\frac{d\ln(e_i)}{dt} w_i + \frac{d\ln(f_i)}{dt} w_i + \frac{d\ln(s_i)}{dt} w_i \right) \quad (A.8)$$

Thus, the term $(d\ln(f_i)/dt) \cdot w_i$ is the relative effect of load factor on energy use per passenger mile for passenger travel subcategory i .

The absolute changes in energy intensity can be obtained from the relative components by multiplying through by $e = (E/A) = \sum_i e_i s_i$, which follows from the fact that,

$$e \frac{d\ln(e)}{dt} = \frac{de}{dt} \quad (A.9)$$

This gives a decomposition of the changes in energy intensiveness. We can estimate annual changes in total energy use due to each factor by multiplying the annual energy intensiveness changes by the total activity level, A . Thus, if we have decomposed $(d\ln(e)/dt)$ into components, k_j , where j indexes factors, then the change in absolute energy intensity due to factor j is ek_j , and the change in total energy use due to j is, Aek_j . To estimate the cumulative change in energy use in year T versus a base year, one must add the annual efficiency changes first and then multiply by the activity level of year T , A_T . Adding up the annual energy use changes would give an incorrect answer.

A.4 THE STRUCTURE OF TRANSPORTATION ENERGY USE

Defining the categories of transportation activity and energy use defines the types of changes in efficiency and modal structure that will be measured by the Divisia method. Typically, transportation is divided into the categories of passenger and freight transport, to distinguish between the functions of moving persons versus goods. Classification is based on predominant use. The basic activity measures for passenger and freight transport are passenger-miles and ton-miles, respectively. The distinction between passenger and freight is to some extent arbitrary in all cases. Even passenger cars carry groceries, luggage, etc. from time to time. In the United States, light trucks are used primarily as passenger vehicles, and are therefore passenger-mile based in this analysis. Likewise, commercial air energy use is assumed to be for passenger travel although the aircraft carry a substantial amount of freight (e.g., mail). On the freight side, all larger single unit trucks are considered freight vehicles, even though some may serve primarily service functions. Military energy use and international shipping are treated as special cases.

Appropriate data are not available for all modes and submodes. For single unit trucks other than light trucks, we assume tons per truck is constant, so that trends in this category are actually vehicle-mile based.¹⁴ Military use of transportation fuels is significant, but some is used for freight transport, some for passenger transport, and some for neither (e.g., jet fighters). We measure the level of activity based on dollars of defense spending on transport, fuel, aircraft, ships, and other vehicles. International waterborne commerce should, in principle, be included with other freight modes, but we treat it separately due to the absence of comparable ton-mile data. The only available ton-mile data for international shipping to and from the U.S. includes only the distance traveled on U.S. territorial waters in computing ton-miles. While this provides a useful index of activity, it cannot be combined with the other ton-mile measures.

¹⁴Light trucks are sometimes defined as trucks under 10,000 lbs. gross vehicle weight (GVW), and other times as trucks under 8,500 GVW. To be consistent with available times series of truck miles, we define all two axle, four tire trucks as light trucks. In the analysis of new light-duty vehicle fuel economy, we will use data on the fuel economy of trucks under 8,500 lbs. GVW as if it applied to the category of light trucks defined above.

A.5 DETAILED DIVISIA EQUATIONS

The Divisia equations used to estimate transportation energy efficiency and energy use components for specific modes and submodes are presented in this section. First, we derive the most general equation for analyzing overall sectoral trends using dollars as the measure of activity. Next, we modify that equation for use in analyzing trends in passenger and freight modes separately. Passenger and freight activities are measured in passenger-miles and ton-miles respectively. Finally, equations for highway and air passenger analyses are presented. These analyses include a consideration of the effect of vehicle occupancy rates on energy efficiency.

Table A.1 Major Categories and Subcategories for Divisia Analysis

PASSENGER MODES

I. PASSENGER MILES

1. **Light Duty Vehicles**
 - (i) **Automobiles** (load factor, vehicle efficiency)
 - (ii) **Light Trucks** (load factor, vehicle efficiency)
2. **Bus**
3. **Passenger Rail**
4. **Commercial Air** (load factor, aircraft size, vehicle efficiency)
5. **General Aviation**

FREIGHT MODES

II. TON-MILES

1. **Single Unit Heavy Trucks**
2. **Combination Heavy Trucks**
3. **Rail Freight**
4. **Air Freight**
5. **Domestic Waterborne Freight**
6. **Pipeline**

OTHER

III. DOLLARS OF OTHER EXPENDITURES/REVENUES

1. **International Waterborne Freight**
2. **Military Transportation**

A.5.1 TRANSPORTATION SECTOR DECOMPOSITION

The energy efficiency identity is,

$$\frac{E}{\$} = \sum_i \frac{E_i}{PM_i} \cdot \frac{PM_i}{\$_i} \cdot \frac{\$_i}{\$} + \sum_j \frac{E_j}{TM_j} \cdot \frac{TM_j}{\$_j} \cdot \frac{\$_j}{\$} + \sum_k \frac{E_k}{\$_k} \cdot \frac{\$_k}{\$} \quad (\text{A.10})$$

where:

E = energy use
 $\$$ = economic output (activity) indexed in 1987 dollars
 PM = passenger-miles
 TM = ton-miles

Index i =
 1 -- Automobile
 2 -- Light truck
 3 -- Bus
 4 -- Passenger Rail
 5 -- Commercial Air
 6 -- General Aviation

Index j =
 1 -- Single Unit Heavy Trucks (SUHT)
 2 -- Combination Heavy Trucks (CHT)
 3 -- Freight Rail
 4 -- Freight Air
 5 -- Domestic Waterborne
 6 -- Pipeline

Index k =
 1 -- International Waterborne Freight
 2 -- Military

The efficiency identity in terms of efficiencies (e), productivities (p), and activity shares (s) is,

$$e = \sum_i e_i p_i s_i + \sum_j e_j p_j s_j + \sum_k e_k s_k \quad (\text{A.11})$$

Note that the definitions of e and p are different for the three categories of transportation activity.

Letting $f' = df/dt$ indicate the derivative of a function with respect to time, t , one obtains:

$$\begin{aligned} \frac{de}{dt} = e' = & \sum_i (e'_i p_i s_i + e_i p'_i s_i + e_i p_i s'_i) + \\ & \sum_j (e'_j p_j s_j + e_j p'_j s_j) + \\ & \sum_k (e'_k s_k + e_k s'_k) \end{aligned} \quad (A.12)$$

Equation (A.12) can be written in terms of the relative change in efficiency by dividing through on both sides by e .

$$\begin{aligned} \frac{e'}{e} = & \sum_i \left[\frac{e'_i}{e_i} \left(\frac{e_i p_i s_i}{e} \right) + \frac{p'_i}{p_i} \left(\frac{e_i p_i s_i}{e} \right) + \frac{s'_i}{s_i} \left(\frac{e_i p_i s_i}{e} \right) \right] + \\ & \sum_j \left[\frac{e'_j}{e_j} \left(\frac{e_j p_j s_j}{e} \right) + \frac{p'_j}{p_j} \left(\frac{e_j p_j s_j}{e} \right) + \frac{s'_j}{s_j} \left(\frac{e_j p_j s_j}{e} \right) \right] + \\ & \sum_k \left[\frac{e'_k}{e_k} \left(\frac{e_k s_k}{e} \right) + \frac{s'_k}{s_k} \left(\frac{e_k s_k}{e} \right) \right] \end{aligned} \quad (A.13)$$

Now note that the terms in parentheses are energy use shares since

$$e_i \cdot p_i \cdot s_i = \frac{E_i}{PM_i} \cdot \frac{PM_i}{\$_i} \cdot \frac{\$_i}{\$} = \frac{E_i}{\$} \quad (A.14)$$

and so dividing through by $e = \frac{E}{\$}$ gives $\frac{E_i}{E}$.

$$\frac{e'}{e} = \sum_i \left[\frac{e'_i}{e_i} w_i + \frac{p'_i}{p_i} w_i + \frac{s'_i}{s_i} w_i \right] + \sum_j \left[\frac{e'_j}{e_j} w_j + \frac{p'_j}{p_j} w_j + \frac{s'_j}{s_j} w_j \right] + \sum_k \left[\frac{e'_k}{e_k} w_k + \frac{s'_k}{s_k} w_k \right] \quad (\text{A.15})$$

where the energy use shares are:

$$w_i = E_i/E$$

$$w_j = E_j/E$$

$$w_k = E_k/E$$

We now have equation (A.15) in terms of relative changes and energy use shares. Multiplying through by e gives the formula for the change in energy efficiency e' , which we now write as Δe to indicate that we are estimating a discrete change over a period of one year.

$$\Delta e = \sum_i \left[\frac{\Delta e_i}{\bar{e}_i} \bar{w}_i \bar{e} + \frac{\Delta p_i}{\bar{p}_i} \bar{w}_i \bar{e} + \frac{\Delta s_i}{\bar{s}_i} \bar{w}_i \bar{e} \right] + \sum_j \left[\frac{\Delta e_j}{\bar{e}_j} \bar{w}_j \bar{e} + \frac{\Delta p_j}{\bar{p}_j} \bar{w}_j \bar{e} + \frac{\Delta s_j}{\bar{s}_j} \bar{w}_j \bar{e} \right] + \sum_k \left[\frac{\Delta e_k}{\bar{e}_k} \bar{w}_k \bar{e} + \frac{\Delta s_k}{\bar{s}_k} \bar{w}_k \bar{e} \right] \quad (\text{A.16})$$

In computing annual efficiency changes we substitute the midpoint values, e.g., $\bar{w}_i = [w_{it} + w_{it-1}] / 2$, of energy use shares for years t and $t-1$, to obtain a better approximation to the continuous Divisia measure than one would get using either w_{it} or w_{it-1} .

