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FREIGHT TRANSPORTATION PETROLEUM CONSERVATION OPPORTUNITIES - VIABILITY EVALUATION

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FINAL REPORT

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16. Abstract

This report develops a comprehensive perspective of current and near-term future energy demand in U.S. freight transportation. Synthesis of studies of many agencies indicate that the annual petroleum fuel demand for freight transportation in 1985 will be 5 billion gallons greater than that in 1975, even with a 7 billion gallon a year savings from conservation measures. This represents an increase in freight's share of the U.S. total transportation fuel demand from 23% to 29%, because of continued freight traffic growth and the greater savings potential in passenger systems.

Freight transport by rail, by highway and by raii/highway intermodal services receives the most attention in this report because these modes offer the greatest promise for significant fuel savings. Fuel consumption and conservation estimates include both intercity and local truck operations, but intercity operations of the competitive, heavy-duty trucks and general merchandise trains are the primary focus because about 60% of the potential truck fuel savings and virtually all of the rail savings in 1985 are projected to come from intercity operations.

Attention is focused on considerations of the transport market place supply and demand interactions in the evaluation of alternative government policies for fuel conservation in freight systems. An overall evaluation approach is presented, analytical tools appraised and several government policy alternatives are given a preliminary assessment.

The results suggest that the most productive conservation strategies are those that focus on technological and operational improvements within the rail and highway modes having estimated savings of 28% and 18% respectively. Shifts of traffic to intermodal rail services although economically viable may prove counterproductive in certain markets in terms of energy consumption.

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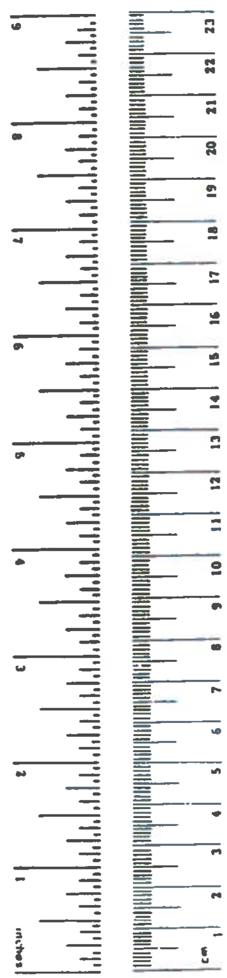
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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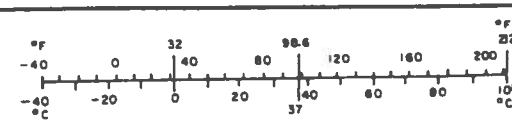
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams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



PREFACE

This report is a synthesis of investigations conducted by and for several offices within the Department of Transportation. It is, therefore, the result of work performed by a number of researchers and analytical teams. In addition to the many references cited in this report, the work of the following people deserves specific recognition here.

Glenn S. Larson (DTS-322) and Paul A. Hoxie (DTS-223) are co-authors of the sections on Energy Conservation Opportunities and Energy Conservation Policy Impact Assessment Process, respectively. David Knapton (Raytheon Service Company) authored the appendix on Fuel Consumption Estimating for Modal Subsystems. The section entitled Total U.S. Energy Consumption was developed with the extensive assistance of Charles T. Phillips (DTS-321) and John K. Pollard (DTS-321) using data compiled by them for the TSC Transportation Energy Project sponsored by the Energy Policy Division (P-13) of the Office of Intermodal Transportation.

The principle author is solely responsible for the section on Assessment of Alternative Policies for Energy Conservation Opportunities. However, the national aggregate statistics and projections presented were obtained from the previous work of and conversations with Robert D. Nutter (P-12) and Martin J. Costello (P-20). The disaggregate statistics, projections and modal shift estimates draw heavily from previous TSC projects for the former Secretarial Offices (TST-10 and TPI-20) as well as from work concurrent with this project by Michael S. Bronzini (CACI, Inc. - Federal) and Paul O. Roberts, et al. (MIT Center for Transportation Studies).

Sponsorship and overall direction of the project has been the responsibility of Robert A. Husted (DPB-25) who provided technical guidance for this report through its many drafts with the objective of making it a datum for pursuit of energy conservation in freight transportation.

Finally, editorial supervision in the preparation of this report for publication was the responsibility of James Sterling (Raytheon Service Company) who deserves credit for substantial contributions toward the readability of this report.

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1. INTRODUCTION

1.1 EXECUTIVE SUMMARY

Business-as-usual demand for petroleum fuel for U.S. freight transportation in 1985 has been projected at about 12 billion gallons per year greater than it was in 1975 unless a comprehensive conservation program, some elements of which have already been initiated, is vigorously pursued. This 12 billion gallons represents a 40% increase in fuel consumption for a 29% increase in ton-miles of freight transportation for 1985, reflecting a continuation of recent trends in modal shifts. Conservation could reduce the projected 1985 business-as-usual freight fuel consumption by some 16% or 7 billion gallons. Even with conservation, and assuming no major changes to the modal share trends, freight's share of the total transportation fuel demand is projected to grow from the 23% of 1975 to 29% in 1985. This share change will result both from the relatively greater fuel savings expected from the higher conservation potentials of automobile transportation, and from overall growth in freight traffic.

Of the foregoing potential savings of 7 billion gallons for freight in 1985, the most substantial potentials are offered by rail and highway modes. These potential savings are 28% and 18% of their respective 1985 business-as-usual petroluem fuel consumptions. This represents a savings potential of about 4.5 billion gallons for highway freight and 1.3 billion gallons for rail. The remaining 1.2 billion gallon savings potential is distributed among the water, pipeline and air modes. These fuel savings are from technological innovations and operational changes within each mode and exclude savings that might result from substantial market shifts from more energy intensive modes to less energy intensive modes. The latter are treated separately.

This report also provides a preliminary assessment of the energy conservation impacts of selected alternative government policies for energy conservation. The impacts of policies involving only the improvements within modes are compared with policies involving modal shifts of competitive rail and truck freight markets. The assessment is founded upon estimates of shipper/receiver trade-offs between transport service quality and price. The following elements are basic to the assessment.

1. The projected demand for transportation specified by commodity, regional origin, destination and shipment size.
2. The price and service characteristics for each alternative modal service available.
3. The mode selection behavior of the buyers of transport services.

No single existing mode share analysis tool can be relied on for all issues because each of the existing models emphasizes a different aspect of the supply/demand interaction. To address a specific policy issue, it is therefore still necessary to choose the model that most faithfully represents the variables most critical to the question at hand. In this study, four DOT developed mode share analysis models were assessed and three actually used to analyze the following four policy options: 1) A base case "do nothing" policy, 2) A coordinated program by government/industry for energy conservation in freight transport, 3) A greatly expanded system of upgraded, dedicated rail/truck intermodal services designed to penetrate medium to long haul markets which might be considered truck markets, 4) Changes in federal and state truck size, weight and configuration limits to permit universal use of higher capacity, multiple-trailer tractor combinations on limited access, divided highways.

The results of this preliminary assessment suggest that a government "do nothing" policy would result in an annual increase of two to three percent in petroleum for freight transportation. A government/industry program of conservation involving improvements within each mode could reduce this annual rate of growth to one percent or less, but the impact on service quality is not yet known. The results also suggest that diversions of freight markets from highway to rail, through the mechanism of intermodal innovations, will result in both positive and negative petroleum fuel savings. Intermodal innovations which effectively penetrate markets currently held by highway or which forestall continued losses of rail markets to highway services will produce significant fuel savings in these specific markets. However, introduction of intermodal innovations in markets heavily involved in conventional rail carload services as well as highway services can result in net increases in petroleum consumption. In these latter markets, intermodal innovations may be desirable as a conservation measure only if a non-petroleum source of energy is more appropriate for rail based systems than for highway.

Specifically, this study suggests that upgraded and expanded rail based intermodal trailer/container on flatcar (TOFC/COFC) services can cause substantial modal diversions from highway as indicated by many studies. However, in some markets, diversions from rail carload services can be greater than diversions from highway. It is possible that the aggregate diversions to rail TOFC can result in insignificant fuel savings at best and substantial increases in fuel consumption at worst because of the relative fuel intensivenesses of rail carload, trailer-on-flatcar (TOFC), and highway services.

With respect to the policy of permitting higher capacity highway vehicles (i.e. one hundred foot long multiple trailer combinations greater than 100,000 pound gross weight), this preliminary assessment suggests that petroleum consumption will be reduced significantly (perhaps as much as 25% for a specific movement) for the freight markets currently served by highway. However, the cost reductions attending the use of such higher capacity vehicles, if passed through to the freight rates, could cause traffic diversion from the rail mode and thereby increase aggregate fuel consumption.

1.2 BACKGROUND AND PURPOSE

The rising cost of energy and the growing awareness of the limits of the world's petroleum supply make conservation of petroleum a major consideration in government planning of future freight transportation.

Although it is generally accepted that the greatest potential for transportation petroleum savings lie with the passenger automobile, it is also true that freight transport systems, particularly trucks and trains, offer significant savings potential. However, there is no consensus on how much fuel can be saved while still providing an acceptable level of freight transportation services. Estimates of fuel savings possible through implementation of certain operational changes and through certain technological innovations have been made. Diversion of freight traffic from more fuel intensive modes to less fuel intensive modes has also been suggested as a petroleum conservation measure. However, no comprehensive estimate of total fuel savings attainable has been made which adequately considers the economic forces of the market environment in which the modes operate.

This report documents the results of a study, for the Office of the Secretary of the Department of Transportation, having four major objectives:

1. Develop a comprehensive perspective of the current and new future energy consumption in freight transportation.
2. Develop a perspective of potential national aggregate fuel savings through synthesis of research by others into modal-specific fuel conservation opportunities.
3. Develop an analytic process for comprehensive assessment of energy consumption impacts and economic impacts of alternative energy conservation policies. The process gives consideration to the supply/demand interactions of the marketplace reflecting the economic forces at work.
4. Conduct a preliminary assessment of a few government policy alternatives using the analytic process.

This report has three major sections. Section 2 provides an overview of total energy consumption in the U.S., and freight transportation's share by mode. It also presents base projections of petroleum fuel consumption, by mode, for 1985, assuming a business-as-usual scenario, as well as projections which assume that feasible conservation measures are implemented through joint industry-government action. Section 3 describes an analytical process for comprehensive assessment of the market share, shipper cost, and fuel consumption impacts of alternative government policies. It also compares several freight mode share models developed under DOT sponsorship which can contribute to evaluations depending upon the required level of detail. Section 4 presents and assesses four alternative policies -

1. A base case "do-nothing" policy.
2. A coordinated program by government and industry for energy conservation in freight transport.
3. A greatly expanded system of upgraded, dedicated rail/truck intermodal services designed to penetrate medium to long haul markets which might otherwise be considered truck markets.
4. Changes in federal and state truck size, weight and configuration limits to permit universal use of higher capacity, multiple trailer combinations on limited access, divided highways.

2. FREIGHT ENERGY CONSUMPTION AND CONSERVATION PERSPECTIVE

2.1 TOTAL U.S. ENERGY CONSUMPTION

The total U.S. consumption of energy from primary energy sources in 1975 was 70.6 x 10^{15} BTUs (70.6 Quads). This figure includes no electrical energy and was distributed among the major sectors of the economy as follows: 1) electrical power generation 29.0 percent, 2) industrial 25.2 percent, 3) household and commercial 19.4 percent, and 4) transportation 26.4 percent.* Transportation's 18.5 Quads are derived mostly from petroleum fuels, i.e., 96.7 percent of the transportation consumption total. Therefore, petroleum fuels are the major consideration of this study.

The total petroleum consumption in the U.S. increased by a factor of 2.6 between 1950 and 1973, and in 1973 the transportation sector consumed 52.1 percent of that year's total. Between 1973 and 1975, the U.S. total petroleum consumption dropped about 6.0 percent, but transportation's share increased to 54.8 percent of the total. In other words, while the total U.S. petroleum consumption dropped by 6.0 percent, transportation dropped by only 1.3 percent after the 1973 fuel crisis. Figure 2-1 illustrates the overall trend in petroleum consumption by the four sectors between 1950 and 1975.

2.1.1 Transportation Sector Petroleum Consumption

The 1975 petroleum consumption of the total transportation sector, which includes both commercial and private is 16.9 Quads for movement of both people and goods. This can be further subdivided into the major passenger and freight services as shown in Table 2-1 and in Figure 2-2. Military fuel consumption is not

*Gross direct consumption of primary sources, not including consumption of electrical energy by each of these consumption sectors. Source: U.S. Department of Interior, Bureau of Mines, Press Release, March 14, 1977.