Since $\Delta e = \frac{E_t}{S_t} - \frac{E_{t-1}}{S_{t-1}}$, it follows $\Delta e S_t = E_t - E_{t-1} \frac{S_t}{S_{t-1}} = E_t - e_{t-1} S_t$, which is the difference between

actual energy use in year t and what it would have been at last year's energy efficiency but this year's activity level.

The constant efficiency change in total energy use is comprised of three components,

$$-\Delta e S_t = - \left[\sum_i \frac{\Delta e_i}{\bar{e}_i} \bar{w}_i + \sum_j \frac{\Delta e_j}{\bar{e}_j} \bar{w}_j + \sum_k \frac{\Delta e_k}{\bar{e}_k} \bar{w} \right] \bar{e} S_t$$

Energy change (save) due to efficiency

$$- \left[\sum_i \frac{\Delta p_i}{\bar{p}_i} \bar{w}_i + \sum_j \frac{\Delta p_j}{\bar{p}_j} \bar{w}_j \right] \bar{e} S_t$$

Energy change due to productivity

$$- \left[\sum_i \frac{\Delta s_i}{\bar{s}_i} \bar{w}_i + \sum_j \frac{\Delta s_j}{\bar{s}_j} \bar{w}_j + \frac{\Delta s_k}{\bar{s}_k} \bar{w}_k \right] \bar{e} S_t \quad (A.17)$$

Energy change due to structural change

Since the three components must sum to $\Delta e S_t$, once any two are determined the third can be computed by subcontracting their sum from $\Delta e S_t$.

Equation (A.17) gives the Divisia decomposition of the change in energy use from year $t-1$ to t . The change in energy use from a base year to the current year is also of interest. The cumulative effect on energy use cannot be obtained by simply summing the year-to-year changes in energy use, since the reference points do not remain at the base year values. The correct procedure is to accumulate the year-to-year changes in efficiency, and then multiply these by the current year activity level. Consider the continuous version of equation (A.17),

$$\frac{de}{dt} = e' = Ae + Be + Ce \quad (\text{A.18})$$

where we use A, B, and C to denote the efficiency, productivity, and structural shift components of energy efficiency change. To get the cumulative effects from $t=0$ to $t=T$, we integrate equation (A.18).

$$\int_0^T de = e(T) - e(0) = \int_0^T Ae \, dt + \int_0^T Be \, dt + \int_0^T Ce \, dt \quad (\text{A.19})$$

The discrete-time analog of (A.19) is,

$$\sum_{t=0}^T \Delta e_t = \sum_{t=0}^T A_t e_t + \sum_{t=0}^T B_t e_t + \sum_{t=0}^T C_t e_t \quad (\text{A.20})$$

Since this gives the complete decomposition of the changes in energy efficiency from $t=0$ to $t=T$, we obtain the changes in energy use by multiplying equation (A.20) through by S_t , the activity level in year T .

A.5.2 PASSENGER MODES DECOMPOSITION

The energy intensity identity is:

$$\frac{E}{PM} = \sum_i \frac{E_i}{PM_i} \cdot \frac{PM_i}{PM} \quad (\text{A.21})$$

- Index i =
- 1 -- Automobile
 - 2 -- Light truck
 - 3 -- Bus
 - 4 -- Rail transit
 - 5 -- Commuter rail
 - 6 -- Intercity rail
 - 7 -- Commercial air
 - 8 -- General aviation

In terms of energy intensity (e) and activity shares (s) equation (A.21) is,

$$e = \sum_i e_i s_i \quad (\text{A.22})$$

from which it follows that,

$$\frac{e'}{e} = \sum_i \left[\frac{e'_i}{e_i} w_i + \frac{s'_i}{s_i} w_i \right] \quad (\text{A.23})$$

and for which the discrete time equation is

$$-\Delta e = - \left[\sum_i \frac{\Delta e_i}{\bar{e}_i} \bar{w}_i \bar{e} \right] - \left[\sum_i \frac{\Delta s_i}{\bar{s}_i} \bar{w}_i \bar{e} \right] \quad (\text{A.24})$$

A.5.3 FREIGHT MODES DECOMPOSITION

The energy intensity identity is

$$\frac{E}{TM} = \sum_j \frac{E_j}{TM_j} \cdot \frac{TM_j}{TM} \quad (\text{A.25})$$

- Index j =
- 1 -- Single-unit heavy trucks
 - 2 -- Combination heavy trucks
 - 3 -- Rail freight
 - 4 -- Air freight
 - 5 -- Domestic waterborne
 - 6 -- Pipeline

The remaining equations are identified to those for the passenger modes.

A.5.4 HIGHWAY PASSENGER TRAVEL DECOMPOSITION

The energy intensity identity now includes vehicle occupancy (i.e., passenger-miles per vehicle mile), though as its inverse.

$$\begin{aligned}\frac{E}{PM} &= \sum_i \left[\frac{E_i}{VM_i} \left(\frac{PM_i}{VM_i} \right)^{-1} \frac{PM_i}{PM} \right] \\ &= \sum_i e_i q_i s_i\end{aligned}\tag{A.26}$$

$$\frac{de}{dt} = e' = \sum_i \left[e'_i q_i s_i + e_i q'_i s_i + e_i q_i s'_i \right]$$

Dividing through by e gives the relative change in intensity,

$$\frac{e'}{e} = \sum_i \left[\frac{e'_i}{e_i} w_i + \frac{q'_i}{q_i} w_i + \frac{s'_i}{s_i} w_i \right]\tag{A.27}$$

The computational form for annual data for Δe is,

$$\Delta e = \sum_i \frac{\Delta e_i}{\bar{e}_i} \bar{w}_i \bar{e} + \sum_i \frac{\Delta q_i}{\bar{q}_i} \bar{w}_i \bar{e} + \sum_i \frac{\Delta s_i}{\bar{s}_i} \bar{w}_i \bar{e}.\tag{A.28}$$

where $\bar{w}_i = \frac{w_i + w_{i-1}}{2}$, and so on.

A.5.5 COMMERCIAL AIR TRAVEL DECOMPOSITION

The energy intensity identity is,

$$\frac{E}{PM} = \frac{E}{SM} \cdot \left(\frac{SM}{AM} \cdot \frac{AM}{PM} \right) = \frac{E}{SM} \cdot \frac{SM}{PM} \quad (\text{A.29})$$

where

AM = aircraft miles

SM = seat miles.

We use $x = \frac{E}{SM}$ as a measure of aircraft energy intensity independent of size, $K = (SM/AM)$ is

a measure of aircraft size and $z = (AM/PM)$ is the inverse of the aircraft load factor. We note that

$r = kz = SM/PM$, or in other words the combined effect of aircraft size and aircraft load factor is equal to the effect of the inverse of the seat load factor. This is useful because the seat-load factor is commonly used in the aircraft industry to gauge an airline's operational efficiency.

Analogously to the highway mode, we have

$$e = xyz \quad (\text{A.30})$$

and

$$\frac{e'}{e} = \frac{x'yz}{e} + \frac{xy'z}{e} + \frac{xyz'}{e} = \frac{x'}{x} + \frac{y'}{y} + \frac{z'}{z} \quad (\text{A.31})$$

In discrete terms this gives the Divisia decomposition of energy intensity,

$$\Delta e = \frac{\Delta x}{\bar{x}} \bar{e} + \frac{\Delta y}{\bar{y}} \bar{e} + \frac{\Delta z}{\bar{z}} \bar{e} \quad (\text{A.32})$$

$$\text{where } \bar{x} = \frac{x_t + x_{t-1}}{2}, \bar{y} = \frac{y_t + y_{t-1}}{2}, \bar{z} = \frac{z_t + z_{t-1}}{2}, \bar{e} = e_t + \frac{e_{t-1}}{2}.$$

A.5.6 RAIL FREIGHT DECOMPOSITION

The energy intensity identity is,

$$e = \frac{E}{TM} = \frac{E}{CM} \cdot \frac{CM}{TM} = xy \quad (\text{A.33})$$

where

CM = railroad car miles

$\frac{TM}{CM}$ = inverse of load factor

Analogously to the commercial air travel decomposition the Divisia decomposition is,

$$\Delta e = \frac{\Delta x}{x} e + \frac{\Delta y}{y} e . \quad (\text{A.34})$$

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8. Smith, F. A. 1993. *Transportation in America*, Eleventh Ed., Eno Transportation Foundation, Inc., Lansdowne, Virginia.

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10. U.S. Department of Energy, Office of Policy, Planning and Analysis and the Office of Conservation and Renewable Energy. 1989. *Energy Conservation Trends: Understanding the Factors that Affect Conservation Gains in the U.S. Economy*, DOE/PE-0092, Washington, DC.

APPENDIX B

TRANSPORTATION ENERGY DIVISIA ANALYSIS: DATA AND METHODOLOGICAL NOTES

TABLE B.1 ENERGY USE (in trillion Btu's):

TABLE 1. ENERGY USE (in trillion Btu's):

YEAR	PASSENGER						FREIGHT					OTHER	
	HIGHWAY						HIGHWAY (5)						
	Automobile (1)	Light Truck(1)	Bus (1)	Rail (2)	Commercial Air(3)	General Aviation(4)	Single Unit Heavy Trucks	Combination Heavy Trucks	Rail (6)	Domestic Water(7)	Pipeline (8)	International Water(9)	Military (10)
1972	9,594	1,895	106	67	1,374	103	645	1,121	548	315	1,034	582	618
1973	9,903	2,105	109	63	1,445	90	687	1,246	564	337	998	591	636
1974	9,454	2,083	113	65	1,290	101	663	1,215	566	283	940	599	579
1975	9,625	2,240	119	64	1,283	122	682	1,194	515	311	832	608	632
1976	10,035	2,522	129	61	1,324	130	727	1,316	538	277	809	755	632
1977	10,124	2,738	132	60	1,386	150	786	1,473	551	274	782	901	691
1978	10,285	3,008	135	59	1,436	159	864	1,673	547	317	781	1,048	632
1979	9,741	3,094	137	64	1,535	167	854	1,778	563	379	864	1,194	648
1980	9,063	2,951	139	62	1,490	169	786	1,756	544	330	889	1,340	650
1981	8,954	2,964	143	59	1,429	162	788	1,793	520	335	896	1,186	670
1982	8,839	2,982	146	60	1,407	171	801	1,749	437	275	855	959	682
1983	8,784	3,196	145	63	1,439	144	870	1,862	432	294	730	857	674
1984	8,635	3,500	154	71	1,607	149	940	2,047	469	307	772	686	679
1985	8,696	3,630	161	72	1,702	144	966	2,116	427	399	767	687	706
1986	8,941	3,785	154	75	1,847	148	999	2,177	412	404	728	882	710
1987	8,888	4,032	157	77	1,945	139	1,027	2,285	418	371	766	914	647
1988	8,994	4,109	159	80	2,049	149	1,052	2,373	432	321	872	951	792
1989	9,080	4,147	163	83	2,087	134	1,074	2,424	433	329	886	1,077	816
1990	9,090	4,156	163	82	2,191	132	1,057	2,421	425	323	936	917	758
1991	8,868	4,080	174	81	2,069	120	1,040	2,377	399	328	872	989	728
1992	9,265	4,156	174	80	2,144	105	1,033	2,452	425	341	856	1,047	472

SOURCES FOR "ENERGY USE"

(1) Automobile, Light Truck, and Bus -

Automobile -- Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 2.10 "Transportation Energy Consumption by Mode, 1970-92," sum of col. "Automobiles" and col. "Motorcycles."

Light Truck -- Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 2.10 "Transportation Energy Consumption by Mode, 1970-92," col. "Light Trucks."

Bus -- Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 2.10: "Transportation Energy Consumption by Mode, 1970-92," col. "Buses."

(2) Passenger Rail -

1972-77: *Transportation Energy Data Book*, Ed. 3, Table 2.8, "Fuel Consumption by Mode of Transportation, 1965 through 1977 (in millions)," row "Rail Passenger."

1978: *Transportation Energy Data Book*, Ed. 4, Table 1.5, "Transportation Fuel Consumption by Mode by Fuel Type, 1978 [civilian consumption only; based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

1979: *Transportation Energy Data Book*, Ed. 5, Table 1.4, "Transportation Energy by Mode and Fuel Type, 1979 [based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

1980: *Transportation Energy Data Book*, Ed. 4, Table 1.8, "Estimated 1980 Transportation Energy by Mode and Fuel Type [civilian consumption only; based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

1981: *Transportation Energy Data Book*, Ed. 5, Table 1.7, "Transportation Energy by Mode and Fuel Type, 1981 Estimates [based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

1982: *Transportation Energy Data Book*, Ed. 8, Table 1.4, "Transportation Energy by Mode and Fuel Type, 1982 [based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

1983: *Transportation Energy Data Book*, Ed. 8, Table 1.5, "Transportation Energy by Mode and Fuel Type, 1983 [based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

1984: *Transportation Energy Data Book*, Ed. 9, Table 1.10, "Transportation Energy by Mode and Fuel Type, 1984 [based on domestic (U.S.) sales of transportation fuels]," row "Rail Passenger."

- 1985: Personal communication with Davis, S. C. (ORNL).
- 1987: *Transportation Energy Data Book*, Ed. 10, Table 2.6, "Domestic Consumption of Transportation Energy by Mode and Fuel Type, 1987 (trillion Btu)," row "Rail Passenger."
- 1988: *Transportation Energy Data Book*, Ed. 11, Table 2.6, "Domestic Consumption of Transportation Energy by Mode and Fuel Type, 1988 (trillion Btu)," row "Rail Passenger."
- 1989: *Transportation Energy Data Book*, Ed. 12, Table 2.7, "Domestic Consumption of Transportation Energy by Mode and Fuel Type, 1989 (trillion Btu)," row "Rail Passenger."
- 1990: *Transportation Energy Data Book*, Ed. 13, Table 2.9, "Transportation Energy Use by Mode, 1990," row "Rail Passenger," col. "Trillion Btu."
- 1991-92: *Transportation Energy Data Book*, Ed. 14, Table 2.9, "Transportation Energy Use by Mode, 1991-92," row "Rail Passenger," col. "Trillion Btu."

For the years in which energy use is not given by Btu's, the conversion to Btu's is based on *Transportation Energy Data Book*, 14th Ed., Table B.1 "Approximate Heat Content for Various Fuels."

(3) Commercial Air -

- 1972-91: Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 6.2, "Summary Statistics for Domestic and International Route Air Carriers (Combined Totals), 1970-91," col. "Energy Use."
- 1992: Department of Transportation Research and Special Programs Administration, *Fuel Cost and Consumption Tables*, Washington, DC, monthly. Annual totals and derived by summing monthly totals for domestic and international air carriers.

(4) General Aviation -

Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 6.3, "Summary Statistics for General Aviation, 1970-92," col. "Energy Use."

(5) Single Unit Heavy Trucks and Combination Heavy Trucks -

Fuel use: Davis, S. C., 1994, *Transportation Energy Data Book*, 14th Ed., Table 3.24, "Summary Statistics for Other Single-Unit and Combination Trucks, 1970-92," col. "Fuel Use (million gallons)." Assumption about fuel use shares were based on special data summaries

from the Census of Transportation, Truck Inventory and Use Surveys for 1977, 1982, and 1987. They are as follows. For single unit trucks: 1) propane at 1.5% of gallons for all years; 2) diesel at 20% through 1982, increasing by 5%/yr. to 45% in 1987 and constant thereafter; and 3) gasoline the remainder. For combination trucks: 1) propane at 0.0% all years; 2) diesel at 95% through 1977 increasing linearly to 98% and again linearly increasing to 99% by 1987 and remaining constant thereafter; and 3) gasoline the remainder. Assumed energy content per gallon are: gasoline 125,000 Btu; diesel 138,700 Btu; and propane 91,300 Btu.

(6) Freight Rail -

Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 6.8, "Summary for Class I Freight Railroads, 1970-92," col. "Energy Use (trillion Btu)."

(7) Domestic Water -

1972-90: Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 6.5, "Summary Statistics for Domestic Waterborne Commerce, 1970-90," col. "Energy Use (trillion Btu)."

1991-92: Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 2.9, "Transportation Energy Use by Mode, 1991-92," row "Nonhighway, Water, Freight, Domestic."

(8) Pipeline -

Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 6.1, "Nonhighway Energy Use by Mode, 1970-92," product of col. "Pipeline (percent of total)" times col. "Transportation energy use (trillion Btu)."

(9) International Water -

1970, 75, 80: Eno Transportation Foundation, Inc., *Transportation in America*, 1992, Ed. 10, p.56, Table "Petroleum Consumption by Mode of Transport (Millions of Barrels)," row "Water, Foreign Trade."

1972-74, 1976-79: Linearly interpolated.

1980-90: U.S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics*, Annual Report, 1992, p.117, Table 42, "Fuel Consumption by Mode of Transportation, 1980-1990," row "Water Transport, Residual Fuel Oil, gals x 10⁶."

Note: Conversion to Btu's is based on the following formula: $\text{Btu} = (\text{total gallons of residual fuel oil}) (149,700 \text{ Btu/gal})$.

1991-92: Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 2.9, "Transportation Energy Use by Mode, 1991-92," row "Water, Freight, Foreign."

(10) Military -

- 1972-77: Interpolated by multiplying military operating expenses (in 1987 indexed dollars, see Table 3. "Operating Expenses or Revenues") with a constant ratio of the energy use for military in year 1978 to the operating expenses for military in year 1978 (in 1987 indexed dollars).
- 1978: Defense Logistics Agency, Defense Fuel Supply Center, *Fact Book*, Table "Retail Consumption (Thousands of Barrels)," col. "Total."
- 1979: *Transportation Energy Data Book*, Ed. 5, Table 1.4, "Transportation Energy by Mode and Fuel Type, 1979 [based on domestic (U.S.) sales of transportation fuels]," row "Military Operations."
- 1980: Defense Logistics Agency, Defense Fuel Supply Center, *Fact Book*, Table "FY 1980 Retail Consumption (Thousands of Barrels)," col. "Total."
- 1981: *Transportation Energy Data Book*, Ed. 5, Table 1.7, "Transportation Energy by Mode and Fuel Type, 1981 Estimates [based on domestic (U.S.) sales of transportation fuels]," row "Military Operations."
- 1982: *Transportation Energy Data Book*, Ed. 8, Table 1.4, "Transportation Energy by Mode and Fuel Type, 1982 [based on domestic (U.S.) sales of transportation fuels]," row "Military Operations."
- 1983: *Transportation Energy Data Book*, Ed. 8, Table 1.5, "Transportation Energy by Mode and Fuel Type, 1983 [based on domestic (U.S.) sales of transportation fuels]," row "Military Operations."
- 1984: *Transportation Energy Data Book*, Ed. 9, Table 1.10, "Transportation Energy by Mode and Fuel Type, 1984 [based on domestic (U.S.) sales of transportation fuels]," row "Military Operations."
- 1985: Personal communication with Davis, S. C. (ORNL).
- 1986: Defense Logistics Agency, Defense Fuel Supply Center, *Fact Book*, Table "Bulk Petroleum Purchases by Category (Thousands of Barrels)," col. "FY 1986."