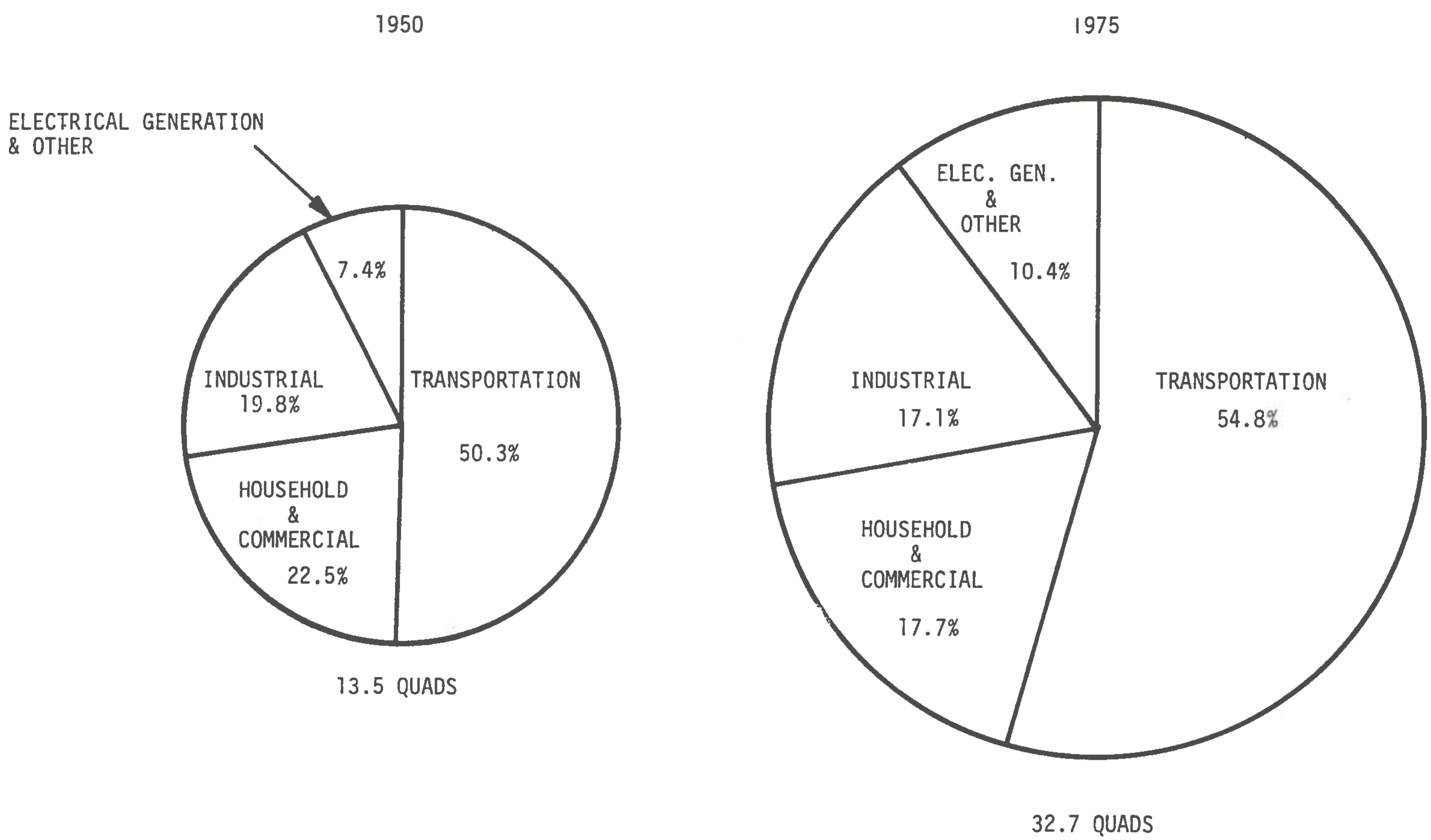


FIGURE 2-1. TRENDS IN PETROLEUM CONSUMPTION BY SECTOR

TABLE 2-1. TRANSPORTATION PETROLEUM DEMAND - QUADRILLION BTU

Service	1975 Domestic[6]	1975 International	1975 Total	1985 (Business-As-Usual) Domestic	1985 (Business-As-Usual) International	1985 (Business-As-Usual) Total	1985 (with Conservation) Domestic	1985 (with Conservation) International	1985 (with Conservation) Total
Passenger									
Auto	9.55	-	9.55	10.41	-	10.41	7.17	-	7.17
Light-Duty Truck[1]	1.92	-	1.92	2.57	-	2.57	1.82	-	1.82
Air[2]	0.98	0.22	1.20	1.90[7]	0.44	2.34	1.12[8]	0.34	1.46
Other[3]	0.42	-	0.42	0.51[7]	-	0.51	0.43[8]	-	0.43
Subtotal	12.87	0.22	13.09	15.39	0.44	15.83	10.54	0.34	10.88
Freight									
Truck[4]	2.40	-	2.40	3.41	-	3.41	2.82	-	2.82
Water	.30	0.46	0.76	0.35	0.74	1.09	0.33	0.72	1.05
Rail	0.51	-	0.51	0.61	-	0.61	0.44	-	0.44
Pipeline[5]	0.08	-	0.08	0.10	-	0.10	0.09	-	0.09
Air	0.04	0.04	0.08	0.07	0.10	0.17	0.05	0.08	0.13
Subtotal	3.33	0.50	3.83	4.54	0.84	5.38	3.73	0.80	4.53
TRANSPORTATION TOTAL	16.20	0.72	16.92	19.93	1.28	21.21	14.27	1.14	15.41

NOTES:

[1] Vans and trucks under 10,000 lbs. G.V.W., includes commercial use.

[2] Commercial only.

[3] Includes local and intercity bus, school bus, passenger rail, motorcycle, general aviation and water recreation, but excludes electric transit.

[4] All commercial trucking over 10,000 lbs. G.V.W.

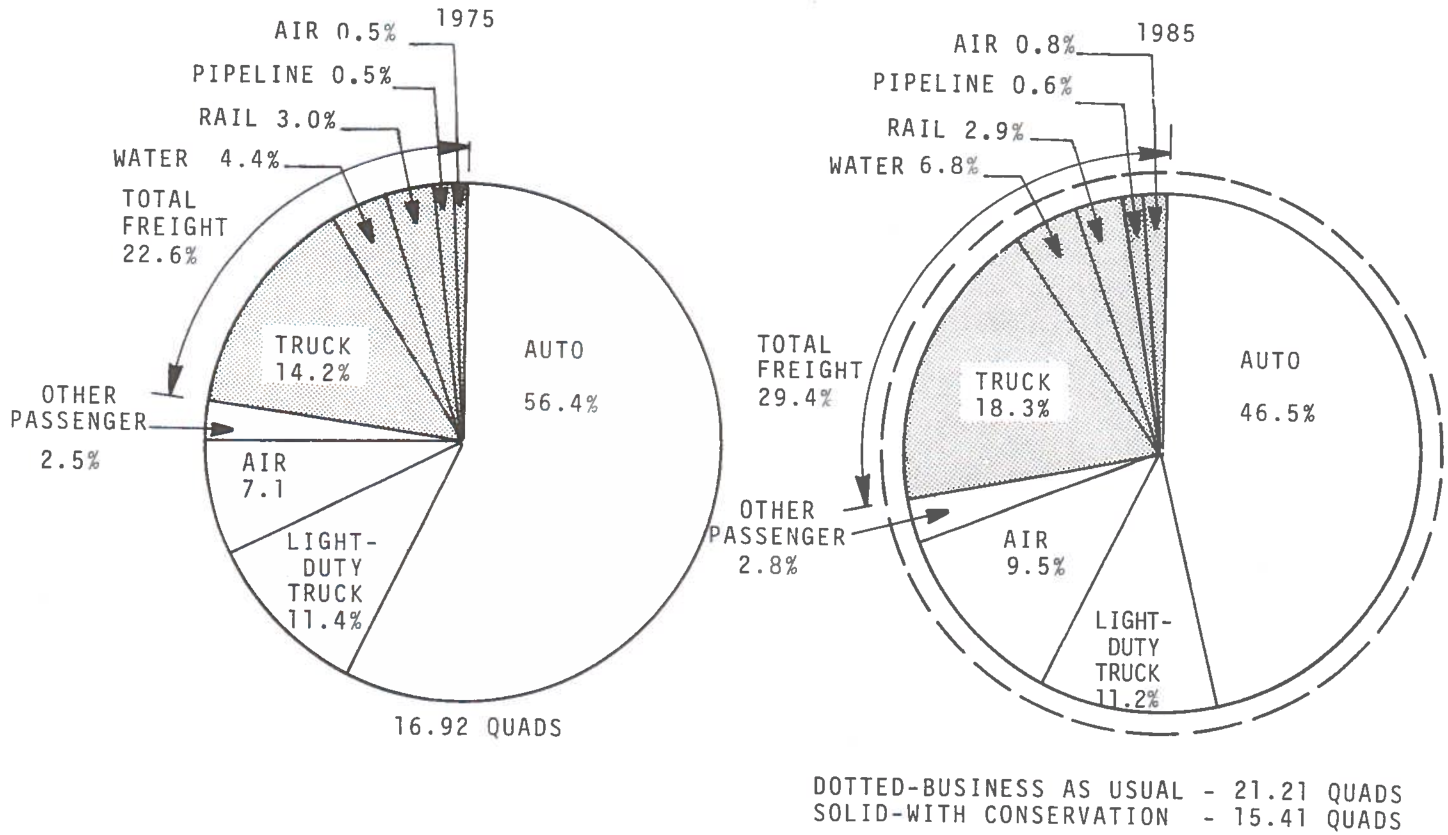
[5] Petroleum consumption for petroleum pipelines estimated at 22% of total pumping energy and 7% of total pumping energy for gas pipelines.

[6] Military consumption from domestic sources not included.

[7] Traffic projected to increase 2%/yr.

[8] Fuel intensiveness projected at 85% of 1975 level.

SOURCE: Derived from Section 4 of Reference (1), except conservation estimates for Truck & Rail which are developed in Section 2.2 of this report.



NOTE: Military consumption from domestic sources and oil and gas pipeline non-petroleum energy consumption not included. Commercial international air and water consumption of petroleum from domestic supplies is included.

Source: Developed from Table 2-1.

FIGURE 2-2. TRANSPORTATION PETROLEUM DEMAND included and non-petroleum energy consumption by oil and gas pipelines and by electric transit are not included.* The base projection of petroleum demand for transportation for 1985, assuming a "business-as-usual" scenario, is shown by the dotted circle in Figure 2-2. The figure also shows the aggregate effect of certain conservation opportunities which have been judged feasible. The modal shares in 1985 reflect the impact of these conservation opportunities. The details of the conservation opportunities for the freight services are discussed in subsequent paragraphs. The estimates for the conservation opportunities for the passenger modes were derived by another study.[1**] The preliminary analyses suggest that implementation of the more likely conservation innovations can more than compensate for the 25 percent increase in petroleum demand projected for the business-as-usual scenario for transportation of people and goods in 1985. Figure 2-2 shows that the freight transportation services will increase their share from 23 to 29 percent of the total transportation demand for petroleum reflecting the greater savings potential of the passenger transportation modes.

2.1.2 U.S. Domestic Freight Transportation Petroleum Consumption

Of the 3.83 Quads of petroleum consumed by freight transportation in 1975, 0.50 Quads were consumed from domestic supplies by international marine and international air freight. The remaining 3.33 Quads of petroleum consumption (approximately 20 percent of the national transportation petroleum consumption and about 5 percent of the total national energy consumption) were for domestic movement of freight. It is this 3.33 Quads of petroleum fuel (25 billion gallons of fuel per year) which is the major concern of this report. This petroleum consumption for domestic freight transportation is projected to increase by 40 percent by 1985 under a "business-as-usual" scenario. Implementation of feasible

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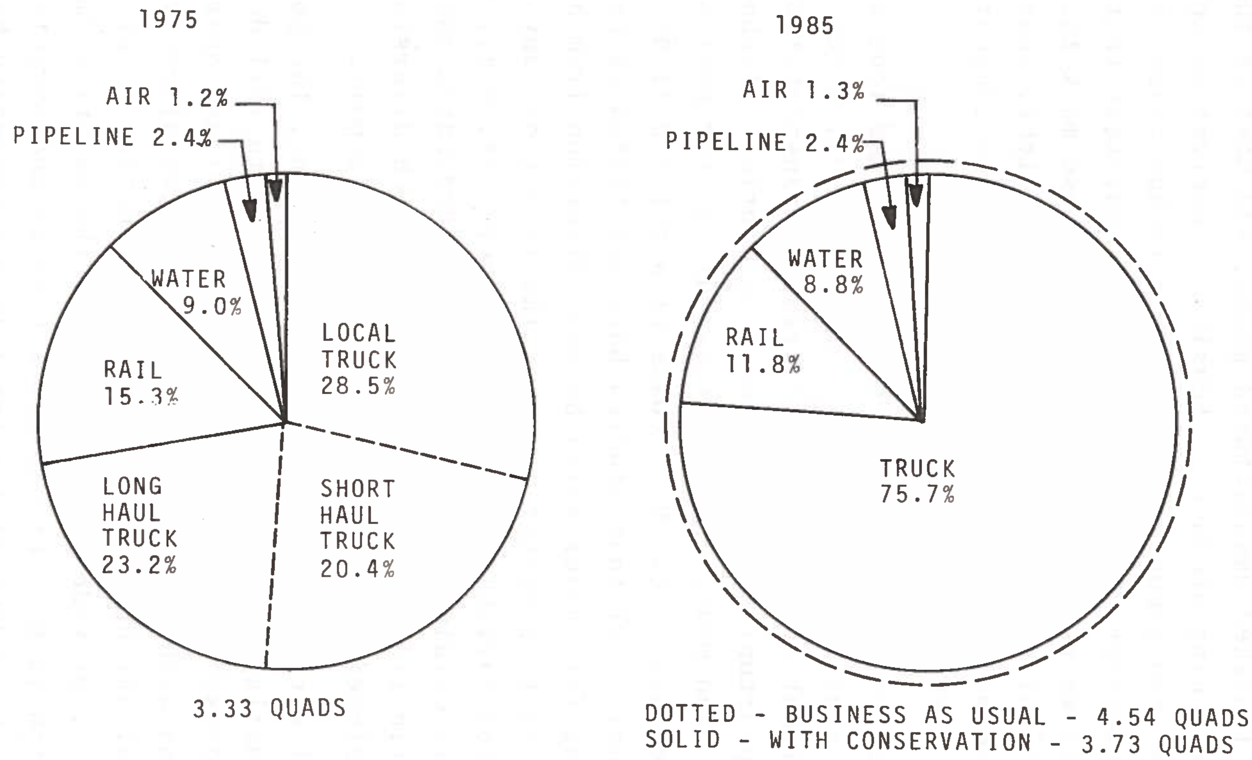
*Direct energy consumption by oil and gas pipelines is estimated to be 78 to 93 percent electricity and natural gas respectively rather than petroleum fuels.

**References are listed at the end of Section 4.

conservation opportunities promises to cut this growth to about 18 percent above the 1975 level. Energy conservation opportunities considered by this study fall into three categories: a) technological innovations within each mode, b) operational changes within each mode and c) shifts in traffic from more energy intensive modes to less energy intensive modes. Each of these categories will be discussed separately later in this chapter. At this point, it is only necessary to present an overall perspective of the potential national impact of any changes to the several modes of freight transportation. Figure 2-3 displays the distribution of petroleum consumption among the domestic freight transportation modes.* It can readily be seen that the truck mode is the most attractive target for conservation of petroleum fuel within the freight transport sector. Trucking becomes even more attractive when one considers that the aggregate 1985 truck freight petroleum consumption is projected to increase about 42 percent above the 1975 level without conservation and even with implementation of certain feasible technological and operational conservation opportunities the projected increase is 18 percent. These conservation opportunities will be elaborated upon later in this chapter, but they do <u>not</u> include the use of long, heavy, multiple trailer rigs (e.g., 100 feet length and GVW 120,000 pounds) nor do they include major shifts in traffic among the freight modes.

Truck freight, however, is not a monolithic system for which a single set of conservation opportunities exist. The trucking system is made of many subgroups, each serving very different transportation functions and having unique problems. Figure 2-3 indicates that in 1975, local trucking consumed 29 percent of the aggregate domestic freight transportation fuel. This subgroup includes all of the intra-urban movement of foods, fuels and general merchandise, and also includes all of the local movement of construction materials and solid waste collection and disposal. The figure also shows that another 20 percent was consumed in

*The modal shares in 1985 reflect the impact of the conservation opportunities considered potentially feasible although institutional and economic feasibilities have been only superficially explored to date.



Source: Developed from Tables 2-1 and 2-2

FIGURE 2-3. U.S. DOMESTIC FREIGHT TRANSPORTATION PETROLEUM DEMAND short haul movements (i.e., beyond the local area but under 200 miles). This subgroup includes much of the unregulated trucking of agricultural products, private trucking of raw material and semifinished and finished manufactured goods, and most of the truck movement of mining products. Feasible conservation opportunities for these two groups must be either technological or operational in character, because it is highly unlikely that the less energy intensive rail mode can penetrate these markets. Substantial shifts of traffic from truck to rail might, however, be feasible in the movement of the bulk goods in the longest of these short haul markets.

The third subgroup of trucking is the medium and long haul movements (i.e., over 200 miles). This latter group, which consumes some 23 percent of the aggregate freight transportation fuel, provides opportunities in all three categories - technological, operational and modal shift. It is this latter portion of the petroleum fuel pie (i.e. 0.77 Quads or about 6 billion gallons of fuel per year) that studies have identified as being the most promising for conservation by some diversion from highway to rail. It is this market which is the target of many proposals for improved rail/highway intermodal services, e.g., trailer on flatcar (TOFC)/container on flatcar (COFC), dedicated run-through and shuttle train etc. An estimate of such diversion potential is developed later in Section 4 of this report.

Although all savings in petroleum are important, the potential savings resulting from diversions from truck to rail do not offer as much promise as savings from technological and operational innovations within the modes. More detailed discussions of these potential savings follow in later subsections, but a glance at Table 2-2 provides a suggestion of the relative importance of innovation in the various truck classes and markets. Table 2-2 shows a breakdown of the total fuel consumption by all truck movement of freight by truck class and by haul market. The greatest fuel conservation payoff is in the heavy-duty trucks over

TABLE 2-2. TRUCK FUEL CONSUMPTION BY CLASS AND BY HAUL

TRUCK CLASS	Percent Distribution of BTU			
	LOCAL	SHORT HAUL (<200 Miles)	LONG HAUL (>200 Miles)	TOTAL
III-V MEDIUM DUTY 10,000 - 19,500 lbs. GVW	8.5	2.0	0.5	11.0
VI LIGHT HEAVY DUTY 19,501 - 26,000 lbs. GVW	13.8	3.9	1.1	18.7
VII HEAVY DUTY 26,001 - 33,000 lbs. GVW	3.0	2.8	2.8	8.6
VIII HEAVY DUTY Over 33,000 lbs. GVW	14.2	19.9	27.6	61.7
TOTAL	39.5	28.5	32.0	100.00%

SOURCE: Derived from Reference (2) Interagency Study on Commercial Motor Vehicle Goals Beyond 1980, assuming 124,952 BTU/Gal gasoline and 138,690 BTU/Gal diesel fuel.

33,000 pounds gross vehicle weight (GVW) in all markets. The next promising group is the light heavy-duty trucks (19,500-26,000 pound GVW) used in local transportation services. The third most promising target is the medium-duty truck used in local transport services.

2.1.3 Modal Trends in Intercity Freight Transportation

Until the middle of the nineteenth century, intercity freight shipments were made primarily by water -- a rather slow service limited to places on waterways. The advent of the railroad coal fired, steam locomotive and steel rail technology promised faster service to nearly all geographical locations. The rapid spread of the rail network, particularly after the Civil War, shifted the emphasis to rail transportation and induced an ever growing demand for more transportation service. In 1850 there were 9,000 miles of railroad, but by 1890 the trackage had increased to almost 157,000 miles.

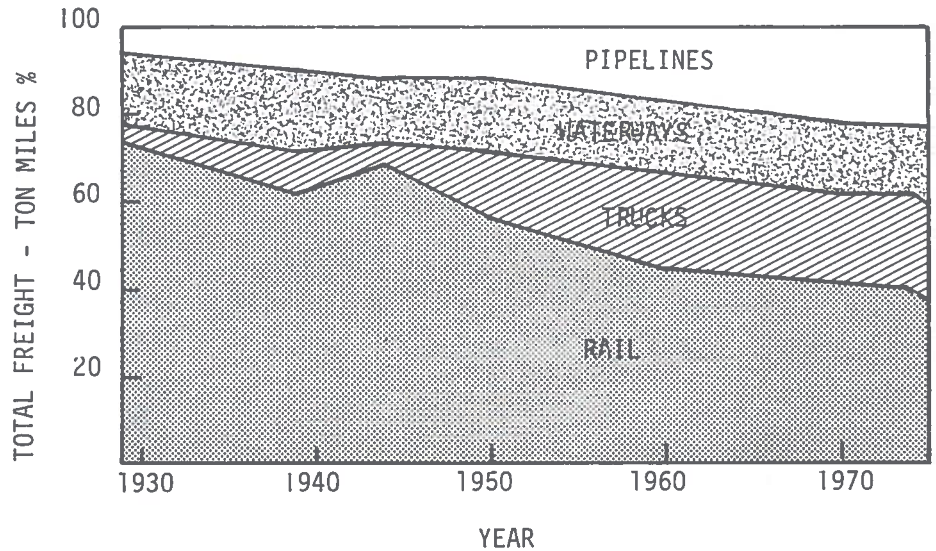
By the middle of the twentieth century, the rail network had passed its peak expansion and was down to about 224,000 miles of roadbed carrying nearly 600 billion ton-miles of revenue freight. The petroleum fueled motor truck and highway technology had already proven to be capable of providing a higher quality of transport service in short haul, intercity movements. Beginning in the mid 1950s, the building of the high capacity, high speed interstate highway system assured the accelerated growth of intercity trucking and the penetration by private and for-hire trucks into the more service oriented markets. During the 1950s, the conversion of transportation from a coal based technology to a petroleum based technology was completed. During this same period, pipelines for the transport of crude oil and petroleum products expanded substantially, presenting the rail and water carriers with strong competition for large volume, rather steady flow movements of these products. Also during this same period, the U.S. inland and coastal waterways system improved its accessibility, economics, and service quality, thus maintaining its competitive position in bulk goods markets. As a result of all this, pipelines and trucks increased their respective shares of the total U.S. transportation market as measured in revenue ton-miles, while the domestic waterways system maintained its share, all at the expense of the rail industry. Since 1960, the jet airplane technology added still another petroleum based, high quality service to intercity freight transportation. Air freight grew to almost 4 billion revenue ton-miles by 1975. Figure 2-4 graphically displays this trend in modal market shares over the past half century. It shows that in 1929, the rails dominated freight transportation by carrying over two-thirds of the revenue ton-miles. Today the rail share is less than one third, while the other three modes split two thirds of the market fairly evenly among them. The distribution of intercity ton-miles of freight for 1975 is as follows:

TABLE 2-3. 1975 INTERCITY MODAL TRAFFIC

	Ton-Miles* (Billions)	Percent of Total
Rail	759	33.2
Truck (all except Local)	454	19.8
Water (Rivers, Lakes and Coastal)	565	24.7
Pipeline (Petroleum)	507	22.1
Air	4	0.2
	2,289	100.0%

It was shown in Section 2.1.2 that 72 percent of the fuel consumed in 1975 for freight transportation was for trucks. It was also shown that the truck fuel consumption was rather evenly divided among the three submarkets - local, short haul and long haul. The distribution of the ton-miles generated in these submarkets is quite different. Actual data is lacking, but it is

*Transportation Facts and Trends, T.A.A.



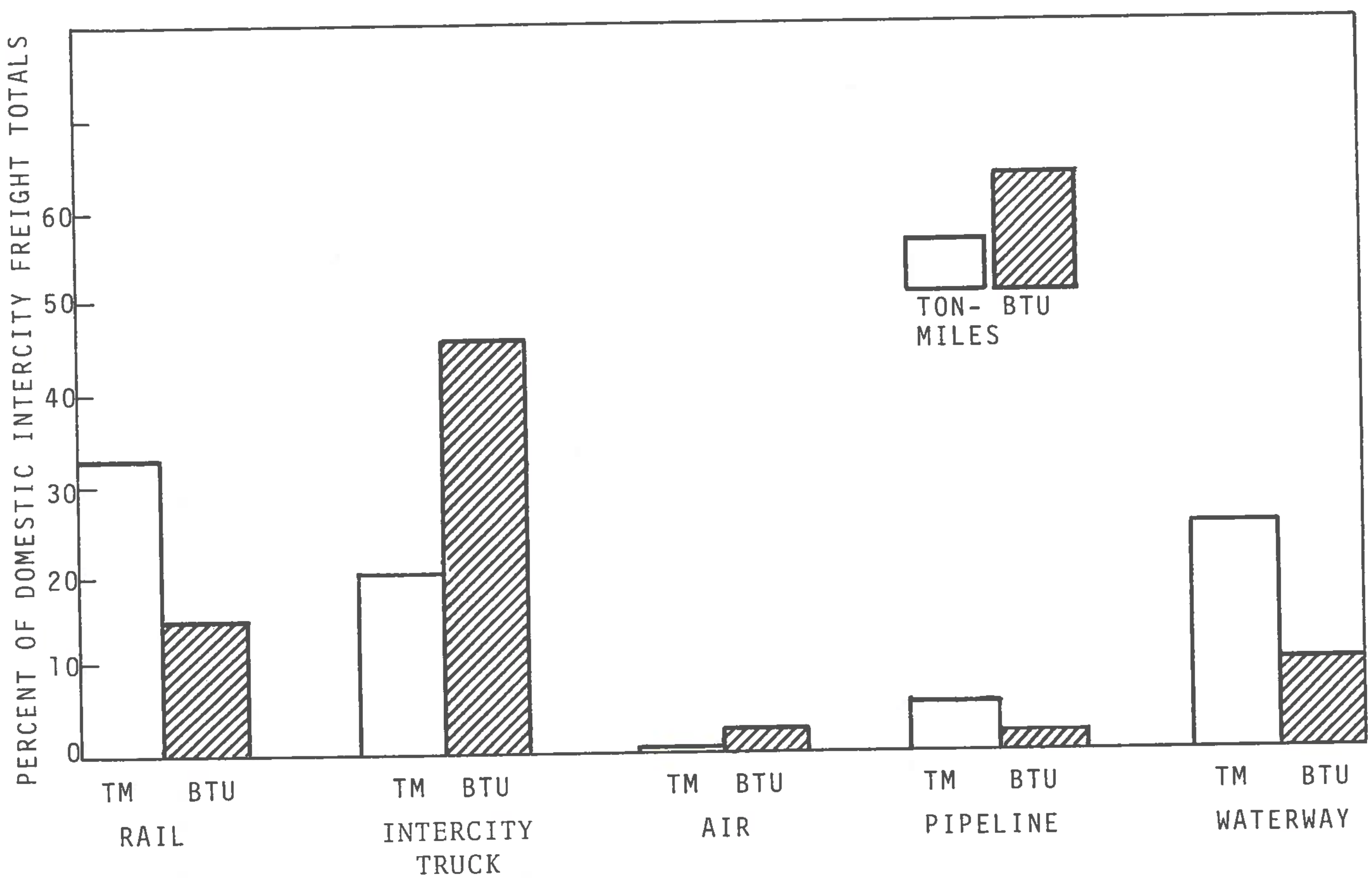
Data Source: (1) AAR Yearbook

FIGURE 2-4. TRENDS IN MODAL SHARES OF INTERCITY FREIGHT TON-MILES estimated that total truck ton-miles are distributed as follows: 47 percent long haul, 38 percent short haul, and 15 percent local.* Therefore, the 454 billion ton-miles shown above for the intercity (non-local) trucking represents 85 percent of the truck ton-miles while consuming only 60 percent of the truck petroleum energy.

2.1.4 Modal Energy Intensiveness

The distribution of freight traffic (measured in ton-miles) among the modes has been shown to be substantially different than the distribution of petroleum fuel consumption. Figure 2-5 displays the modal shares of both ton-miles of revenue freight and the petroleum fuel consumption. Observation of this difference has led to the concept of modal fuel (or energy) intensiveness[3], i.e., energy consumed per ton-mile of freight transportation. This concept, although useful for development of factors for projecting future total consumption of each mode (given a projection of future ton miles), tends to be misleading when it is used to compare the relative fuel "efficiencies" of the modal systems in the aggregate. This is because in the aggregate, the concept ignores the very different transportation jobs being done in each modal market. The modal average energy intensiveness factor, when calculated simply by dividing the total fuel consumed in the mode by the total ton-miles of revenue freight service provided, makes no allowance for differences in service quality, type of products transported or terrain traversed. Energy intensiveness comparisons among modes are meaningful only when the character of the freight markets and the services rendered are similar. This means that disaggregate values must be considered and since they are not generally available, usually must be estimated. Variations among markets within a mode can be nearly as great as the difference between two aggregate modal averages. For example, rail energy intensiveness in 1972 varied from a low of 366 BTU/ton-mile for coal movement to a high of 1889 BTU/ton-mile for

*Estimated from data presented in Reference (2) The Interagency Study on Commercial Motor Vehicle Goals Beyond 1980.



Note: Pipeline Ton-Miles shown is 22% of Total because 78% estimated to be powered by electricity.

Source: Developed from Tables 2-1 and 2-3

FIGURE 2-5. MODAL PERCENTAGE SHARES OF TRAFFIC AND PETROLEUM CONSUMPTION - 1975 transport of electrical machinery. The average for rail was 687 while the average for intercity trucking was 2343 for this period. The rail differential (i.e., 1523) is not greatly different from the 1656 BTU/ton-mile difference between the averages for rail and truck.*

The aggregate values are meaningful for analyzing and projecting trends in energy intensiveness within a mode, provided that the commodity mix, the character of the markets served and service quality are unchanged during the period analyzed. This was not the case in the rail industry between 1950 and 1970 during which time the gross overall energy intensiveness is reported to have been reduced by a factor of five. This reduction has been attributed to the change from coal fired steam locomotives to diesels, but some credit for this reduction must also be given to other changes such as improved axle bearings, larger cars, and larger trains. Also during this period, the mix of freight shifted toward higher density shipments since much of the lower density shipments, including virtually all the less-than-carload traffic, was yielded to the truck competition, thus increasing the average rail-car payload. It follows that a reduction in energy intensiveness within a mode may not necessarily be consistent with petroleum conservation if this result is attained from loss of low density traffic to a more energy intensive mode.

Relative intensiveness loses its meaning also when the primary source of energy is different, whether the difference occurs over time within a mode as described above or exists at a single point in time between modes. An example of the latter is a comparison between a diesel powered rail system (which is obviously based on a source now believed to be scarce and non-renewable) and an electrically powered pipeline (which is fueled by primary sources other than petroleum which may be adequate or renewable). To be meaningful, the distinction between the basic energy sources must be maintained throughout the analysis and in the presentation of the results. Alternatively, a weighting factor must be developed for

*Tables 2-3 and 2-8 of Reference (4).

each basic source to reflect its relative scarcity and value to society. Stated another way, basically, this is no longer an engineering issue because in a sense all BTUs are not equivalent and interchangeable regardless of source. It is basically an economic issue and relative replacement costs must be introduced. All of these factors can be given consideration in the energy conservation option impact assessment process described in Section 3.

2.2 ENERGY CONSERVATION OPPORTUNITIES

This subsection summarizes the results of previous studies of fuel conservation opportunities in the freight transportation sector of the economy. Technological innovations and operational improvements in first the trucking industry and then the rail industry are discussed. All of these opportunities represent changes that could be implemented in some portion, if not all, of the respective modal systems. In-depth analyses of the economic feasibility or the overall costs and benefits have not as yet been performed. Nor has an assessment been made of the overall national impact of alternative conservation programs. The fuel conservation estimates, developed by others and presented here, represent either reasonably good estimates of incremental fuel reduction technically possible for some system subcomponent or very crude estimates of aggregate fuel savings possible if a specific change could be universally effective.

The sources cited in this report differ in their approaches, data sources and conclusions. They are considered by the authors of this report to be preliminary explorations rather than definitive works, and their projected schedules of probable large scale effective implementation of conservation measures are judgemental rather than the result of rigorous analysis of the industries involved. Therefore, in comparing the aggregate estimates presented below with similar estimates presented in any one of the cited sources, the reader should be aware that different implicit as well as explicit assumptions have been made relative to the magnitude and the likely implementation rate of specific conservation opportunities.

2.2.1 Trucking Conservation Opportunities

2.2.2.1 Technological Innovations - Technological innovations include two major categories.

A. Aggregate Fleet Conservation - Recent studies have indicated that improvements in engines, transmissions, tires, lubricants, accessory drives, and aerodynamic drag reduction, and dieselization of local fleets could reduce 1985 total commercial truck fuel consumption by about 0.55 Quads (4.2 billion gallons of fuel per year). This is a reduction of about 17 percent below the 1985 truck demand based on a business-as-usual scenario and it does not include any reductions which could be realized by increases in average load per vehicle which will be discussed later. The technical improvements apply differently to the different classes of trucks and haul markets. As a result, the distribution of potential savings among the different truck/market categories is uneven, as shown in Table 2-4.