- 1987: *Transportation Energy Data Book*, Ed. 10, Table 2.6, "Domestic Consumption of Transportation Energy by Mode and Fuel Type, 1987 (trillion Btu)," row "Military Operations."
- 1988: *Transportation Energy Data Book*, Ed. 11, Table 2.6, "Domestic Consumption of Transportation Energy by Mode and Fuel Type, 1988 (trillion Btu)," row "Military Operations."
- 1989: *Transportation Energy Data Book*, Ed. 12, Table 2.7, "Domestic Consumption of Transportation Energy by Mode and Fuel Type, 1989 (trillion Btu)," row "Military Operations."
- 1990: *Transportation Energy Data Book*, Ed. 13, Table 2.9, "Transportation Energy Use by Mode, 1990," row "Military Operations," col. "Trillion Btu."
- 1991-92: *Transportation Energy Data Book*, Ed. 14, Table 2.9, "Transportation Energy Use by Mode, 1991-92," row "Military Operations," col. "Trillion Btu."

Note: Conversion to Btu's is based on the formula below:

$$\text{Btu} = \{(\text{barrels of AVGAS}) / (0.0238 \text{ bbl/gal}) * (120,200 \text{ Btu/gal}) + (\text{barrels of JP4}) / (0.0238 \text{ bbl/gal}) * (127,500 \text{ Btu/gal}) + (\text{barrels of JP5}) / (0.0238 \text{ bbl/gal}) * (135,000 \text{ Btu/gal}) + (\text{barrels of MOGAS}) / (0.0238 \text{ bbl/gal}) * (125,000 \text{ Btu/gal}) + (\text{barrels of distillates}) / (0.0238 \text{ bbl/gal}) * (138,700 \text{ Btu/gal}) + (\text{barrels of residuals}) / (0.0238 \text{ bbl/gal}) * (149,700 \text{ Btu/gal}) + (\text{barrels of fuel oils}) / (0.0238 \text{ bbl/gal}) * (144,200 \text{ Btu/gal})\} * (0.69 \text{ purchases in US} / \text{total purchases}).$$

TABLE B.2 ACTIVITY LEVELS IN 1987 INDEXED DOLLARS (in million) (1):

YEAR	PASSENGER						FREIGHT				OTHER		
	HIGHWAY						HIGHWAY						
	Automobile (2)	Light Truck(2)	Bus	Rail	Commercial Air	General Aviation	Single Unit Heavy Trucks	Combination Heavy Trucks	Rail	Domestic Water	Pipeline	Internationa Water	Military
1972	309,855	45,066	14,480	6,472	14,690	7,040	56,820	95,560	23,430	5,249	49,519	10,083	40,500
1973	311,040	49,860	14,812	6,593	16,805	7,532	60,884	102,676	25,695	5,219	51,436	12,409	32,500
1974	293,380	50,451	15,177	6,955	16,776	7,884	60,486	100,643	25,669	5,158	50,647	10,590	30,500
1975	294,748	54,219	15,013	6,731	16,706	8,025	62,594	92,306	22,752	5,006	49,232	11,144	31,400
1976	300,667	59,675	16,219	6,732	18,489	8,518	65,820	103,692	23,953	5,295	50,096	12,943	28,600
1977	302,457	64,737	16,675	6,682	19,863	9,011	71,154	112,842	24,925	5,409	51,684	14,186	31,200
1978	309,976	71,518	16,701	6,836	22,843	9,926	77,319	121,788	25,885	7,219	54,308	15,325	31,200
1979	298,815	74,021	17,053	7,302	25,997	10,911	75,989	123,617	27,561	7,280	56,240	15,636	34,100
1980	295,967	73,083	17,212	7,107	25,805	10,348	72,012	112,842	27,710	7,896	54,654	14,296	36,600
1981	298,393	73,737	17,362	6,451	25,066	10,278	71,569	107,149	27,455	7,950	52,721	14,292	39,000
1982	304,593	75,447	16,861	6,215	26,259	9,222	72,733	105,725	24,064	7,485	51,616	11,896	41,400
1983	309,590	79,966	16,671	6,403	28,448	8,940	78,516	116,908	24,985	7,676	49,959	10,556	46,700
1984	312,899	87,448	19,642	6,433	30,796	9,152	84,215	123,211	27,798	7,554	51,698	11,946	48,800
1985	318,315	91,206	18,133	6,716	33,839	8,659	84,975	124,024	26,454	7,554	50,857	10,912	53,600
1986	324,764	95,191	21,159	6,916	36,523	8,729	87,567	128,497	26,175	7,409	50,812	10,847	59,800
1987	334,222	101,735	18,421	7,229	40,273	8,518	89,600	134,800	28,468	7,592	52,251	11,071	63,700
1988	348,334	107,714	20,021	7,443	42,183	8,870	92,678	142,323	30,050	7,607	53,856	12,234	58,000
1989	355,740	111,444	19,754	7,784	43,131	9,222	95,808	145,576	30,582	7,098	53,457	14,513	54,300
1990	359,572	114,422	18,622	7,655	45,517	9,152	96,665	149,439	31,190	7,105	53,387	15,513	55,400
1991	359,795	116,177	20,159	7,540	44,655	8,870	97,287	154,115	31,338	6,938	53,299	16,513	58,900
1992	369,630	117,193	21,128	7,561	47,534	8,588	96,779	165,704	32,179	7,059	53,845	17,513	48,500

SOURCES FOR "1987 INDEXED DOLLARS"

(1) 1987 Indexed Dollars -

Conversion to 1987 indexed dollars by the following formula:

$$1987 \text{ indexed dollars} = [\text{Rev}_{1987} / \text{Activity}_{1987}] * \text{Activity}$$

where:

<u>For Mode</u>	<u>Activity Means</u>
Automobile	PM
Light Truck	PM
Bus	PM
Passenger Rail	PM
Commercial Air	PM
General Aviation	PM
Single Unit Heavy Truck	TM
Combination Heavy Truck	TM
Freight Rail	TM
Domestic Water	TM
Pipeline	TM
International Water	TM
Military	1987 \$'s

For Rev. values - see "Operating Expense or Revenue" table.

For Activity values - see "VM and PM for Highway Passenger Modes," "VM and PM for Non-Highway Passenger Modes," and "VM and TM for Freight Modes" tables.

(2) 1987 indexed dollars for Automobile and Light Truck -

Conversion to 1987 indexed dollars was done using the same method as in (1). The Rev_{1987} for Automobile (including Motorcycles) and Rev_{1987} for Light Truck were obtained by the following formula:

$$\frac{\text{Rev}(\text{Auto.})_{1987}}{\text{VM}(\text{Auto.})_{1987}} = \frac{\text{Rev}(\text{Auto. \& Light Truck})_{1987}}{\text{VM}(\text{Auto. \& Light Truck})_{1987}} *$$

$$\frac{\text{Rev}(\text{Light Truck})_{1987}}{\text{VM}(\text{Light Truck})_{1987}} = \frac{\text{Rev}(\text{Auto. \& Light Truck})_{1987}}{\text{VM}(\text{Auto. \& Light Truck})_{1987}} *$$

TABLE B.3 OPERATING EXPENSES OR REVENUES (in millions of current \$'s):

YEAR	PASSENGER					FREIGHT					OTHER		GNP Deflator
	HIGHWAY					HIGHWAY						Military (million of 1987 \$'s) (1)	(1987=1.00) (13)
	Automobile & Light Truck(1)	Bus (2)	Rail (3)	Commercial Air(4)	General Aviation(5)	Single Unit Heavy Trucks(6)	Combination Heavy Trucks(7)	Rail (8)	Domestic Water(9)	Pipeline (10)	International Water(11)		
1972	126,354	3,220	935	8,207	3,735	33,144	40,000	13,105	2,255	13,134	3,501	40,500	2.435
1973	138,254	3,455	1,062	9,164	4,111	35,934	44,648	14,801	2,496	13,126	4,488	32,500	2.301
1974	143,290	3,892	1,222	10,800	4,411	35,888	48,818	16,953	3,074	15,837	5,266	30,500	2.117
1975	156,550	4,948	1,983	11,581	4,801	37,287	47,400	16,509	3,293	20,056	4,928	31,400	1.936
1976	186,649	5,797	2,565	13,337	5,071	41,620	56,245	19,196	3,635	25,323	5,441	28,600	1.840
1977	217,581	6,276	2,944	14,851	5,445	43,904	67,356	20,463	4,020	31,750	6,686	31,200	1.738
1978	244,081	6,825	3,210	17,098	5,833	49,052	77,916	21,896	5,580	38,377	7,303	31,200	1.619
1979	267,031	7,976	3,702	20,371	6,611	52,875	89,338	24,763	6,036	40,892	7,791	34,100	1.490
1980	276,699	9,582	4,195	25,098	8,053	60,545	94,551	27,858	7,219	63,165	8,279	36,600	1.363
1981	307,318	11,000	4,714	26,789	9,391	67,799	97,093	30,502	7,962	70,864	8,698	39,000	1.247
1982	312,554	11,710	5,025	26,841	8,187	62,467	99,940	27,134	7,503	78,989	8,097	41,400	1.175
1983	340,139	12,345	5,121	29,662	7,444	70,700	111,098	27,325	7,647	79,215	8,389	46,700	1.130
1984	379,024	16,128	6,307	33,626	8,236	78,700	120,700	30,549	7,713	80,028	10,316	48,800	1.083
1985	410,313	16,758	6,893	35,860	7,900	82,200	123,200	29,150	7,704	76,158	10,745	53,600	1.054
1986	407,079	17,704	6,937	36,384	8,172	84,800	128,200	27,933	7,448	61,260	11,345	59,800	1.026
1987	435,957	18,421	7,229	40,273	8,518	89,600	134,800	28,468	7,592	52,251	11,071	63,700	1.000
1988	471,452	19,341	7,828	43,820	9,478	96,200	142,700	29,899	7,837	51,372	12,220	58,000	0.966
1989	498,055	20,091	8,287	46,874	9,506	102,450	151,300	29,922	7,554	50,476	12,267	54,300	0.930
1990	518,026	18,367	8,569	49,506	10,272	108,350	162,300	30,403	7,730	48,675	13,118	55,400	0.894
1991	499,141	19,369	7,828	48,938	10,131	109,650	164,600	29,852	7,855	45,728	12,342	58,900	0.855
1992	521,713	19,928	7,478	49,242	10,248	116,000	176,800	30,473	7,935	42,781	11,960	48,500	0.826