TABLE 2-4. DISTRIBUTION OF POTENTIAL FUEL CONSERVATION

TRUCK CLASS *	1985 CONSERVATION QUADS/YR.
III - V	0.04
VI	0.08
VII	0.03
VIII (Local)	0.08
VIII (Intercity)	0.32
TOTAL	0.55

*See Table 2-2 for truck class information.

Source: Reference (1), Table 4-6, Barrels per day converted to Quads per year year using 42 gallons per barrel, 365 days per year, 125,000 BTU per gallon of gasoline and 139,000 BTU per gallon for diesel fuel.

The greatest conservation potential is estimated to be in heavy duty Class VIII trucking in intercity hauling. Most of this saving is projected to result from technological innovations other than conversion to diesel engines because nearly 90 percent of the fuel consumed in this category is already diesel. However, conversion to diesel engines is the dominant factor in the projected fuel savings for Class VIII trucks in local service and the other truck classes which provide local freight services.

B. Individual Truck Vehicle Fuel Conservation Opportunities - The most comprehensive study of potential technological improvements for individual vehicle fuel conservation was made by an Interagency Task Force under the direction of the Energy Resources Council.[2] Fuel consumption improvements for the several technological innovations mentioned above were estimated for the post 1980 era.

This study estimated that conversions from gasoline engines to diesel engines offer up to a 30 percent reduction in fuel consumption for a given operation. Also, modified gasoline engine designs such as lean burn, fuel injection, turbo charging or stratified charge, individually offer in the range of 10 percent improvement in fuel consumption for a given operation.

These technological changes are the dominant changes for all the Class III through Class VII trucks and are reflected in the conservation estimates for those classes shown in Table 2-4. These estimates resulted from projections of a steady rate of conversion of the aggregate fleets to a particular mix[1] of these new engines between 1975 and 1990 (the target year of the source study). Based on these projections, estimates of fuel intensiveness, improvements for 1985 range from a low of 12 percent for truck Class VII to a high of 25 percent for Class VIII intercity operations.

The major focus of this present report, however, is the Class VIII trucks in intercity service which promise about 58 percent of the potential projected truck fuel conservation in 1985. Table 2-5 shows the estimated fuel savings in Class VIII intercity and local truck operations, respectively, attributable to each of the specific technological improvements. Some of these changes are applicable to both local and intercity service whereas others are

TABLE 2-5. ESTIMATED SAVINGS IN FUEL FROM TECHNOLOGICAL IMPROVEMENTS APPLICABLE TO CLASS VIII TRUCKS (REF 2).

TECHNOLOGICAL IMPROVEMENTS	INTERCITY	LOCAL
High Torque Rise Low RPM Engines w/low Axle Ratios and 5-6 Speed Transmissions	5-9%	5-9%
Improved Lubricants	1-2	1-3
Temperature Demand Drive Fan	5-8	3-7
Radial Tires	5-9	3-5
Bolt-on Aerodynamics	7-12	
Automatic Transmission	..	3-5
Additional Engine Improvements	10	10
Compounded Fuel Savings from Aggregate of all Improvements	29-41	23-33

applicable to only one or the other. These incremental improvements are in addition to any conversions from gasoline to diesel engines. Assuming that implementation of all of these changes is feasible in a given operation, fuel savings of 29 to 41 percent are possible for intercity operations and 23 to 33 percent for local operations. These projections were based on the then known characteristics of 1975 operations and assumed no change in the gross vehicle weights or in the average payload per vehicle. These projections, however, are now believed to be too high. Actual field tests (References 5 and 6) indicate that the intercity estimates should be reduced to about 25 to 40 percent. The interagency study itself noted that these projected savings should be modified downward for any truck tare weight increase which might result from compliance with noise and safety regulations and also from compliance with more stringent emissions standards which will be in effect by 1985. Other studies (References (4) and (7)) suggest that the 25 to 40 percent is a more realistic estimate for Class VIII truck operations.

The conservation estimates presented in Tables 2-1 and 2-4 represent an assumption of about 70 percent implementation of these technological innovations (including additional dieselization) into the truck fleet by 1985.

2.2.1.2 Operational Improvements - The operational changes to intercity trucking which promise to reduce energy intensiveness attempt to increase the ratio of net revenue ton-miles to vehicle miles traveled.* The most celebrated changes involve proposals to change state laws and regulations which limit the volume and weight capacity of the over-the-road tractor trailer combination rigs. These changes are discussed and quantified later, but first another group of operational changes is discussed for which no clear consensus has developed as to the net impacts on fuel consumption. This later group of changes addresses I.C.C. economic regulations and involves eliminating commodity and route restrictions, reducing gateway and circuity restrictions of regulated intercity motor carriers, and removing restrictions on unregulated carriage of exempt commodities and private trucking operations. One study[8] estimates that the total fuel savings, if all of these changes were made, could be as high as 0.02 Quads (154 million gallons) for current operations which would project to about 0.03 Quads for 1985. It is possible, however, that the intermodal competition impact of these changes to I.C.C. regulations might be great enough to cause

*There is some indication (Reference 1) that more comprehensive enforcement of the 55 speed limit could also produce significant additional fuel savings.

an increase in the overall energy consumption of the total freight system by causing diversions of traffic from the rail mode.

Impacts on fuel consumption due to changes in vehicle size and weight have been quantified and are discussed below. They are divided into two groups: 1) those resulting from recent changes in Federal weight limits not fully implemented by all states and 2) those resulting from proposed new changes to state size and weight limits.

Recent analysis (Reference (1)) indicates that full implementation by all states of the recent increase in permissible maximum gross vehicle weights (GVW) from 73,280 pounds to 80,000 pounds offers a fuel savings potential of 0.04 Quads per year (308 million gallons per year) in the 1980s. This represents an additional 1 percent reduction in the business-as-usual truck total for 1985. When added to the technological potential savings, the total reduction is 0.59 Quads below the business-as-usual scenarios for 1985 as shown in Table 2-1.

New proposals for additional increases in state truck size and weight limits involve, in turn, two types of changes with separable fuel conservation opportunities. Both proposals assume full implementation of the 80,000 pound GVW limit in all states. The first proposal proceeds from this position to permit operation of "Western Doubles" (double 27 to 28 foot trailers in combination with cab over tractor) in the Eastern states which currently prohibit their use. The Western Doubles rig meets the 80,000 pound GVW limit and the overall length limit of 65 feet. Traffic which would benefit from this change is, for the most part, Class VIII, long-haul truck traffic. However, it is only that portion of the Class VIII long-haul (and some short-haul) traffic which moves within the restrictive Eastern states and between these states and the Western states permitting these double rigs. It is also traffic with low physical density (pounds per cubic foot payload) and is predominately less-than-truck load (LTL) general commodity shipments moving by regular route common carrier. Within this subgroup the benefit is also limited to those movements which experience an economic advantage using these double rigs rather than the more standard single trailer combination within the same size and weight limits.

Although basic data exists to develop credible estimates of this mode, time and resource limitations have precluded a detailed analysis by this study. A very crude estimate may be obtained by the following assumptions:

> Using data presented in previous subsections of this report, the 1985 Class VIII long-haul fuel consumption including technological conservation is estimated as 0.76 Quads in 1985.
>
> (3.41) (0.276) - (0.32) (0.581) = 0.76
> (1) (2) (3) (4)
>
> (1) Total truck Quads 1985 business-as-usual from Table 2-1.
> (2) Class VIII long-haul percentage of (1) from Table 2-2.
> (3) Class VIII intercity technology conservation in Quads from Table 2-4.
> (4) Long-haul percentage of Class VIII total for non-local BTUs from Table 2-2.
>
> If one assumes that as much as 50 percent of the Class VIII truck long-haul intercity ton-miles moves within or to-or-from the states in question; and if one assumes that about 30 percent of these ton-miles is generated by low density commodities and will find the Western Doubles advantageous; and if, further, one estimates the energy intensiveness of these doubles at 84 percent* of that for single trailer rigs, then the potential energy conservation can be estimated as follows:
>
> (0.76) (0.50) (0.30) (0.16) = 0.02 Quads

*See Appendix A for derivation of this estimate.

This represents an additional 0.5 percent reduction in the 1985 business-as-usual truck fuel consumption for the proposed extended operations of Western Doubles.

The second major truck size and weight increase proposal involves permitting longer and heavier multiple-trailer tractor combination rigs on divided highways. This involves the use of double 40 foot trailers or triple 27 foot trailers with an overall length about 100 feet and a gross vehicle weight about 120,000 pounds and axle loads at current limits. Here again, the basic data exists to develop a credible estimate of this market, but because of time and resource limitations it was not done in this study. A crude estimate may be obtained in the same manner as the previous estimate for the western doubles. The base fuel consumption for the 1985 Class VIII truck long-haul traffic which might benefit from these increased limits is 0.76 Quads, as before.

> If it is assumed that as much as 50 percent of the Class VIII truck long-haul intercity ton-miles can take advantage of these new limits; and if it is estimated that the energy intensiveness of these doubles is about 75 percent* of that for the single trailer rigs, then the potential energy conservation can be estimated as follows:

$$(0.76)\ (0.50)\ (0.25) = 0.10 \text{ Quads}$$

This represents an additional 2.8 percent reduction in the 1985 business-as-usual truck fuel consumption, if universal use of long, heavy, multiple trailer combinations on the interstate highways and other highways of like design standards is permitted.

These estimates of potential petroleum fuel savings resulting from proposed changes in size and weight limits are based on one additional implicit assumption: no diversion of rail traffic to trucking will result from these changes. This assumption can be valid only if implementation of these new limits does not result

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*See Appendix A for derivation of this estimate.

in significant change in the relative prices of the two modes. Stated another way, any economic benefits resulting from the use of higher capacity trucks must be retained as contributions to carrier profits or labor compensation rather than passed through as reductions in rates. If such economic benefits are, in fact, passed through as rate reductions, then the relative price structure of the rail and highway modes will be changed and diversions from rail to highway can be expected. Such diversions will contribute toward increases rather than decreases in energy consumption. The issue of modal shifts is discussed in a later subsection.

2.2.2 Rail Conservation Opportunities

Recent studies (References (4) and (9)) have identified the most promising areas for rail fuel conservation to be improved locomotive efficiency, lighter weight rolling stock, and a number of improvements to all aspects of train and yard operations. These groupings of petroleum conservation opportunities are based on a categorization of petroleum fuel consumption by rail into five major functions: direct transport of the revenue freight (28 percent of total), moving the tare weight of the rolling stock (36 percent), locomotive idle time and other non-traction time (20 percent), circuitous routing (6 percent), and spillage and unaccounted for fuel consumption (10 percent). Table 2-6 shows this percent distribution, the historical source fuel estimates, and the impact on the projected 1985 fuel consumption in Quads for the business-as-usual scenario.

Fuel conservation opportunities are separated here into first, technological improvements covering all improvements to locomotive efficiency and lighter weight rolling stock, and secondly, operational improvements. If all improvements were universally implemented, the total rail fuel consumption would be reduced by 62 percent. However, it is not expected that all these improvements could be universally implemented. Furthermore, it is likely that only a small portion of the technological improvements could begin to be implemented by 1985 because of the long lead time required

TABLE 2-6. RAIL FREIGHT FUEL CONSUMPTION CATEGORIES

	BILLIONS GALLONS*	PERCENT DISTRIBUTION	1985** QUADS
1. TOTAL	3.66	100%	0.61
2. Spillage and Unaccounted for	0.37	10	0.06
3. Locomotive Consumption (line 1 minus line 2)	3.29	90%	0.55
4. Moving Rolling Stock Tare Weight	1.30	36	0.22
5. Locomotive Idle Time and other Non-Train Traction Time	0.74	20	0.12
6. Circuitous Routing	0.21	6	0.04
7. Direct Transport of Freight (line 3 minus lines 4,5, and 6)	1.04	28%	0.17

*1973 Data from Reference (9).
**Business-as-usual projection from Table 2-1 allocated as per the percentages derived in column 2.

for such changes to proliferate through the rail system, while a rather large portion of the operational changes could be in effect by 1985. An aggregate reduction of about 28 percent from the 1985 business-as-usual scenario has been estimated, which translates into 0.17 Quads or 1.3 billion gallons of fuel per year.

2.2.2.1 Technological Innovations - In the area of equipment efficiency improvements, the SRI* study highlighted the most promising opportunities as two technical changes: waste heat recovery and seal torque reductions. Significant amounts of waste heat are exhausted in diesel locomotives. This waste heat can be transformed into mechanical power and directly coupled to the drive shaft. One of the more promising approaches uses a Rankine cycle engine to accomplish this energy conservation. The seal torque reduction refers to axle seals that keep dust out and lubricants in the locomotive and railcar wheel bearings. Some recent advances in seal design give promise for reducing frictional losses. The SRI study estimated the incremental fuel savings for universal implementation of these two changes at 8 percent and 6 percent, respectively, of the fuel actually consumed in moving trains. The PMM* study identified eight other improvements to locomotives. These improvements represent changes (i.e. diesel engine construction, power management, parasitic load reduction and locomotive design) which individually produce very small improvements but in the aggregate yield a total compounded savings of about 10 percent of total fuel. A conservative estimate of 19 percent of total was selected as the compounded total for equipment efficiency improvements (see Table 2-7).

The PMM and SRI studies both estimate that a 10 to 15 percent reduction in total rail fuel could be obtained from lighweight rail cars alone. The SRI study also suggested that a lightweight locomotive equipped with positive traction control could produce another 6 percent reduction in the fuel actually consumed in moving trains. Such traction control devices reduce wheel slippage for a

*Stanford Research Institute (Ref.9)
**Peat, Marwick and Mitchell (Ref.4)

TABLE 2-7. ESTIMATED PETROLEUM FUEL SAVINGS FOR TECHNOLOGICAL IMPROVEMENTS

IMPROVEMENTS	INCREMENTAL FUEL SAVINGS AS PERCENT* OF TOTAL RAIL FUEL CONSUMED IF UNIVERSALLY IMPLEMENTED
Equipment Efficiency Improvement	19% (Compounded)**
Locomotive Waste Heat Recovery	6%
Seal Torque Reduction	4%
Loco Power Management, parastic load, etc.	10%
Rolling Stock Tare Weight Reduction	16% (Compounded)
Cars	12%
Loco w/Posi-Traction	4%
Miscellaneous Equipment Changes	14% (Compounded)
Locomotive Streamlining	7%
Car Streamlining	6%
Other Car Improvements	2%
Compounded Total for All	41%

*Source: Mean values selected from ranges of values provided by References (4) and (9).

**Example calculation [1.00 - (1.00-0.06)(1.00-0.04)(1.00-0.10)]=0.19

given weight on the drivers, thus permitting weight reduction of the locomotive for a given traction effort. Conversely, the same weight locomotive could pull a heavier train with positive traction control. An estimate of 16 percent of total fuel consumption compounded has been selected for the total of rolling stock tare weight reductions.

The PMM study identified some additional locomotive and car changes each with incremental fuel savings, ranging from 3 to 12% for locomotive streamlinings, from 3 to 10% for car streamlining, and 1 to 3% for other car improvements.* The mean value in each case was selected and the compound total calculated as 14 percent of the total for the aggregate group shown under the heading of miscellaneous equipment changes on Table 2-7.

It is not clear how much double counting might be included in these categories, but the total compounded savings of 41 percent of total fuel consumption estimated by this process appears to be consistent with the overall assessments made by each of the two studies.

Alternative energy sources are a radical approach to reduction of petroleum use. These were discussed in the studies used as sources for this report but there is no indication of significant penetration of alternative energy sources for rail operations by 1985 and therefore they were not included here.

Implementation of the listed technological improvements is expected to be a slow process. Even under the most favorable conditions, universal adoption of these improvements would probably take on the order of 25 years. The PMM study estimated implementation times for the various groups of options but they are all on the order of 20 percent adoption in about 5 years and 40 percent adoption in about 10 years. It is not clear that anything more than 25 percent universal adoption and effective impact can be expected by 1985. If one assumes 25 percent effective

*Table 5-1, p. 5-4, Ref. (4).

TABLE 2-8. ESTIMATED FUEL SAVINGS FOR OPERATIONAL IMPROVEMENTS

IMPROVEMENTS	INCREMENTAL FUEL SAVINGS* AS PERCENT OF TOTAL RAIL FUEL CONSUMED IF UNIVERSALLY IMPLEMENTED
Fuel Handling	7%
Circuity Reductions	2%
Line Speed Reductions	7%
Loco/Train Load Matching	5%
Empty Car-Mile Reduction	7%
Car Load Increases	2%
Train Configuration Changes	2%
Yard Improvements and By-Passing	2%
Caboose Elimination and Reduction of Stops and Delays	2%
COMPOUNDED TOTAL FOR ALL	35%

*Source: Mean values selected from ranges of values provided by References (4) and (9) application of all the technological changes shown, then a 10 percent effective savings (or 0.06 Quads) may be estimated for 1985.

2.2.2.2 Operational Improvements - A large number of rather mundane incremented improvements are identified by both studies as potential opportunities for rail fuel conservation. Table 2-8 lists eight changes promising the largest incremental savings. Here again, a range of values was estimated by one or both of the source studies. A mean value was selected for each improvement for use here. A total compounded value for this list calculates at 35 percent savings of the total rail fuel consumption.

Operational improvements, unlike technological improvements, should be implementable in the rail system in a few years. However, it is unreasonable to expect 100 percent adoption and full effectiveness by 1985. If one assumes 50 percent adoption and effective application of all of the operational improvements shown, then an 18 percent effective saving (or 0.11 Quads) may be estimated for 1985.

When the potential 1985 fuel savings from operational and technological improvements are added, the aggregate rail system savings are 0.17 Quads. This represents an aggregate reduction optimistically estimated at 28 percent of the projected total for the business-as-usual scenario.

2.2.3 Highway Rail Modal Shifts

In the previous subsections, opportunities for energy conservation through changes in technology and in operations within the highway and the rail modes were discussed and estimated. One additional opportunity for energy conservation suggested earlier in this report is the often advocated shifting of markets from the more energy intensive mode (highway) to the less energy intensive mode (rail). It is generally recognized that, in the multiple choice transportation marketplace, if substantial shifts are to be expected, the rail system must offer service quality at least as high as the truck alternative at a price at least as low as truck. Greatly improved rail/highway intermodal services (e.g. TOFC/COFC* dedicated run-through and shuttle trains etc.) have been proposed as a means of attracting freight movements that would otherwise choose trucking. Several studies[10,11,12,13] have suggested that substantial economic benefits could be realized by the rail industry and the shipping public. When the situation is analyzed from an energy perspective, however, the possible petroleum fuel savings may be outclassed by these potential economic benefits.

These studies suggest that a high quality, rail based intermodal service is technically feasible, viable and capable of penetrating the long-haul truck markets by one third to one half of the ton-miles generated in those markets. However, an improved intermodal rail/highway service, while diverting substantial traffic from long-haul trucking would also divert traffic from conventional rail-carload service in some markets. In total, this shift of rail traffic might well result in increased petroleum usage over the present balance. The studies just referenced indicate that the substantial service quality improvements promised would outweigh the price premium for a large number of current users of conventional carload service. Mode split model analyses[13,14] indicate that diversions from conventional carload rail service could in some markets be greater than the diversions from trucking. Large diversions from conventional rail could be detrimental to the energy conservation program. This is discussed in additional detail in Section 4 of this report.

Although rail based intermodal systems are less energy intensive than over-the-road-trucking for long-haul shipments, they are more energy intensive than conventional carload service. Conventional carload is by far the least energy intensive service on a door-to-door basis in high volume corridors, but the energy advantage is predominantly in the line haul portion of the trip.

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*TOFC Trailer on Flatcar
COFC Container on Flatcar

The collection/distribution function at both ends of a trip may be as energy intensive as either intermodal or truck services depending on the volume of traffic and the geographical dispersion of the final origin/distribution. The line-haul portion of the intermodal service is more energy intensive than conventional carload service though it is less than that for trucking. Table 2-9 displays average system line-haul energy intensiveness estimates developed specifically for direct comparison among the several competing rail and highway systems serving the general commodity markets. Details on the construction of the 1975 estimates are in Appendix A. The 1985 estimates represent incorporation of the fuel conservation estimates outlined in the previous subsections.

The table indicates that the average energy intensiveness of the intermodal systems is about one half of the conventional highway combination rigs but is about twice the energy intensiveness of conventional carload systems. Lightweight TOFC car systems are already being introduced and offer a 13 percent fuel savings wherever they are used and the energy intensiveness of the dedicated TOFC system relative to the carload and truck systems is immediately improved. It is likely that by 1985 there will be some mix of lightweight and the current TTX TOFC cars in operation.

No matter what assumption one makes as to the rate of penetration of all of the innovations, it is apparent that diversions from the highway transport must be greater than those from rail carload transport in order to contribute to overall freight energy conservation.

However, if the basic source for the rail portion of the intermodal system is something other than petroleum (e.g. hydro or nuclear) then any diversion from highway (even when accompanied by a diversion from carload service) will conserve petroleum.

TABLE 2-9. CURRENT AND PROJECTED RELATIVE ENERGY INTENSIVENESS OF COMPETITIVE SYSTEMS

SYSTEM	LINE-HAUL INTENSIVENESS BTU/NET TON-MILE 1975	1985
Conventional Rail Carload in Mixed Consist Trains	403	290[1]
Dedicated TOFC Trains	862	741[2]
Light Weight Dedicated TOFC Trains	752	650[2]
Conventional Single Trailer Long-Haul Combination Rig	1914	1474[3]

Source: See Appendix A for development of 1975 energy intensiveness values.

[1] 28 percent reduction for all technological and operational improvements per Section 2.2.2.

[2] 14 percent reduction for technological and operational improvements per Section 2.2.2 selected as applicable to this specific type of service.

[3] 23 percent reduction from all technological improvements for Class VIII trucks per Table 2-4 plus fuel savings from universal application of 80,000 pound GVW limit per Section 2.2.1.2.

3. ENERGY CONSERVATION POLICY IMPACT ASSESSMENT PROCESS

3.1 THE PROBLEM

Opportunities for energy conservation in freight transportation may be grouped into three broad categories:

1. Technological changes within existing modal systems (e.g. more efficient power units or reduced rolling resistance).
2. Operational changes within existing modal systems (e.g. trade-offs between resource management and service quality).
3. Reallocation of markets among modal systems (e.g. shifts from more energy intensive modes to less energy intensive modes).

Estimates of potential energy savings from innovations in these three categories are usually the result of the following activities:

1. An engineering study of hardware components which yields an estimated incremental reduction in fuel consumption per vehicle mile, or per operating hour.
2. An operational analysis which suggests that there is potential for increases in the average payload per vehicle or for reductions in equipment idle time or for reductions in routing circuity.
3. A modal share analysis which indicates that a certain shift in the percentage shares could result from a deliberate management decision (in either the private or the public sector) to change the relative modal attractiveness by adjusting the relative prices or relative service qualities of the competing modal systems.

Assessing the economic impact of identified energy conservation opportunities involves consideration of complex market issues. The buyer of transportation chooses a particular service based on his individual perception of a beneficial trade-off between price and quality of the service. Fuel saving by the transportation supplier might result in higher quality service or a lower price or both. Conversely, the fuel conservation innovation might result in lower quality and higher prices.

The latter could cause the buyer to select the more energy intensive service rather than the more energy efficient mode because it satisfies his perception of economic efficiency. In the aggregate, the free market forces move toward an equilibrium between supply and demand for various transportation services. The quality of service (there are many facets of service quality) and prices charged are the determinants which will drive the demand toward or away from energy conserving transportation services. It is this complex transportation market process that must be addressed in any assessment of energy conservation opportunities.

The utility of any assessment process is determined by its two primary characteristics - the level of aggregation of the models applied and the precision and accuracy of the input data. In general, the accuracy of the results is directly related to the extent of disaggregation of the supply and demand functions and to the accuracy to which these functions are specified. There is a concomitant requirement that the fineness of detail and the level of precision be consistent throughout all elements of the assessment process. The appropriate level of aggregation and the precision of the input data depend on overall desired accuracy and the time and resources available.

First level approximations of the potential energy savings can be obtained by analysis of national aggregate and/or modal aggregate data such as those presented and discussed in Chapter 2 of this report. These types of estimates tend to have limited utility in assessing energy conservation potential and they may even mislead the policy makers into treating <u>potential</u> savings as <u>realizable</u> savings. Such first level estimates do not accurately reflect the economic* viability of proposed changes in each of the constituent carrier groups within each mode and in each market.

The modal aggregate or national aggregate estimates of energy savings resulting from operational "improvements," or "desirable" modal shifts, cannot reflect the unique economic characteristics of certain regions, corridors or city-pair markets, characteristics which determine the feasibility of some of these changes. Stated another way, national and modal aggregate estimates may be inadequate because energy savings opportunities are not singular in nature nor universal in application. Ultimately, the opportunities for conservation within each modal system and in each market segment may be a complex mix of changes tailored to the unique attributes of each mode and market. The mix in each case will result from a set of trade-offs between maximum fuel conservation on one hand, and satisfaction of the transportation needs of specific users on the other. Maximum energy conservation at the expense of substantial reductions in service quality will not be tolerated by the various users. It is for these reasons that a complex method of analysis involving a spatially oriented treatment of the supply/demand interaction of the freight transportation markets is required.

3.2 ANALYSIS APPROACH

An evaluation process addressing freight transportation should have three basic characteristics.

1. The demand for service should be specified by commodity type, by regional origin, and destination of flow, and, in many cases, by shipment size.
2. The supply of transportation services should be represented by the price and service characteristics for each

*Institutional feasibility is another important consideration which must be subjectively considered subsequent to the economic evaluation.

modal service available in the city-pair corridors or system networks involved.

3. The mode selection behavior of the users of transportation services should be modeled by a demand response function which reflects either their historical behavior patterns or economically rational responses in a projected future economic environment.

Other important considerations such as technology, modal system operating policies, and government regulations and policy also influence the way in which transport service suppliers respond to the changing demand patterns. It is through this latter group of variables that the Government can influence the entire market and induce the private sector to move toward a better balance between energy efficiency and economic efficiency.

The freight transportation market supply/demand interactions may be depicted as shown in Figure 3-1. Four computer based models have been developed for DOT to integrate these components into comprehensive analysis tools.* The solid blocks in the figure represent the specific elements which are currently integrated into the operating version of the computer programs of these models. The dotted blocks represent elements which at present are not contained within the computer programs and which must be specifically dealt with as required in the application of any of these models to specific problems. The dotted blocks also represent the points of access for testing alternative Government policies. Potential technological and operational changes enter into the analysis as parameters of the supply functions. Government policies which affect the economic activity in specific industries, and/or the overall economic activity at the regional or national level, enter the analysis via the definition of the basic demand for transport services.

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*Only two at present have energy consumption accounting elements directly incorporated.

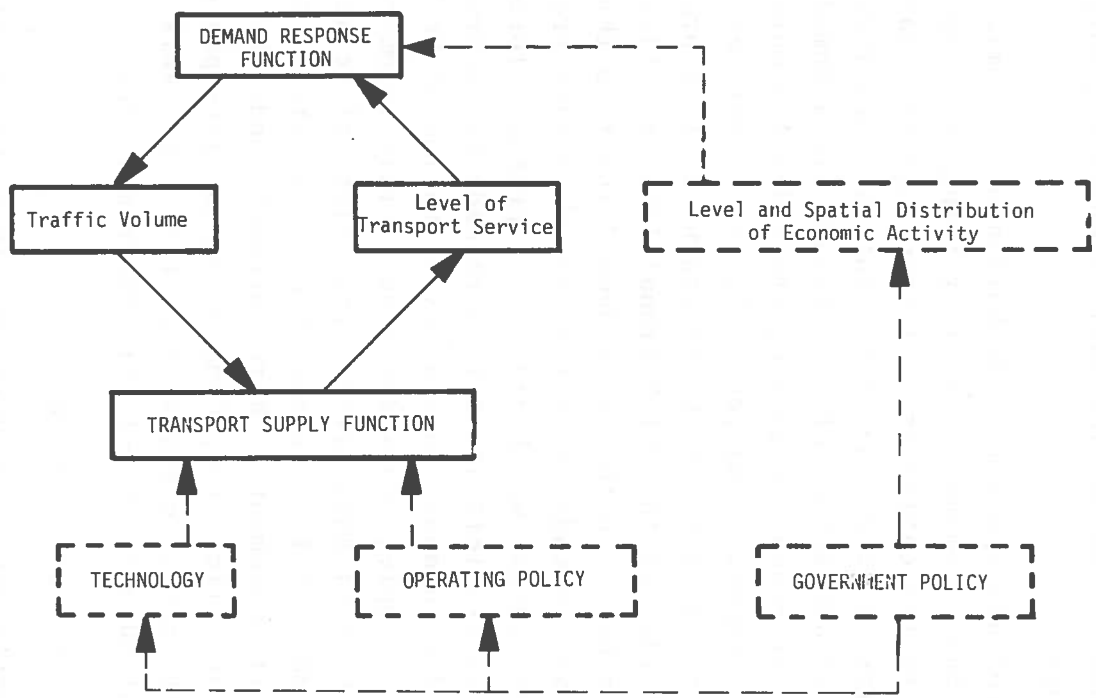

FIGURE 3-1. COMPONENTS OF THE FREIGHT TRANSPORT MARKET

Changes to any combination of the supply and demand parameters may or may not result in a significant shift in allocation of traffic among the competing modal services. The impacts of a given combination of changes may be evaluated in terms of the change in total energy consumption, change in the cost of transportation and the change in the service quality which are outputs of the computer programs.

The level and spatial distribution of economic activity which creates the basic demand for freight transportation services is fundamental to the entire freight transportation market analysis. In the studies to date, the status quo has been treated as fixed, and simple extrapolations of past trends are assumed because there was not time or resources to adequately develop more realistic possible future economic scenarios. The only comprehensive commodity flow forecast available at the beginning of this project was the one developed by TSC for the DOT National Transportation Planning effort in FY-76. It has been the basic demand input to three of the four models. It was intended to serve only as a base projection of recent trends against which other more probable forecasts would be tested, and no explicit attempts were made to incorporate impacts of economic developments such as exploitation of Western coal sources, for example. Consideration of this resource exploitation alone could significantly alter projections of related economic activity in many of the regions which originate or terminate the major commodity movements. Work currently underway by the National Transportation Policy Study Commission involves projections of plausible alternative economic features. This work promises to be a substantial advancement of this important area.