SOURCES FOR "OPERATING EXPENSE OR REVENUE"

(1) Automobile & Light Truck -

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.8-9, Table "Nation's Passenger Bill (Millions of Dollars)," row "Auto, Total."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 6, Table "Nation's Passenger Bill," row "Auto, Total."

(2) Bus -

Total annual operating revenues for bus is sum of operating revenues for transit bus, intercity bus and school bus.

For transit bus:

1972-75: First, operating revenues for overall transit was obtained by multiplying overall transit vehicle miles with a constant ratio of operating revenues for overall transit in year 1976 to overall transit vehicle miles in year 1976. Then, operating expense for transit bus was obtained by multiplying the operating revenues for overall transit with a ratio of transit bus vehicle miles to overall transit vehicle miles for each year.

1976-87: Operating revenues for overall transit was obtained from American Public Transit Association, *1992 Transit Fact Book*, October 1992, 1201 New York Avenue, N.W., Washington, DC 20005, p. 46, Table 16, "Trend of Transit Expenses by Function Class, Dollars," col. "Operating Expense, Total." Then, operating expense for transit bus was obtained by interpolated using a ratio of total transit bus vehicle miles to overall transit vehicle miles for each year.

1988-92: American Public Transit Association, *1993 Transit Fact Book*, November 1993, 1201 New York Avenue, N.W., Washington, DC 20005, p. 48, Table 18, "Trend of Transit Operating Expenses by Mode, Dollars," sum of col. "Trolley Bus" and col. "Motor Bus."

For intercity and school bus:

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.8-9, Table "Nation's Passenger Bill (Millions of Dollars)," row "For-Hire Transportation, Intercity, Bus" and row "For-Hire Transportation, Local, School Bus,"

- 1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 6, Table "Nation's Passenger Bill," row "For-Hire Transportation, Intercity, Bus" and row "For-Hire Transportation, Local, School Bus."

(3) Passenger Rail -

Total annual operating revenues for passenger rail is sum of operating revenues for intercity rail, commuter rail, and transit rail.

For intercity rail:

- 1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.8-9, Table "Nation's Passenger Bill (Millions of Dollars)," row "For-Hire Transportation, Intercity, Rail."
- 1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 6, Table "Nation's Passenger Bill," row "For-Hire Transportation, Intercity, Rail."

For commuter and transit rail:

- 1972-75: First, operating revenues for overall transit was obtained by multiplying overall transit vehicle miles with a constant ratio of operating revenues for overall transit in year 1976 to overall transit vehicle miles in year 1976. Then, operating expense for transit rail was obtained by multiplying the operating revenues for overall transit with a ratio of transit rail vehicle miles to overall transit vehicle miles for each year.
- 1976-87: Operating revenues for overall transit was obtained from American Public Transit Association, *1992 Transit Fact Book*, October 1992, 1201 New York Avenue, N.W., Washington, DC 20005, p. 46, Table 16, "Trend of Transit Expenses by Function Class, Dollars," col. "Operating Expense, Total." Then, operating expense for transit rail was obtained by interpolated using a ratio of total transit rail vehicle miles to overall transit vehicle miles for each year.
- 1988-92: American Public Transit Association, *1993 Transit Fact Book*, November 1993, 1201 New York Avenue, N.W., Washington, DC 20005, p. 48, Table 18, "Trend of Transit Operating Expenses by Mode, Dollars," sum of col. "Light Rail," col. "Heavy Rail," and col. "Commuter Rail."

(4) Commercial Air -

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.8-9, Table "Nation's Passenger Bill (Millions of Dollars)," row "For-Hire Transportation, Intercity, Air."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 6, Table "Nation's Passenger Bill," row "For-Hire Transportation, Intercity, Air."

(5) General Aviation -

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.8-9, Table "Nation's Passenger Bill (Millions of Dollars)," row "Private Transportation, Air, Totals."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 6, Table "Nation's Passenger Bill," row "Private Transportation, Air, Totals."

(6) Single Unit Heavy Truck-

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.6-7, Table "Nation's Freight Bill (Millions of Dollars)," row "Truck - Local."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 5, Table "Nation's Freight Bill," row "Truck - Local."

(7) Combination Heavy Truck -

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.6-7, Table "Nation's Freight Bill (Millions of Dollars)," the sum of row "Truck - Intercity, ICC Authorized" and row "Truck - Intercity, non ICC Authorized."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 5, Table "Nation's Freight Bill," the sum of row "Truck - Intercity, ICC Authorized" and row "Truck - Intercity, non ICC Authorized."

(8) Freight Rail -

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.6-7, Table "Nation's Freight Bill (Millions of Dollars)," row "Railroads."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 5, Table "Nation's Freight Bill," row "Railroads."

(9) Domestic Water -

1972-82: Eno Transportation Foundation, Inc., *Transportation In America, Historical Compendium 1939-85*, p.6-7, Table "Nation's Freight Bill (Millions of Dollars)," sum of row "Water, Coastal / Intercoastal," row "Water, Inland Waterways," row "Water, Great Lakes," and row "Water - Locks, Channels."

1983-92: Eno Transportation Foundation, Inc., *Transportation In America*, Ed. 11, September 1993 supplements, p. 5, Table "Nation's Freight Bill," sum of row "Water, Inland Waterways," row "Water, Great Lakes," row "Water - Locks, Channels," and "Water, Coastal/Intercoastal."

(10) Pipeline -

1972-91: U. S. Department of Transportation, Research and Special Programs Administration, National Transportation Statistics, Annual Report, 1993, p.48, Table 4, "Total Operation Revenues, 1960-1991 (million dollars)," sum of col. "Oil Pipeline - Total" and col. "Gas Pipeline - Total."

1992: Linearly extrapolated based on 1990-91 trend.

(11) International Water -

1972-76: Transportation Association of America, *Transportation Facts and Trends*, Ed. 14, July 1978, p.4, Table "The Nation's Estimated Freight Bill (in Millions of Dollars)," row "Water, International."

1977-79: Transportation Association of America, *Transportation Facts and Trends*, Ed. 16, July 1980, p.4, Table "The Nation's Estimated Freight Bill (in Millions of Dollars)," row "Water, International."

1980-82: Eno Transportation Foundation, Inc., *Transportation in America*, Ed. 10, December, 1992 supplements, Updates and Corrections, p.5, Table "Nation's Freight Bill (Millions of Dollars)," row "Water, International."

1983-92: Eno Transportation Foundation, Inc., *Transportation in America*, Ed. 11, September, 1993 supplements, Updates and Corrections, p.5, Table "Nation's Freight Bill (Millions of Dollars)," row "Water, International."

(12) Military -

- 1972-88: U. S. Department of Commerce, Bureau of Economic Analysis, *National Income and Product Accounts of the United States*, Volume 2, 1959-88, Table 3.11, "National Defense Purchases in Constant Dollars, 1972-88 (Billions of 1987 dollars; quarters seasonally adjusted at annual rates)," the sum of row "Aircraft," row "Ships," row "Vehicles," row "Petroleum Products," row "Transportation of Material," and row "Travel of Persons."
- 1989-92: U. S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis, *Survey of Current Business*, Table 3.11, "National Defense Purchases in Constant Dollars (Billions of 1987 dollars)," the sum of row "Aircraft," row "Ships," row "Vehicles," row "Petroleum Products," row "Transportation of Material," and row "Travel of Persons."

(13) GNP Deflator -

Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table B.12, "Gross National Product (GNP) Implicit Price Deflator," col. "1987."