3.3 COMPUTER MODELS OVERVIEW

Four models have been developed to focus on various aspects of the freight transport market interactions as described in the previous paragraphs. They differ from each other in terms of the level of detail in the specification of the supply of and the demand for services. Even more important, they differ in terms of the specification of the demand response function and the interaction of the demand response with the supply functions.

3.3.1 MIT/DOT/FEA City-Pair Logistics Model*[12,14]

The MIT/DOT/FEA City-Pair Logistics Model performs a highly refined analysis of the way the shipper/receiver might logically respond to changes in transport service level and prices. It analyzes a small sample of manufacturing establishments as buyers/ receivers of partially manufactured goods, and uses their mode decision process to allocate the total flow of commodities between two economic regions. Individual firms are sampled from historical data files and their output of commodities are identified at the 5-digit STCC code level. Output is measured in dollar value of production. Bulk commodities such as unprocessed products of farms, mines and forests are not included in the model. The model estimates volume of firm inputs in dollar value from input/output tables and then converts the input volume to physical units and makes modal choice and shipment size decision to minimize the receiving firm's theoretical total logistics costs. The results of the sample analysis are expanded to agree with the total commodity flows of the pertinent commodities between the selected region pair as reported by the Bureau of Census, Commodity Transportation Survey, or they may be expanded to projected flows. A single base year (1967)** has been selected for which all cost and traffic data inputs are available; no forecasts have been made to date. The mode choice decision is in response to rates and service quality alternatives presented by the model for consideration of the receiver. Rate models were developed from published rates for rail and motor-carrier services (air, water and pipeline modes could be included). Modal innovations are represented by adjustment factors applied to the basic rate models to reflect estimated incremental cost changes which are assumed to be passed through to the freight rate. In the case of entirely new services

*The nomenclature used here is intended to denote first the author of the model, secondly the sponsoring agency and finally the generic type of model.

**Work is currently underway to update to 1972.

for which the rate models are considered inadequate, a hypothetical cost based rate model is constructed. The basic rates are historical, regional averages, are oriented toward car load, trailer load, and less than truckload services, and vary with the trip distance. Service frequency and speed are city-pair specific and reflect actual and postulated (in the case of innovations) operating practices for the modal system. Rates vary by commodity by virtue of the physical density and the space and weight capacities of the vehicles.

The model does not vary the level of service or price to reflect changes in traffic volume captured. Profitability of the innovation being tested, given the initially postulated rates and service quality and the traffic volume actually captured must be analyzed separately. Several iterations may be necessary to reach supply/demand equilibrium. System capacity problems and traffic congestion effects are not an issue in a city-pair analysis tool such as this. These latter issues can only be analyzed in a network context and require simultaneous treatment of all commodity flows on all network links.

This model is best suited for testing several submodes (competing services within each mode) for which rate and service quality models can be developed. Its application is limited to a manageable number of city-pairs for which detailed input data can be obtained. It is a normative model representing idealized economic decisions. The demand response function has a strong theoretical basis but it has not been calibrated against historical data. Energy accounting is accomplished by a separate computer program module which applies average energy intensiveness factors to the traffic captured by each modal service.

3.3.2 COMSYS/DOT Interzonal Mode Share Model

The COMSYS/DOT Interzonal Mode Share Model uses a simpler demand response function, which it applies to forecasts of aggregate commodity flows and treats all commodities (bulks and manufactures) and all regional flows in an origin/destination matrix context. This model is descriptive rather than normative in that it apportions each origin/destination tonnage flow to all available modal paths in inverse proportion to the total distribution cost of using the alternative paths. The model calculates the total distribution cost as the sum of the transportation charges and the users' internal time related costs. However, the model is forced to approximate historical mode choice behavior by a calibration factor calculated for each modal path for each commodity. The calibration constants are developed from 1972 shares of six modes of aggregate flows of 20 aggregate commodity groups among 171 BEA* regions representing the 48 contiguous states.

Transport charges for the base year are calculated by a set of cost equations for the six modes. Modal costs are system averages which do not reflect regional differences and do not relate costs with traffic volume. A user's internal time related costs are a function of the average value of the unit transported and the transit time. Transit time is a function of national average line-haul speeds and the origin/destination (O/D) trip distances. The modal routes are represented by great circle distances between BEA key cities corrected by a national average circuity factor for each mode.

Physical networks with links having characteristics such as route distances, connectivity, capacity and terrain differences are not represented explicity so that analysis of link flows and capacities is not possible. Submodes (i.e. competing services) have not been developed. The analysis to date has been limited to allocation of future traffic flows to the existing modes. Modal innovations have not been developed. Energy accounting is accomplished by a separate analysis which applies average energy intensiveness factors to the aggregate modal ton-miles.

*Bureau of Economic Analysis

3.3.3 TSC/DOT Abstract Network Mode Share Model[13]

The TSC Network Mode Share Model also uses a simplified logic for the demand response function, but it applies this function to more aggregate representations of the regional origin and destination flows and abstract representations of the connecting rail and highway networks. The model accepts, as input, some future year forecast of ten groupings of all commodities flowing between 45 zones (aggregations of 171 BEAs) after all air, water, and pipeline flows are deleted. The ten commodity groups are then subdivided into three shipment size groups -- less-then-truck-load (LTL), truck load/carload, and multiple carload. Abstract representations of physical modal networks are developed by linking zonal centroids where major modal routes occur and assigning the route mileage obtained from rail and highway atlases. The model represents all competing rail and highway services by six submodes on separately defined subnetworks.

This model is normative in that it assigns each commodity/shipment size group between each O/D pair to the minimum total distribution cost path on an "all-or-nothing" basis. Transportation charges are calculated from cost based rates which are system averages specific to the modal subsystem, shipment size and commodity density group and which are a function of distance. Users' internal time related costs are a function of a commodity specific time value of the shipment unit and the transit time. A unit time value was estimated for each commodity group from historical rail and motor carrier flows in selected markets giving this model some empirical basis. Transit time is a function of regional average system speeds and O/D trip distances.

This model is focused, at present, on the competitive aspects of highway and rail (and rail/highway intermodal) transport of manufactured goods. Bulk flows by rail are included, but competition among rail, water and pipeline services for bulk movements are not included. The cost functions are not sensitive to traffic volume nor can network capacity be treated directly by this model as presently developed. The model will provide modal link (route) traffic loadings which represent the total demand for all physical routes for each mode between the respective zones. The comparison of these traffic values with estimates of aggregate capacity of all routes serving these markets can provide an indication of potential line-haul capacity shortages. Energy accounting is not yet performed by this model, but a simple modification will permit simultaneous accounting of fuel consumed by modal system, by commodity/shipment group and by route.

3.3.4 CACI/DOT Physical Network Mode Share Model[15]

The CACI/DOT Physical Network Mode Share Model also uses a simplified logic for the demand response function. It is applied to a set of four detailed physical modal networks - rail, highway, water and oil pipeline. Detailed modal "simulators" describe in some depth the modal service quality and cost of operations. This model attempts to directly model the supply-demand interaction, and to reflect the effects of link congestion on service and rates.

The modal simulators generate cost based rates and service quality measures for each competing mode. The rates and service are sensitive to traffic volumes on the routes. The simulators are adaptations of cost models developed by several government and industry organizations. All network links are classified into a small number of categories each having unique cost and speed functions. Traffic congestion on certain modal paths raises the cost to the user and forces the use of less costly paths. The model accepts a 171 x 171 region origin/destination, 20 commodity flow projection for a given year. It assigns each O/D commodity group flow to the path which minimizes the total distribution cost. Therefore, this is also a normative model, an all-or-nothing assignment model. Submodes (i.e. competing services within modes) are not developed. All modal costs are adjusted to a base year, but fuel costs are segregated to permit testing the impact of large increases in the price of fuel relative to the other factor inputs. This model is described in greater detail in Reference (15).

3.3.5 Summary Observations on Models

Each of these models reflect the diversity in the simplifying assumptions made by their respective developers in order to focus limited resources on one or two elements of the entire freight transportation supply/demand market process. The network models and the interzonal mode share model attempt to address the collection of modal services as a national multimodal system. They also attempt to treat forecasts of flows among all areas of the country, and they treat all commodities. They do this at the expense of a greatly simplified demand response function. The city-pair model on the other hand attempts to provide a greatly refined demand response function which must be applied to one city-pair at a time. Also, it treats only manufactured goods; bulks have not been treated. All of these models are basically optimizing in that they make theoretically sound, desirable, economic mode choices rather than replicating, through strictly statistically derived equations, the historical behavior patterns of actual decision makers. However, the developers of the network and interzonal models did make attempts to adjust the traffic assignments to approximate aggregate historical modal data. Table 3-1 provides a visual comparison of the four models.

Two of the models (COMSYS/DOT and CACI/DOT) provide for all four major surface transportation modes (rail, highway, pipeline, and water), but they make no provision for competitive analysis of the important submodes within rail and highway. On the other hand, the city-pair model and the TSC network model focus on the several highway and rail submodes and set aside the water and pipeline modes. The level of detail in the network representations is an obvious determinant of the suitability of each of these models to specific applications.

The demand response functions for all of these models have the same philosophical base - i.e., minimizing total cost of distribution. There is apparent unanimity of opinion on the use of cost based rate structures for this type of analysis; but there is some concern for the comparability among the cost models for the competing modes

TABLE 3-1. MODE SHARE MODELS OVERVIEW

MODEL	DEMAND RESPONSIVE FUNCTION AND ROUTE ASSIGNMENT	MODES REPRESENTED	MODAL SUB-SYSTEM CAPABILITY	MODAL SUB-SYSTEMS TESTED	COMMODITY GROUPS	SHIPMENT SIZES	TOTAL MODAL LINKS	NUMBER O/D REGIONS
MIT/DOT/FEA CITY-PAIR LOGISTICS	o MINIMUM TDC o OPTIMIZING o ALL-OR-NOTHING	o RAIL o HIGHWAY o (WATER)	6	13	o COMMODITIES AT 5 DIGIT LEVEL o MANUFACTURES	o LTL[1] o TL/CL	5	10
TSC ABSTRACT NETWORK MODE SHARE	o MINIMUM TDC o OPTIMIZING o ALL-OR-NOTHING	o RAIL o HIGHWAY	12	16	o 10 COMMODITIES o MANUFACTURES o BULKS	o LTL o TL/CL o MULTIPLE CAR	500	45
CACI/DOT PHYSICAL NETWORK MODE SHARE	o MINIMUM TDC BASED ON VOLUME/COST o OPTIMIZING o ALL-OR-NOTHING	o RAIL o HIGHWAY o WATER o PIPELINE	4	6	o 20 COMMODITIES o MANUFACTURES o BULKS	o TL/CL o BULK o TRUCK COST ADJUSTED FOR LTL	3,400	171
COMSIS/DOT INTERZONAL MODE SHARE	o DESCRIPTIVE o INVERSE PROPORTION TO TDC	o RAIL o HIGHWAY o WATER o PIPELINE o AIR	6	6	o 20 COMMODITIES o MANUFACTURES o BULKS o (WESTERN COAL)		180,000[2]	171

[1] Shipment size is a decision variable

[2] BEA to BEA distances are calculated from locations of centroids and modified by modal circuity factors - not a true network.

within a given model. There is also some concern over the applicability of the logistics cost or value of time approach when applied to bulk commodities mode choice decisions. There is another, perhaps more obvious, deficiency in the demand response function of the network models (CACI/DOT and TSC) - the all-or-nothing assignment. These two models would be greatly improved by an assignment algorithm which realistically reflected the diversity of modal decisions within the highly aggregated shipment categories. These two models modified by incorporation of an empirically based demand response function could be made to produce more realistic results.

Table 3-2 provides a summary of potential uses of each of the three more promising models and a listing of the most critical development needs.

TABLE 3-2. MODE SHARE ANALYSIS MODELS - USES AND DEVELOPMENT NEEDS

MODEL & USE	DEVELOPMENT NEEDS
CITY-PAIR LOGISTICS o SPECIFIC MARKETS o SPECIFIC CARRIER TYPES o SHIPPER RESPONSE TO CHANGE	o COMPLETE COST/REVENUE/PROFIT EQUILIBRIUM o EXPAND SHIPPER SAMPLE, RATES AND SERVICE QUALITY MODELS BEYOND 5 ROUTES o EXPAND AND REGIONALIZE RATE SAMPLES AND UPDATE TO REFLECT CHANGING RATE RELATIONSHIPS o ADD COST INDEX TO RATE MODELS o ADD FORECAST CAPABILITY (E.G. OBERS GROWTH RATES) o CALIBRATE MODEL USING '72 OR '77 CTS DATA (RATE MODELS SHOULD BE UPDATED TO '72 OR '77)
ABSTRACT NETWORK o NATIONAL PERSPECTIVE o SCREEN ALTERNATIVES o SKETCH PLANNING o AGGREGATE MARKET RESPONSE TO CHANGE	o REPROGRAM FOR MIN. PATH ALGORITHM ON PDP-10 o PROGRAM POST PROCESSORS FOR AGGREGATE OUTPUT REPORTS BY COMMODITY, MODE AND ROUTE o EXPAND NETWORKS TO DOUBLE THE EXISTING NUMBER OF NODES o DISAGGREGATE CERTAIN COMMODITY GROUPS o DEVELOP SEPARATE CALIBRATION FACTORS FOR LTL o ADD ENERGY VARIABLE - (FACTORS AVAILABLE) o NEW ASSIGNMENT ALGORITHM OTHER THAN "ALL-OR-NOTHING"?
PHYSICAL NETWORK o NATIONAL PERSPECTIVE o REGIONAL IMPACTS o SCALE AND CONGESTION EFFECTS o INTERACTION OF BULK AND MANUFACTURES SERVICES	o ADD SUBMODE CAPABILITY o NEW ASSIGNMENT ALGORITHM OTHER THAN "ALL-OR-NOTHING"? o EVALUATE COMPARABILITY OF THE MODAL COST MODELS o TEST TRAFFIC VOLUME/COST RELATIONSHIPS

4. ASSESSMENT OF ALTERNATIVE POLICIES FOR EXPLOITING ENERGY CONSERVATION OPPORTUNITIES

This chapter presents an analysis of the results of mode share and energy consumption projections produced by the CACI/DOT Physical Network Mode Share Model. These model results are supplemented by other mode share analyses conducted either prior to or in parallel with this project using the MIT/DOT/FEA City-Pair Logistics model and the TSC Abstract Network Mode Share Model. Three future supply/demand scenarios are analyzed for their respective impacts on modal shares of traffic and fuel consumption. Also several alternative government policies involving these three scenarios are discussed and are evaluated in a preliminary fashion.

The first scenario assumes that in 1990 the existing freight modal systems will be performing much as they were in the base year except that a 52 percent increase in ton-miles will be accommodated and petroleum fuel prices will inflate at about 3 times the inflation rate of other factor inputs to production of the transportation services.

The second scenario assumes the universal existence of improved, dedicated TOFC intermodal services on all mainline rail routes. Improved TOFC is defined in the other reports[13,14] but briefly it means fast, frequent, trailer-load service fully competitive in price and service quality to highway motor carrier services. The effect of the existence of this new modal service is estimated from the results of the referenced studies and superimposed on the first scenario.

The third scenario assumes the absence of the improved dedicated TOFC system but the existence of universal use of larger, heavier, multiple trailer-tractor combination rigs on all interstates and other 4 lane, divided, limited access routes. These larger units are represented in the references as double 40 foot trailer rigs with gross vehicle weights about 120,000 to 130,000 pounds.

The second and third scenarios are synthesized from the results of market penetration analyses for these new modal systems which were conducted with the MIT/DOT/FEA City-Pair Logistics Model and the TSC Abstract Network Mode Share Model. The current inability of the Physical Network Mode Share Model to simultaneously represent the competitive rail and highway submodes precludes using that model to test the intermodal competitive impacts of new modal systems such as improved TOFC and highway doubles.

4.1 EFFECTS OF DEFICIENT DEMAND DATA INPUTS

Before proceeding to a detailed discussion of the results, it is well to first obtain a perspective of the traffic demand data used with the CACI/DOT Physical Network Mode Share Model for this mode share and energy analysis. As indicated in Chapter 3, one commodity flow data base and forecast to 1990 is the foundation for all DOT national freight mode share projections. It is the 20 commodity, 171 BEA to 171 BEA tonnage flow matrix developed for 1972 and projected to 1975, 1980 and 1990.[16,17] This data (referred to herein as the TSC File) is incomplete, but it was the most comprehensive interregional commodity flow data file and forecast available for this type of analysis. Table 4-1 compares the modal tonnages represented in this file with modal tonnages reported by the Transportation Association of America. The TAA data is believed to be the most complete national aggregate traffic data for all the freight modes, but commodity detail and origin-destination flow detail is not available from this source. The differences between the TAA data and the TSC file can be explained as follows.

The TSC file does not include many truck movements incidental to rail and water transport, nor exempt-commodity movements by truck. Fresh fruit and vegetable movements by rail and truck are excluded. Movements of manufactures from origins, other than manufacturing plants and foreign imports are excluded as well. The TSC file also excludes the domestic coastal water movements and pipeline flows of petroleum products. The reasons for these deficiencies are discussed in the referenced reports.[16,17]

TABLE 4-1. U.S. DOMESTIC INTERCITY FREIGHT TRAFFIC MODE SHARES BASE YEAR

	TONS (MILLIONS)							TON-MILES (BILLIONS)							
	TAA 1972		TSC FILE 1972		NETWORK[1] MODEL OUTPUT 1972		DOT[2] TRENDS & CHOICES 1975	TAA 1972		TSC FILE 1972		NETWORK[1] MODEL OUTPUT 1972		DOT TRENDS & CHOICES 1975	
RAIL	1,531	29%	1,286	40%	950	45%	-	784	34%	511	40%	600	56%	761	34%
HIGHWAY	1,934	37%	771[3]	24%	655[3]	31%	-	470	20%	212[3]	17%	195[3]	18%	441	19%
WATER	895	17%	730[5]	23%	203[4]	10%	-	603	26%	369[5]	29%	105[4]	10%	557	25%
PIPELINE	876[6]	17%	389[7]	12%	286[7]	14%	-	476[6]	20%	176[7]	14%	167[7]	16%	510	22%
TOTAL	5,236		3,176		2,094		-	2,333		1,268		1,067		2,269	

[1] EXCLUDES: INTERCITY MOVEMENTS WHICH ARE INTRABEA, MANUFACTURES SHIPMENTS FROM PLACES OTHER THAN MANUFACTURING PLANTS, FRESH FRUITS AND VEGETABLES, AND FLOWS TO AND FROM AND WITHIN BEAS 172 AND 173, ALASKA AND HAWAII

[2] SOURCE REPORT DOES NOT DEVELOP TONNAGE BY MODE CONSISTENT WITH TON-MILES

[3] EXCLUDES TRUCK MOVEMENTS INCIDENTAL TO RAIL AND WATER TRANSPORT AND EXEMPT COMMODITY MOVEMENTS

[4] EXCLUDES GREAT LAKES AND COASTAL AND LOCAL WATER MOVEMENTS, ONLY INTERNAL WATER SYSTEM (I.E. RIVERS AND CANALS) INCLUDED

[5] EXCLUDES COASTAL WATER MOVEMENTS: GREAT LAKES, LOCAL AND INTERNAL WATERWAYS INCLUDED

[6] INCLUDES BOTH CRUDE PETROLEUM AND PETROLEUM PRODUCTS

[7] EXCLUDES PETROLEUM PRODUCTS

Definitions

TAA - Transportation Association of America - Transportation Facts and Trends
TSC File - References (16) and (17)
Net work Model - Ref. (15)
DOT Trends & Choices - Ref. (18)

The Physical Network Mode Share Model accepted this TSC file as input and subsequently deleted from the output all internal BEA flow and all water flows not related to the inland waterways system (i.e. rivers system) and all flows to, from and within Alaska and Hawaii. After these latter deletions the model output represents about 40 percent of the actual total U.S. domestic tonnage.

Table 4-1 also shows ton-mile data from these same sources for comparison. One additional source is shown for the ton-mile modal data - the DOT Trends and Choices Report of January 1977. This latter source is shown here because it is the base year data (although 1975 instead of 1972 as for the other two sources) for the only other comprehensive forecast to 1990 by the Department. It provides another point of comparison for the results of the Physical Network Mode Share Model. The base year data shown under the heading of Trends and Choices 1975 is in full agreement with Transportation Association of America (TAA) data for that year.

The TSC file data in ton-miles and the Network Model output data are calculated values. The ton-mile values shown are the product of the BEA origin to destination tonnage flows and a route mileage estimate between the O/D BEA key cities rather than actual shipment route miles.* The values produced by the network model result from network link mileages for the modal path assigned to each commodity group O/D flow. The values shown under the TSC file result from a single distance estimate between each BEA Key City O/D pair. The TAA values, on the other hand are a combination of data reported to the I.C.C. by the regulated carriers and estimates of unregulated traffic developed by the TAA from a variety of sources.

Given this diversity in the base year model traffic estimates, one should not expect full agreement in the ton-mile forecasts based on these sources.

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*Actual shipment route miles are unavailable.

4.2 PROJECTED MODAL SHARES

Table 4-2 displays projections to 1990 produced directly from the TSC file, those produced by the CACI/DOT Physical Network Mode Share Model and also projections published in the DOT Trends and Choices report.[18] All three are based on essentially the same national economic scenario (i.e. OBERS Series E. projections) with a few notable exceptions. The Trends and Choices projections include developments not considered in developing the TSC file projections. The Trends and Choices projections are based on all traffic as reported in the TAA data projected to 1990. It also includes estimates of the movement of Western coal and the North Slope crude oil movement by pipeline and coastal water. The TSC file (and therefore the Network Model output) does not, at this time, include any of this movement of energy commodities. Projections of tons by mode are not shown for the Trends and Choices source because tonnage projections consistent with the ton-mile projection by mode were not published in the report.*

Table 4-2 shows absolute values, modal percentage shares and average annual growth rates for the period from the base year to 1990. The overall growth in ton-miles is projected by Trends and Choices to be about 82 percent for the 15 year period when Western coal and Alaskan oil are included. The TSC file and the network model output suggest a more modest increase of about 50 percent for ton-miles and about 45 percent for tons for their eighteen year period. The difference between the ton-mile and the growth figures reflects a continued trend toward higher growth in the longer haul movements.

Using the TSC file projections as the base forecast, comparisons may be made of the ton-mile modal growth and resultant modal shares presented by the Network Model and Trends and Choices. The TSC File modal shares result from an input assumption that each

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*The summary data shown on Table 11.11, p. 69 of the Trends and Choices report are known to be in error and are not consistent with data shown in greater detail in the body of that report.

TABLE 4-2. U.S. DOMESTIC INTERCITY FREIGHT TRAFFIC-BASE PROJECTIONS 1990 MODE SHARES

	MILLIONS TONS					BILLIONS TON MILES					
	TSC FILE		NETWORK MODEL OUTPUT		DOT TRENDS & CHOICES	TSC FILE		NETWORK MODEL OUTPUT		DOT TRENDS & CHOICES[1]	
RAIL	1,819 (1.9)	39%	1,505 (2.5)	50%	-	764 (2.2)	41%	1,004 (2.9)	62%	1,827 (6.0)	44%
HIGHWAY	1,224 (2.6)	27%	932 (2.0)	31%	-	336 (2.5)	18%	264 (1.6)	16%	659 (2.7)	16%
WATER	1,042 (2.0)	23%	236 (0.8)	8%	-	547 (2.2)	29%	157 (2.2)	10%	838 (2.7)	20%
PIPELINE	511 (3.3)	11%	352 (1.1)	11%	-	228 (1.4)	12%	200 (1.0)	12%	813 (3.1)	20%
TOTAL	4,596 (2.1)		3,026 (2.0)		-	1,875 (2.2)		1,625 (2.3)		4,137 (4.1)	

VALUES IN ( ) INDICATE AVERAGE ANNUAL GROWTH RATE FROM BASE YEAR IN PERCENT

[1] INCLUDES WESTERN COAL AND ALASKAN OIL.

mode in each market (i.e. O/D Pair and Commodity group) will capture the same share in 1990 as in the 1972 base year. Changes in modal shares in the aggregate, therefore, are the result of differential growth projections of individual commodity groups in individual O/D pairs. The TSC file shows only changes in modal shares of only one or two percentage points from 1972 to 1990. The Trends and Choices and the network model output show modal share changes as great as 10 percentage points. The movement of Western coal by rail and Alaskan oil by pipeline and water greatly influences the apparent modal shifts shown by the Trends and Choices data. Rail increased its ton-mile share from 34 percent to 44 percent while the highway share dropped from 19 percent to 16 percent, water from 25 percent to 20 percent and pipeline from 22 percent to 20 percent, even though each of these modes experienced substantial increases in absolute terms.

The Network Model, on the other hand, shows a rail increase from 56 percent to 62 percent while the highway share dropped from 18 percent to 16 percent, water held its own at 10 percent and pipeline dropped from 16 percent to 12 percent. The shifting of modal shares in this case is not attributable to large specific increases in coal and oil traffic, but rather is attributable to changes in the relative prices of the modal services. The modal price changes were caused partly by increased fuel prices which, because of the different fuel intensiveness of the competing modes, had a greater effect on some modes than on others. They were partly caused also by traffic congestion on some modal paths which increased operating costs. Each commodity group and each mode experienced different cost impacts.*

Despite all of the deficiencies in the demand data input to the Network Model and despite the absence of portions of the waterway system and pipeline system networks in the model, the model results, in the aggregate, appear roughly consistent with the

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*See Appendix B for fuel cost, other cost and traffic volume changes for each commodity group and mode.

basic TSC projections and the Trends and Choices projections. This network analysis represents the only comprehensive treatment of inter-city freight movements giving equal consideration to spatial distribution, shipment characteristics, modal system performance and network characteristics and the interaction of supply and demand as discussed in Section 3. This overall comparison at the modal national aggregate level serves only to provide some perspective with which to judge the credibility of the disaggregate analysis which is the heart of the impact assessment process recommended by this report.

4.3 IMPACTS OF ALTERNATIVE GOVERNMENT POLICIES

The primary focus of this study was the overall changes in energy consumption that could result from different energy conservation programs and government policy options. Several government policy/program alternatives are implicitly represented in the analyses conducted for this project and for the source studies which have contributed to this project.

The following discussion involves a comparison of the network model analysis approach with the analysis approach presented in Section 2 of this report for two policy options - the "business-as-usual" and the conservation program policies. These two analysis approaches are referred to below as the "disaggregate analysis" and the "national aggregate analysis" respectively. Subsequently, analysis of alternative policies involving extended use of rail TOFC services or heavy, multiple trailer-tractor highway services using the "disaggregate analysis" approach only are discussed.

4.3.1 "Do Nothing"

The first of these policy alternatives considered may be called a "do nothing" policy or let the private sector and existing government regulation interactions continue as in the present course. The "business-as-usual" scenario used in Section 2 of this report is shown again on Table 4-3 under the "National Aggregate Analysis" heading. It suggests that if the operating policies of

TABLE 4-3. IMPACTS OF "DO-NOTHING" POLICY

	NATIONAL AGGREGATE ANALYSIS[1]				DISAGGREGATE ANALYSIS[2]			
BILLIONS TON-MILES	1975		1985		1972		1990	
RAIL	754[3]	31%	896	29%	600	56%	1,004	62%
HIGHWAY	570[3]	24%	825	27%	195	18%	264	16%
WATER	566[3]	24%	659	21%	105	10%	157	10%
PIPELINE	507[3]	21%	721	23%	167	16%	200	12%
TOTAL	2,397		3,101 (2.3%/YR.)		1,067		1,625 (2.3%/YR.)	
TRILLIONS BTUs								
RAIL	514	16%	610	14%	371	41%	624	46%
HIGHWAY	2,400	74%	3,410	77%	455	50%	606	44%
WATER	303	9%	350	8%	41	4%	57	4%
PIPELINE	37	1%	378	1%	46	5%	75	6%
TOTAL	3,254		4,425 (3.1%/YR.)		913		1,362 (2.2%/YR.)	

[1] ASSUMES NO MODAL SHIFTS OTHER THAN CONTINUATION OF RECENT TRENDS

TOTAL DOMESTIC TRAFFIC

[3] SOURCE: TAA, Except Highway which includes 116 for local truck

[4] Oil pipeline only and total pumping energy.

[2] REFLECTS DIFFERENTIAL MODAL COST INCREASES FROM CONGESTION AND FUEL USING NETWORK MODEL

INTER BEA TRAFFIC ONLY

Values in ( ) indicate average annual growth rate from base year.

the government and the industry transportation patterns and the relative energy intensiveness of the modes all remain as they were in the base year, modest changes in mode shares will occur. The overall ton-miles are shown increasing at about 2.3 percent per year while the overall energy consumption increases at about 3.1 percent per year. This increase in overall energy intensiveness results from the continued growth in highway freight at the expense of rail, and assumes that no energy conservation steps have been taken by the carriers within each mode.

The disaggregate analysis using the Network Model suggest that even without a positive attempt on the part of the modes to conserve fuel, beneficial modal shifts could occur which would indirectly reduce the overall consumption. The overall growth rate of freight ton-miles for the disaggregate analysis is the same as for the national aggregate analysis (i.e. 2.3 percent per year), but the overall growth rate of energy is slightly less at 2.2 percent per year. This reduction in fuel consumption has occurred because of an implicit policy to (a) allow the projected traffic congestion to slightly degrade the service quality and to slightly increase operating costs of certain routes on the competing modes, to (b) allow the market price of petroleum fuel to inflate at about 3 times the inflation rate of all other factor inputs and to (c) allow the cost increases to pass through as changes in the freight rates. As a result, the relative attractiveness of the competing modes changed, and shipments whose choice between highway and rail was marginal, (or likewise between rail and water, etc.) shifted to a new mode to obtain the least total distribution cost.

4.3.2 Fuel Tax Increase

A logical extension of a passive government policy which allows fuel prices to rise is an active policy to gradually impose additional taxes on petroleum fuels to increase the inflation rate relative to other factor inputs by substantially more than a factor of 3. Such a fuel tax policy could accelerate the shift from the more fuel intensive modes to the less fuel intensive modes thus reducing the energy consumption rate still further. Additional runs of the Network Model are required to obtain data on the sensitivity of modal shifts and overall energy consumption to a broad range of fuel prices and/or taxes.