TABLE B.4 VM AND PM FOR HIGHWAY AND NON-HIGHWAY PASSENGER MODES (in millions):

YEAR	Automobile			Light Truck			Intercity		Bus Transit		School	
	VM	PM/VM	PM	VM	PM/VM	PM	VM (6)	PM (7)	VM (8)	PM (9)	VM (10)	PM (11)
	(1)	(2)	(3)	(1)	(4)	(5)						
1972	1,025,696	2.07	2,125,755	156,622	2.02	315,887	1,182	25,600	1,482	19,266	2,359	47,180
1973	1,051,175	2.03	2,133,885	176,833	1.98	349,334	1,178	26,400	1,501	19,513	2,412	48,240
1974	1,012,696	1.99	2,012,733	182,757	1.93	353,475	1,195	27,700	1,521	19,773	2,450	49,000
1975	1,039,579	1.95	2,021,981	200,700	1.89	379,875	1,126	25,400	1,541	20,033	2,500	50,000
1976	1,084,218	1.90	2,062,725	225,834	1.85	418,103	1,118	25,100	1,597	20,761	2,862	57,240
1977	1,115,592	1.86	2,075,001	250,591	1.81	453,570	1,102	25,700	1,638	21,294	2,950	59,000
1978	1,153,664	1.84	2,126,587	279,414	1.79	501,082	1,081	25,400	1,644	20,942	2,991	59,820
1979	1,122,277	1.83	2,050,019	291,905	1.78	518,618	1,132	27,200	1,645	21,597	2,980	59,600
1980	1,121,810	1.81	2,030,476	290,935	1.76	512,046	1,162	27,400	1,690	22,009	3,000	60,000
1981	1,141,517	1.79	2,047,120	296,343	1.74	516,625	1,134	27,100	1,697	23,266	3,000	60,000
1982	1,176,166	1.78	2,089,659	306,141	1.73	528,603	1,115	26,900	1,683	20,282	3,000	60,000
1983	1,206,783	1.76	2,123,938	327,643	1.71	560,270	1,120	25,600	1,693	20,372	3,000	60,000
1984	1,233,703	1.74	2,146,643	357,999	1.71	612,690	1,098	24,600	1,860	21,959	3,400	78,300
1985	1,269,651	1.72	2,183,800	373,072	1.71	639,019	933	23,800	1,878	21,467	3,400	70,000
1986	1,310,611	1.70	2,228,039	389,047	1.71	666,938	1,021	23,700	2,017	21,700	3,700	89,100
1987	1,364,836	1.68	2,292,924	415,449	1.72	712,792	991	23,000	2,094	21,193	3,900	72,900
1988	1,439,603	1.66	2,389,741	439,496	1.72	754,677	996	23,100	2,112	20,964	4,100	83,200
1989	1,488,140	1.64	2,440,550	454,339	1.72	780,814	1,034	24,000	2,124	20,967	4,000	80,600
1990	1,522,741	1.62	2,466,840	466,092	1.72	801,678	991	23,000	2,144	21,174	3,800	74,200
1991	1,542,730	1.60	2,468,368	472,848	1.72	813,974	1,013	23,500	2,196	21,344	4,300	83,300
1992	1,604,964	1.58	2,535,843	476,587	1.72	821,091	1,035	23,700	2,199	20,601	4,400	90,000

YEAR	Transit		Rail Commuter		Intercity		Commercial Air			General Aviation		
	VM (12)	PM (13)	VM (14)	PM (15)	VM (16)	PM (17)	VM (18)	PM (18)	SM (18)	# craft (19)	air hrs (19)	PM (19)
1972	418	11,264	166	5,700	213	4,329	2,337	152,406	287,411	145,000	27	10,000
1973	439	11,142	166	5,500	240	5,049	2,402	174,352	322,992	148,000	29	10,700
1974	459	10,881	173	6,200	260	5,800	2,351	174,052	310,130	161,502	30	11,200
1975	447	10,423	173	6,300	254	5,422	2,241	173,324	315,823	168,475	30	11,400
1976	428	10,115	173	6,200	264	5,834	2,320	191,823	338,349	177,964	32	12,100
1977	382	10,071	175	6,200	261	5,711	2,418	206,082	361,172	184,294	34	12,800
1978	383	10,722	174	6,213	255	5,556	2,608	236,998	381,113	199,178	37	14,100
1979	400	11,167	176	6,492	255	6,365	2,859	269,719	425,411	210,339	40	15,500
1980	402	10,939	179	6,516	235	5,925	2,924	267,722	448,479	211,045	41	14,700
1981	437	10,590	176	6,236	223	4,397	2,703	260,063	438,778	213,226	41	14,600
1982	445	10,428	175	6,027	217	3,993	2,804	272,435	455,938	209,779	36	13,100
1983	424	10,741	177	6,097	224	4,227	2,923	295,144	480,977	213,293	35	12,700
1984	453	10,531	168	6,207	235	4,427	3,264	319,504	534,104	220,943	36	13,000
1985	468	10,777	183	6,534	251	4,785	3,462	351,073	565,677	210,654	34	12,300
1986	493	11,018	189	6,723	250	5,011	3,873	378,923	623,073	220,044	34	12,400
1987	509	11,603	189	6,818	261	5,361	4,182	417,830	670,871	217,183	33	12,100
1988	538	11,836	202	6,964	278	5,686	4,355	437,649	696,337	210,266	34	12,600
1989	553	12,539	210	7,211	285	5,859	4,442	447,480	703,888	219,737	35	13,100
1990	561	12,046	213	7,082	301	6,057	4,724	472,236	753,211	212,211	35	13,000
1991	555	11,190	215	7,344	312	6,273	4,662	463,296	738,030	198,475	30	12,600
1992	554	11,441	219	7,342	307	6,091	4,856	493,163	771,788	184,433	26	12,200

**SOURCES FOR "VM AND PM FOR HIGHWAY PASSENGER MODES"
AND "VM AND PM FOR NON-HIGHWAY PASSENGER MODES"**

(1) Automobile and Light Truck VM -

U. S. Department of Transportation, Federal Highway Administration, *Highway Statistics*, "Summary to 1985" edition, table VM-201A, and each of the annual editions since 1985, tables VM-1:

Automobile --- sum of col. "Passenger Vehicles, Personal Passenger Vehicles, Passenger Cars" and col. "Passenger Vehicles, Personal Passenger Vehicles, Motorcycles."

Light Truck --- col. "Trucks, Single-Unit, 2-Axle 4-Tire".

(2) Automobile PM/VM (occupancy rates) -

1969: U. S. Department of Transportation, Federal Highway Administration, *Nationwide Personal Transportation Survey*, April, 1972, Washington, DC, Report No. 1, p. 8, Table 1, "Average Occupancy in Automobile Trips Classified by Major Purpose of Travel and by Place of Residence," row "All Places and Areas," col.: "All Purposes."

1977: U. S. Department of Transportation, Federal Highway Administration, *1977 Nationwide Personal Transportation Study, Vehicle Occupancy*, 1981, Rep. No. 6, p. 35, Table 16, "Average Vehicle Occupancy by Trip Purpose and Vehicle Type," row "Automobiles," col. "Trip Purpose, All."

1983, 1990: *National Passenger Transportation Survey (NPTS)*. Jennifer Young (ORNL) ran the NPTS tapes.

See below for the tabulated results:

Year:	<u>1969</u>	<u>1977</u>	<u>1983</u>	<u>1990</u>
PM/VM:	2.2	1.86	1.76	1.62

1972-76, 78-82, 84-89: Linearly interpolated.

1991-92: Linearly extrapolated based on 1983-90 trend.

(3) Automobile PM -

Determined by multiplying VM times the estimated load factor (PM/VM).

(4) Light Truck PM/VM (occupancy rates) -

1977: U. S. Department of Transportation, Federal Highway Administration, *1977 Nationwide Personal Transportation Survey, Vehicle Occupancy*, 1981, Rep. No. 6, p. 35, Table 16, "Average Vehicle Occupancy by Trip Purpose and Vehicle Type," row "Vans, Trucks, Recreational Vehicles," col. "Trip Purpose, All."

1983, 1990: *National Passenger Transportation Survey (NPTS)*. Jennifer Young (ORNL) ran the NPTS tapes.

See below for the tabulated results:

Year:	<u>1977</u>	<u>1983</u>	<u>1990</u>
PM/VM:	1.86	1.76	1.62

1972-76: Estimated by using the relative annual change in PM/VM for cars from 1969-77. This was a decline of 0.27%/yr.

1978-82, 84-89: Linearly interpolated.

1991-92: Linearly extrapolated based on 1983-90 trend.

(5) Light Truck PM -

Determined by multiplying VM times the load factor (PM/VM).

(6) Intercity Bus VM -

1972-90: Davis, S. C., and Strang, S. G., *Transportation Energy Data Book*, 1993, Ed. 13, Table 3.30, "Passenger and Vehicle Travel by Bus Type, 1970-90," col. "Vehicle Travel (million miles), Intercity Bus."

1991: Davis, S. C., *Transportation Energy Data Book*, 1994, Ed. 14, Table 3.27, "Summary Statistics on Bus Type, 1970-91," col. "Intercity Bus, Vehicle-miles(millions)."

1992: Linearly extrapolated based on 1990-91 trend.

(7) Intercity Bus PM -

1972-79: U. S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics*, 1982, whose source was the American Bus Association, *Bus Facts*, 1981.

1980-90: U. S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics*, 1992, p. 52, Table 6, "Passenger-Miles, 1980-1990 (millions)," row "Highway, Intercity Bus."

1991: Interpolated by dividing the previous years' load factor of 13 into the 1991 PM.

1992: Eno Transportation Foundation, Inc., *Transportation In America*, 1993, Ed. 11, p. 12, Chapter "Domestic Intercity Passenger Miles by Mode," paragraph 3.

(8) Transit Bus VM -

1972-74: Linearly interpolated between given values for 1970 and 1975.

1970, 75-91: American Public Transit Association, *Transit Fact Book*, 1992, p.79, Table 39, "Trend of Vehicle Miles Operated," sum of col. "Trolley Bus" and col. "Motor Bus."

1992: American Public Transit Association, *Transit Fact Book*, 1993, p.79, Table 39, "Trend of Vehicle Miles Operated," sum of col. "Trolley Bus" and col. "Motor Bus."

(9) Transit Bus PM -

1972-77: Interpolated by multiplying VM by a constant load factor of 13.0, because during the years 1978-81, the actual load factor was 13.0, before steadily decreasing.

1978-91: American Public Transit Association, *Transit Fact Book*, 1992, p.78, Table 38, "Trend of Passenger Miles," sum of col. "Trolley Bus" and col. "Motor Bus."

1992: American Public Transit Association, *Transit Fact Book*, 1993, p.78, Table 38, "Trend of Passenger Miles," sum of col. "Trolley Bus" and col. "Motor Bus."

(10) School Bus VM -

1972-79: U. S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics*, 1982.

1980-90: U. S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics*, 1992, p. 50, Table 5, "Vehicle-Miles, 1980-1990 (millions)," row "Highway, School Bus."

1991: National Safety Council, *Accident Facts*, 1992 Ed., p.71, Table "School Bus Accidents by State, 1990-1991," row "U. S.," col. "Annual Bus Mileage."

1992: National Safety Council, *Accident Facts*, 1993 Ed., p.75, Table "School Bus Accidents by State, 1991-1992," row "U. S.," col. "Annual Bus Mileage."

(11) School Bus PM -

1972-79: Interpolated by using an average early 1980's load factor of 13.75.

1980-90: U. S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics*, 1992, p. 52, Table 6, "Passenger-Miles, 1980-1990 (millions)," row "Highway, School Bus."

1991: National Safety Council, *Accident Facts*, 1992, p.70, Paragraph "Pupil Passenger Miles and Average Bus Occupancy," last sentence.

1992: National Safety Council, *Accident Facts*, 1993, p.74, Paragraph "Pupil Passenger Miles and Average Bus Occupancy," last sentence.

(12) Transit Rail VM -

Davis, S. C., *Transportation Energy Data Book*, Edition 14, Table 6.11, "Summary Statistics for Rail Transit Operations, 1970-92," col. "Vehicle-Miles (millions)."

(13) Transit Rail PM -

Davis, S. C., *Transportation Energy Data Book*, Edition 14, Table 6.11, "Summary Statistics for Rail Transit Operations, 1970-92," col. "Estimated Passenger-Miles (millions)."

(14) Commuter Rail VM -

1972-74: Created by superimposing the PM curve on the beginning (1975) of the VM curve and interpolating backwards to 1972.

1975-90: American Public Transit Association, *Transit Fact Book*, 1992, p.79, Table 39, "Trend of Vehicle Miles Operated," col. "Commuter Rail."

1991-92: American Public Transit Association, *Transit Fact Book*, November 1993, p. 27, Table 6, "Transit Modal Statistics at Glance," row "Commuter," col. "Passenger Miles (millions)."

(15) Commuter Rail PM -

- 1972-77: Eno Transportation Foundation, Inc., *Transportation in America, Historical Compendium 1939-85*, p.13, Table "Railroad Intercity and Commutation Passenger-Miles (millions)," row "Commutation."
- 1978-90: American Public Transit Association, *Transit Fact Book*, 1992, p.78, Table 38, "Trend of Passenger Miles," col. "Railway, Commuter Rail."
- 1991-92: American Public Transit Association, *Transit Fact Book*, November 1993, p.27, Table 6, "Transit Modal Statistics at a Glance," row "Commuter Rail," col. "Vehicle Miles Operated (Millions), 1992."

(16) Intercity Rail VM -

Davis, S. C., and Strang, S. G., *Transportation Energy Data Book*, Ed. 14, Table 6.10, "Summary Statistics for the National Passenger Corporation (Amtrak), 1971-92," col. "Car-miles (thousands)."

(17) Intercity Rail PM -

- 1972-76: Eno Transportation Foundation, Inc., *Transportation in America*, the 1939-1985 Historical Compendium, p.13, Table "Railroad Intercity and Commutation Passenger-Miles (millions)," sum of row "Intercity" and row "Amtrak."
- 1977-80: AAR, *Statistics of Class 1 Railroads*, 1971-81.
- 1981-92: Davis, S. C., and Strang, S. G., *Transportation Energy Data Book*, Ed. 14, Table 6.10, "Summary Statistics for the National Passenger Corporation (Amtrak), 1971-92," col. "Revenue Passenger-Miles (millions)."

(18) Commercial Air VM, PM, and SM -

- 1972-90: Davis, S. C., *Transportation Energy Data Book*, Ed. 14, Table 6.2, "Summary Statistics for Domestic and International Certificated Route Air Carriers (Combined Totals), 1970-91":

VM --- col. "Revenue Aircraft-Miles,"

PM --- col. "Revenue Passenger-Miles,"

SM --- col. "Available Seat-Miles."

- 1991-92: Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation*, 800 Independence Avenue, S.W., Washington, DC 20591,

report No.: FAA-AP0-94-5, Table 6.2, "Traffic Data, All Services (Scheduled and Nonscheduled) of the Large Certificated Air Carriers, 1991 and 1992":

VM --- row "Revenue Aircraft Miles Flown (000),"

PM --- row "Revenue Passenger Miles Flown (000,)"

SM --- row "Available Seat Miles (000)."

(19) General Aviation # Craft, Air Hrs, and PM -

Davis, S. C., *Transportation Energy Data Book*, Ed. 14, Table 6.3, "Summary Statistics for General Aviation, 1970-92":

Craft --- col. "Total Number of Aircraft,"

Air Hrs --- col. "Hours Flown (thousands),"

PM --- col. "Intercity Passenger Travel (billion passenger-miles)."

TABLE B.5 VM AND TM FOR FREIGHT MODES (in millions):

YEAR	Single Unit Heavy Trucks	Combination Heavy Trucks		Rail		Domestic Water	Pipeline				International Water
	VM	VM	TM	VM	TM	TM	Oil	Nat. Gas			TM
	(1)	(1)	(2)	(3)	(2)	(2)	TM (2)	bil. ft' (4)	Ton (5)	TM (6)	(7)
1972	31,414	40,706	470,000	30,309	776,746	690,000	476,000	22,100	494	306,579	66,476.8
1973	33,661	45,649	505,000	31,248	851,809	686,000	507,000	22,049	493	305,871	81,806.4
1974	33,441	45,966	495,000	30,719	850,961	678,000	506,000	21,223	475	294,413	69,819.1
1975	34,606	46,724	454,000	27,656	754,252	658,000	507,000	19,538	437	271,038	73,466.5
1976	36,390	49,680	510,000	28,530	794,059	696,000	515,000	19,946	446	276,698	85,327.5
1977	39,339	55,682	555,000	28,749	826,292	711,000	546,000	19,521	437	270,802	93,527.4
1978	42,747	62,992	599,000	29,076	858,105	949,000	586,000	19,627	439	272,272	101,034.4
1979	42,012	66,992	608,000	29,436	913,669	957,000	608,000	20,241	453	280,790	103,086.9
1980	39,813	68,678	555,000	29,277	918,621	1,038,000	588,000	19,877	445	275,740	94,249.4
1981	39,568	69,134	527,000	27,968	910,169	1,045,000	564,000	19,404	434	269,179	94,223.1
1982	40,212	66,668	520,000	23,952	797,759	984,000	566,000	18,001	403	249,716	78,428.2
1983	43,409	69,754	575,000	24,358	828,275	1,009,000	556,000	16,835	377	233,541	69,596.0
1984	46,560	77,367	606,000	26,409	921,543	993,000	568,000	17,951	402	249,022	78,758.2
1985	46,980	79,600	610,000	24,920	876,984	993,000	564,000	17,281	387	239,728	71,941.2
1986	48,413	82,696	632,000	24,414	867,722	974,000	578,000	16,221	363	225,023	71,509.4
1987	49,537	86,064	663,000	25,627	943,747	998,000	587,000	17,211	385	238,757	72,988.2
1988	51,239	90,158	700,000	26,339	996,182	1,000,000	601,000	18,030	403	250,118	80,656.6
1989	52,969	95,349	716,000	26,196	1,013,841	933,000	584,000	18,801	421	260,814	95,682.3
1990	53,443	96,367	735,000	26,159	1,033,969	934,000	584,000	18,721	419	259,704	102,273.5
1991	53,787	96,942	758,000	25,628	1,038,875	912,000	578,000	19,054	426	264,323	108,864.7
1992	53,506	99,032	815,000	26,128	1,066,781	928,000	582,000	19,387	434	268,943	115,455.9

SOURCES FOR "VM AND TM FOR FREIGHT MODES"

(1) VM for Single Unit Heavy Trucks and Combination Heavy Trucks -

Single Unit Heavy Trucks -- Davis, S. C., 1994, *Transportation Energy Data Book*, ORNL-6798, Oak Ridge National Laboratory, P. O. Box 2009, Oak Ridge, TN, Ed. 14, Table 3.2, "Highway Vehicle Miles Traveled by Mode, 1970-92," col. "Other Single-Unit Trucks."

Combination Heavy Trucks -- Davis, S. C., 1994, *Transportation Energy Data Book*, ORNL-6798, Oak Ridge National Laboratory, P. O. Box 2009, Oak Ridge, TN, Ed. 14, Table 3.2, "Highway Vehicle Miles Traveled by Mode, 1970-92," col. "Combination Trucks."

(2) TM for Combination Heavy Trucks, Rail Freight, Domestic Water, and Oil Pipeline -

Combination Heavy Trucks -- Eno Transportation Foundation, Inc., *Transportation in America*, 1993, p.44, Table "Intercity Ton-Miles by Mode," sum of col. "Trucks, ICC Truck, Amount" and col. "Trucks, Non-ICC Truck, Amount."

Freight Rail -- Economic & Finance Department, Association of American Railroads, *Railroad Facts*, Ed. 1993, p.27, Table "Revenue Ton-Miles," col. "United States."

Domestic Water -- Eno Transportation Foundation, Inc., *Transportation in America*, 1993, p.44, Table "Intercity Ton-Miles by Mode," sum of col. "Water, Rivers/Canals, Amount," col. "Water, Great Lakes, Amount," and item "Domestic Coastwise (Billions of Ton-Miles)."

Oil Pipeline -- Eno Transportation Foundation, Inc., *Transportation in America*, 1993, p.44, Table "Intercity Ton-Miles by Mode," col. "Oil Pipeline, Amount."

(3) Freight Rail VM -

Davis, S. C., *Transportation Energy Data Book*, 1994, ORNL-6798, Oak Ridge National Laboratory, P. O. Box 2009, Oak Ridge, TN, Ed. 14, Table 6.8, "Summary for Class I Freight Railroads, 1970-92," col. "Car-Miles (millions)."

(4) Nat. Gas billion Ft³ -

1972-90: Davis, S. C., and Strang, S. G., *Transportation Energy Data Book*, Ed. 13, Table 6.8, "Pipeline Shipments of Energy, 1972-90," col. "Domestic Natural Gas Consumption (billion cubic feet)." Volume consumed (Ft³) refers to total annual amount sold.

1991: U. S. Department of Energy, Energy Information Administration, *Natural Gas Annual 1991*, Washington, DC, October 1992, P.4.

1992: Extrapolated based on 1989-90 trend.

(5) Nat. Gas Ton -

Calculated by multiplying Ft^3 value with an estimated density -- a density for methane ($0.7168 \text{ kg/m}^3 = 0.04479 \text{ lb/ft}^3$) [obtained from *CRC Handbook of Chemistry and Physics*, 73rd. Ed., p.8-50].

(6) Nat. Gas TM -

Calculated by multiplying Ton by an estimated average length of haul (620 miles, see Ross, 1989, "Energy and Transportation in the United States," *Annual Reviews of Energy*, vol. 14, Table 2, footnote: j).

(7) International Water TM -

1972-90: Department of the Army, Corps of Engineers, Water Resources Support Center, *Waterborne Commerce of the United States*, 1990, Part 5 "National Summaries," Table 1-4, "Total Waterborne Commerce, 1971-1990, Ton-Miles, Tons and Average Haul by Type of Traffic," col. "Foreign, Total, Ton-Miles(millions)."

1991-92: Extrapolated based on 1989-90 trend.

APPENDIX C

LIGHT DUTY VEHICLE FUEL ECONOMY ANALYSIS DATA

Passenger Car and Light Truck Sales and Fuel Economy

PASSENGER CARS																				
	All Cars		Two-Seaters		Minicompacts		Subcompacts		Compacts		Midsize		Large		Small Wagon		Midsize Wagon		Large Wagon	
Year	Sales	MPG	sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG
1975	8238	15.8	244	19.7	941	23.0	1011	19.2	1893	16.2	1631	13.6	1555	13.1	477	22.4	289	13.2	197	11.9
1976	9721	17.5	203	19.4	913	26.0	1368	22.2	2557	17.5	1964	15.7	1679	14.2	345	23.9	485	16.0	207	13.5
1977	11297	18.3	221	20.0	915	27.9	1577	23.9	2767	17.9	2226	16.4	2319	15.9	384	25.5	548	16.3	340	15.5
1978	11174	19.9	191	19.4	901	27.4	2056	24.6	1482	20.2	3339	18.6	2048	16.8	361	24.3	503	18.6	293	15.9
1979	10793	20.3	256	20.1	436	27.6	3044	24.1	668	19.5	3211	19.1	2111	17.4	310	25.7	482	19.1	275	16.1
1980	9444	23.5	200	20.6	383	28.1	3552	27.1	690	22.4	2987	21.6	963	19.1	310	28.6	257	21.1	102	19.1
1981	8733	25.1	162	21.9	227	34.3	2712	29.3	976	26.7	2902	22.9	956	20.4	418	30.0	272	23.1	108	19.9
1982	7818	26.0	263	25.7	178	35.5	2329	29.1	1268	29.0	2136	24.0	832	20.7	382	30.6	284	23.7	146	19.2
1983	8002	25.9	137	23.9	156	35.7	1968	30.0	1456	28.8	2269	23.9	1079	20.2	531	32.2	276	24.4	130	19.6
1984	10674	26.3	348	26.7	42	25.6	2545	29.6	2731	29.7	2770	24.1	1236	20.5	461	31.9	365	25.0	176	19.9
1985	10789	27.0	335	26.9	73	36.0	2181	30.1	2929	29.8	2777	24.9	1512	22.3	496	32.5	341	25.2	145	20.9
1986	11013	27.9	303	28.1	176	30.7	2376	30.6	3348	29.8	2666	25.9	1267	23.9	348	31.0	409	26.0	120	22.0
1987	10731	28.1	282	27.5	71	30.7	2088	31.1	4012	29.7	2252	26.0	1218	23.9	361	30.7	359	25.6	88	22.1
1988	10735	28.6	203	27.4	43	31.1	2143	32.0	4317	29.9	2113	26.7	1303	24.2	253	31.3	285	26.2	75	22.8
1989	10017	28.1	113	26.9	28	26.9	1950	31.2	3585	29.9	2591	26.6	1289	24.0	159	31.5	239	25.6	63	22.5
1990	8835	27.7	177	27.7	76	26.3	1974	31.5	2771	29.0	2339	26.2	1122	23.5	160	29.4	185	25.3	31	22.7
1991	8538	27.9	177	29.0	95	28.6	2303	31.4	2472	28.9	2114	26.0	1012	23.6	209	30.5	122	25.9	34	22.9
1992	7813	27.7	94	26.1	102	30.8	1942	31.5	2303	28.9	1948	25.8	1072	23.5	155	29.8	167	25.9	30	22.7
1993	9098	28.0	170	29.8	106	30.8	2069	31.5	2745	29.5	2212	26.0	1424	24.3	219	30.7	125	25.6	28	22.5

Source: Heavehrich, Murrell, and Hellman, 1993, Tables 14-22, "Characteristics of 1975 to 1993 Passenger Cars."

LIGHT TRUCKS															
	Year	All Trucks		Small Pickup		Large Pickup		Small Van		Large Van		Small Utility		Large Utility	
		Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG	Sales	MPG
1975	1986	13.7	21.7	21.7	22.1	11.26	13.1	1	20.7	4.55	13.1	5.3	16.1	13.4	12.1
1976	2610	14.4	22.7	23.5	22.1	16.39	13.9	1	19.9	5.00	13.8	6.0	15.9	18.3	13.2
1977	2822	15.6	26.3	17.19	26.3	14.9	14.7	2	22.2	5.12	14.7	7.3	17.0	21.0	14.5
1978	3272	15.3	26.3	19.28	26.3	14.7	14.7	3	20.0	6.22	14.2	9.3	16.7	28.7	13.8
1979	3088	14.8	23.4	17.48	25.3	14.3	18.7	8	18.7	4.72	13.5	10.5	16.7	29.6	11.6
1980	1863	18.6	48.9	25.3	25.3	9.47	16	16	19.0	2.26	16.5	6.0	18.8	12.5	14.3
1981	1820	20.1	44.9	28.1	28.1	9.90	18.9	11	18.5	2.34	17.4	4.3	20.4	9.3	15.6
1982	1913	20.5	59.1	27.5	27.5	8.49	19.0	15	21.7	2.96	17.1	4.2	20.5	12.0	16.8
1983	2299	20.9	87.5	26.9	26.9	7.54	18.4	14	19.7	3.68	17.7	15.6	21.9	13.2	16.5
1984	3344	20.5	90.5	26.0	26.0	11.38	18.8	21.7	24.7	4.59	17.1	41.7	21.9	20.8	15.5
1985	3668	20.6	88.6	26.9	26.9	11.92	18.6	44.2	23.5	4.12	16.4	52.4	22.1	21.2	15.8
1986	4349	21.5	125.3	26.8	26.8	12.79	19.1	65.0	23.2	3.94	17.4	5.69	22.2	20.4	16.3
1987	4133	21.7	110.8	26.9	26.9	10.39	19.2	86.8	23.2	3.98	17.1	5.77	22.4	14.3	15.8
1988	4558	21.2	104.0	26.3	26.3	14.18	19.0	80.4	23.1	3.29	17.5	7.63	22.0	20.4	16.1
1989	4433	20.9	88.2	26.2	26.2	13.49	18.8	92.2	23.1	3.55	17.3	7.09	21.6	21.6	16.0
1990	3805	20.7	52.6	26.0	26.0	13.08	19.2	97.0	22.8	2.92	17.4	5.34	21.4	17.5	16.2
1991	4047	21.2	80.3	25.6	25.6	11.48	19.6	83.6	22.6	1.98	17.5	9.69	20.8	9.3	16.0
1992	4419	20.4	59.6	25.2	25.2	15.14	19.0	102.0	22.3	2.88	17.3	8.80	20.5	12.1	16.2
1993	4727	20.8	32.8	25.4	25.4	18.93	19.9	112.1	22.9	2.41	17.8	8.54	21.0	29.0	17.6

Source: Heavenrich, Murrell, and Hellman, 1993, Tables 23-28, "Characteristics of 1975 to 1993 Light Trucks."

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