4.3.3 Implement Modal Conservation Program

If, on the other hand, instead of policies of passive or active fuel price induced modal diversion, a positive conservation program is initiated, a still greater reduction in total energy consumption is possible. The result of a coordinated government and industry program to implement procedures and devices exploiting the conservation opportunities is shown in Table 4-4 under the column heading 1985 "National Aggregate Analysis." The national aggregate analysis suggests that although the total freight ton-miles might increase by 2.3 percent per year; the total petroleum fuel consumption need only increase 1.1 percent per year. The modal share trends are assumed to continue as in the "Do-Nothing" case.

It is not clear what the impact might be on modal ton-mile shares of the modal energy conservation program. The national aggregate analysis bypassed the issue by assuming no significant changes in mode share trends. Modal energy intensiveness factors used in the Network Model runs could be adjusted to reflect the incremental savings presented in Section 2 but the companion cost changes induced by the individual devices and procedures is not yet known. One cannot expect that all of these energy conservation motivated changes can be implemented at no cost or at reduced costs to the carriers. Detailed cost/benefit analysis of each of these energy conservation initiatives should precede any attempt to introduce them into mode share analyses. One can speculate that if the dollar cost to the carriers is less than the dollar cost of the fuel saved, then implementation should be certain. However, the question remains - how much, if any, of the net cost savings will be passed through to shippers in the form of freight rate reductions? Without rate changes or service quality changes which change the relative attractiveness of the modes, no mode shifts

TABLE 4-4. IMPACTS OF COORDINATED GOVERNMENT/INDUSTRY MODAL CONSERVATION PROGRAM

	NATIONAL AGGREGATE ANALYSIS[1]		DISAGGREGATE ANALYSIS[2]	
	1975	1985	1972	1990
BILLIONS TON-MILES				
RAIL	31%	29%	56%	?
HIGHWAY	24%	27%	18%	
WATER	24%	21%	10%	
PIPELINE	21%	23%	16%	
TOTAL	2,397	3,101 (2.3%/Yr.)	1,067	
TRILLIONS BTUs				
RAIL	16%	12%	41%	?
HIGHWAY	74%	78%	50%	
WATER	9%	9%	4%	
PIPELINE	1%	1%	5%	
TOTAL	3,254	3,641 (1.1%/Yr.)	913	

[1] ASSUMES NO MODAL SHIFTS OTHER THAN CONTINUATION OF RECENT TRENDS

TOTAL DOMESTIC TRAFFIC

[2] IMPACTS OF MODAL CONSERVATION INITIATIVES ON MODAL SHARES NOT TESTED

INTER BEA TRAFFIC ONLY

can be expected. Conversely, the cost of implementing some of these conservation measures may be greater than the cost of the fuel saved at the projected market price of fuel. In this latter case, perhaps, increased fuel taxes could be used to induce a more favorable cost/benefit ratio, but such a policy would not result in a freight rate reduction. A rate increase might even be the result. The change in the relative attractiveness of the competing modes therefore would depend upon the net cost effects on each mode resulting from the modal conservation program.

4.3.4 Expand Improved Dedicated TOFC Service

Another method of inducing energy conservation through traffic diversion from the more energy intensive highway to the less energy intensive rail is a government policy to encourage and promote the expansion of improved dedicated TOFC rail service. Two independent, DOT sponsored mode share analyses[13,14] have estimated the potential traffic diversions to a greatly improved dedicated TOFC train service. The MIT study using the City-Pair Logistics Model analyzed a total of 2 billion ton-miles of manufactures in three city-pair routes at a highly disaggregate level of detail. A TSC study using the Abstract Network Mode Share Model analyzed a total of 152 billion ton-miles of manufactures and bulks originating at four large economic regions and destined to all markets. This was, of course, a much more aggregate analysis. Both of these studies modeled the rates and service quality of the competing motor carrier, private/direct trucking, rail carload services and the proposed TOFC service. Both, as described in Section 3, assigned traffic to minimize total distribution costs. Both assumed that rates for the new system would be cost based and that all cost changes would be passed through to the freight rates thus influencing the mode choice decision.

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*The TSC study shows 12 percent including the bulks which when adjusted for manufactures yields 15 percent. The manufactures are estimated to be about 80 percent of the total ton-miles analyzed in that study.

The results of both of these analyses of modal competition suggest that a modal shift of about 12 percent to 15 percent* of the total highway plus rail manufactures ton-miles can be expected from highway to the new TOFC service. However, a diversion from highway is not all that may be expected as a result of introducing the new TOFC service. Both of these studies suggest that a diversion from rail carload service can also be expected. A percentage share diversion about equal to the highway diversions was shown by both studies. The FRA National Intermodal Network Feasibility Study of May 1976 supports these results.

Merging these study results with those of the Network Mode Share Model provides some indication of possible energy impacts if this policy were to be initiated. Table 4-5 displays the ton-mile shares and related energy consumption for 1990 under two policy scenarios. The first represents the base case* results of permitting traffic congestion and fuel cost increases to effect a minor modal shift. The second represents the result of superimposing the traffic diversion potential of an improved TOFC service on the base case.

The second scenario represents an assumption that 12 percent of the total base case rail and highway ton-miles (111 billion) are diverted from highway to TOFC and an additional 111 billion ton-miles are diverted from rail carload to TOFC. The average energy intensiveness of the new TOFC is estimated at 2.2** times the base case average for rail.

This analysis suggests that as long as the relative intensivenesses of the competing modal systems remain as estimated here and as long as equal volumes of traffic are diverted from rail carload as well as highway, there will be no significant change in the total petroleum fuel consumption. TOFC freight rates lower than highway are mandatory in this case or little diversion to TOFC

*Discussed earlier as the disaggregate analysis of the "do-nothing" policy using the physical network mode share model.

**From Table 2-9.

TABLE 4-5. ENERGY IMPACT OF MODAL SHIFTS INDUCED BY EXPANDING IMPROVED DEDICATED TOFC SERVICES[1]

BILLIONS TON-MILES	1990 BASE		1990 WITH TOFC	
RAIL	1,004	62%	1,115[2]	69%
HIGHWAY	264	16%	153[2]	9%[2]
WATER	157	10%	157	10%
PIPELINE	200	12%	200	12%
TOTAL	1,625		1,625	
TRILLIONS BTUs				
RAIL	624	46%	860[3]	64%[2]
HIGHWAY	606	44%	351	26%
WATER	57	4%	57	4%
PIPELINE	75	6%	75	6%
TOTAL	1,362		1,343 (-1%)	

[1]DISAGGREGATE ANALYSIS USING SEVERAL MODE SHARE MODELS. ASSUMES ALL COST CHANGES "PASS THROUGH" TO FREIGHT RATES. INTERREGIONAL TRAFFIC ONLY.

[2]73% OF RAIL PLUS HIGHWAY SUBTOTAL IS MANUFACTURED GOODS; 12% OF THIS SHIFTS FROM HIGHWAY TO TOFC AND 12% OF RAIL CARLOAD SHIFTS TO TOFC.

[3]TOFC ENERGY INTENSIVENESS 2.2 TIME RAIL CARLOAD ENERGY INTENSIVENESS COMPUTED AS FOLLOWS [$624 \times 10^{12} \div 1.004 \times 10^{12}$) = 622 BTU/Ton-Mile]

from highway will occur, because TOFC and highway services are postulated as being essentially equal in quality.

The reader is reminded that these results are based upon modal share data for 1967 and 1972. It is unclear at this writing whether all of the traffic which these models indicate could be diverted from conventional rail carload service is actually still in the rail share today. If it is, it might be speculated that rail will continue to lose this service sensitive traffic to highway carriers anyway if improved intermodal service (such as described in this section) is not provided by the rail carriers.

4.3.5 Permit Higher Capacity Highway Vehicles

Still another method of petroleum fuel conservation mentioned in Section 2, under operational improvements in trucking, is a federal and state policy permitting the use of larger, heavier multiple trailer-tractor combination rigs on the interstate system and other four lane, divided, limited access highways. Table 4-6 displays the ton-mile mode shares and related energy consumption for 1990 under this third policy scenario. The TSC Abstract Network mode share study[13] and city-pair logistics modal study[14] tested also the modal share impacts of universal availability of oversized and overweight highway vehicles. Both studies modeled the rate and service characteristics of double 40 foot trailer rigs with overall length of approximatly 100 feet with existing single tandem axle limits and gross combination weights of between 120,000 - 130,000 pounds.

This size and weight limit configuration is used by both studies to represent the outer limits of load carrying capacity likely in this time frame. Double 27 foot trailer rigs, 65 feet long, and with gross weights of 80,000 lbs were also examined in a recent study using the city-pair logistics model. Still other changes (i.e. larger single trailers, wider trailers, heavier axle loads) have been proposed but have not been specifically analyzed because types of combinations that could be tested are almost without number and it is believed by the authors that they fall within

TABLE 4-6. ENERGY IMPACT OF MODAL SHIFTS INDUCED BY UNIVERSAL AVAILABILITY OF HIGHER CAPACITY HIGHWAY VEHICLES[1]

	1990 BASE	1990 WITH HIGH CAPACITY VEHICLES
BILLIONS TON-MILES		
RAIL	62%	50%[2]
HIGHWAY	16%	28%[2]
WATER	10%	10%
PIPELINE	12%	12%
TOTAL	1,625	1,625
TRILLIONS BTUs		
RAIL	46%	33%
HIGHWAY	44%	58%[3]
WATER	4%	4%
PIPELINE	6%	5%
TOTAL	1,362	1,530 (+12%)

[1]DISAGGREGATE ANALYSIS USING SEVERAL MODE SHARE MODELS. ASSUMES ALL COST CHANGES "PASS THROUGH" TO FREIGHT RATES. INTERREGIONAL TRAFFIC ONLY.

[2]73% OF RAIL PLUS HIGHWAY SUBTOTAL IS MANUFACTURED GOODS; 20% OF THIS SHIFTS FROM RAIL TO HIGHWAY

[3]DIVERTED RAIL TRAFFIC PLUS 50% CLASS VIII INTERCITY TRAFFIC EXPERIENCES 25% REDUCTION IN ENERGY INTENSIVENESS

the boundaries established by the double 40s herein specified. Both studies made the implicit heroic assumption that all problems related to highway traffic safety and highway maintenance could be resolved without drastically affecting the economic estimates of the studies.

4.3.5.1 Cost Reductions Pass-Through to Freight Rates - The results shown on Table 4-6 reflect an assumption that cost reductions resulting from use of these large vehicles will pass through as reductions in the average freight rates.

The City-Pair Logistics Model analysis assumed that only about one half of the potential highway traffic could effectively take advantage of the economies of the larger multiple trailer rigs; therefore, only 50% of the estimated cost savings of a doubles operation were passed through to the average freight rate. The Abstract Network Mode Share Model analysis, on the other hand, implicitly assumed 100% effectiveness and pass-through to freight rates.

The City-Pair Logistics Model analysis showed a 22% shift (of highway-plus-rail ton-miles) from rail to highway. The results of the Abstract Newtork Mode Share analysis (when adjusted for manufactures and for a 50% pass-through) shows that about 18% of the total (highway-plus-rail ton-miles) would be diverted from rail to highway if these double 40s were permitted.

The average fuel intensiveness of that portion of the total highway traffic using the highway doubles* is estimated at 75% of the base case average for highway. Superimposing these estimates on the base case energy consumption results in a total energy increase of about 12% over the 1990-base case. These results are predicated on the implicit assumption that the cost reductions realized by the carriers using the double rigs are allowed to pass through to the freight rates.

*Traffic diverted to doubles from rail plus Class VIII intercity portion of total basic highway ton-miles (47%); 50% of this traffic assumed to use doubles (62 billion ton-miles).

4.3.5.2 Prohibit Cost Reduction Pass-Through to Freight Rates - Another alternative policy, of course, is to permit the doubles operation but prohibit (by some regulation) the cost reduction pass-through thus forestalling potential diversions from rail. If this latter policy is followed, then the energy savings potential would be about 36 trillion BTU or 2.6% of the total base case fuel.

In Section 2, the national aggregate analysis estimated the reduction for the universal use of double 40s at 180 trillion BTU or 4.0 of the total business-as-usual freight fuel consumption. This previous estimate was based on 825 billion ton-miles for highway mode share as opposed to 264 billion ton-miles used in the disaggregate analysis. In either case the result is a positive reduction in total fuel consumption from the use of higher capacity vehicles if diversions from rail are prevented.

One possible justification for this policy might be that the cost reductions that accrue to the motor carriers by using these high capacity rigs could be applied to the cost of implementation of the other fuel conservation devices and procedures outlined in Section 2. The net result of a government policy encouraging this method of fuel conservation could be as high as a 20 to 22% reduction in the total fuel consumption instead of the 18% shown in Section 2 for all other technological and operational changes if universally applied.

4.4 SUMMARY OF FUEL CONSERVATION VIA MODAL SHIFTS

The results of this preliminary assessment suggest that diversions of freight markets from highway to rail, via the mechanism of intermodal innovations, will result in both decreases and increases in petroleum consumption. Intermodal innovations which effectively penetrate markets currently held by highway or which forestall continued losses of rail markets to highway services will produce significant fuel savings in these specific markets. However, introduction of intermodal innovations in markets heavily involved in conventional rail carload services as well as highway services can result in net increases in petroleum consumption.

In these latter markets, intermodal innovations may be desirable as a conservation measure only if a non-petroleum source of energy is more appropriate for rail based systems than for highway.

Upgraded and expanded rail-based intermodal trailer/container on flatcar (TOFC/COFC) services can cause substantial modal diversions from highway as indicated in many studies. However, in some markets, diversions from rail carload services can be greater than diversions from highway. It is possible that in the aggregate, diversions to rail TOFC could result in insignificant fuel savings at best, and substantial increases in fuel consumption at worst, because of the relative fuel intensivenesses of rail, TOFC, and highway services. It has been suggested by some industry analysts that the "old" traffic data underlying the recent mode shift studies does not reflect the recent (and possibly future) loss of standard rail carload traffic to highway services and that the modeled diversions from carload service may in fact represent diversions back to rail (via TOFC) that were formerly lost by rail to truck. If this hypothesis were to be proved true, then, of course, the new TOFC/COFC services would greatly enhance petroleum fuel conservation as well as overall freight transportation economics.

The alternative of highway-to-rail market diversions via a public policy allowing highway costs and services to degrade to the point that rail carload services became preferable for a substantial segment of the market may appear beneficial from an energy perspective, but one must expect that further investigation will prove such a policy to be economically and/or institutionally non-viable.

With respect to the policy of permitting higher capacity highway vehicles, this preliminary assessment suggests that petroleum consumption will be reduced significantly for the freight markets currently served by highway. However, the cost reductions attending the use of such higher capacity rigs, if passed through to the freight rates, will cause traffic diversions from the rail mode and thus increase the aggregate fuel consumption.

This partial application of the disaggregate analysis approach to evaluation of a selection of alternative energy conservation policies is offered as a demonstration of the recommended approach and an attempt to provide a quantitative perspective for future DOT policy development.

APPENDIX A - FUEL CONSUMPTION ESTIMATING FOR MODAL SUBSYSTEMS

A-1. INTRODUCTION

A method is given to allow estimation of intercity line-haul freight transportation fuel consumption for various transportation services. The purpose is to provide a means for approximating freight fuel needs for planning future transportation services and systems. System variables which the method accounts for include: shipping distance, payload weight and empty backhaul. While other vehicle, environmental, and operational variables also enter into fuel consumption rates, it is desirable to separate the demand related variables (mentioned above) and to average the supply variables so that systems fuel trade-off studies may be performed.

Vehicle variables including engine and tire characteristics, aerodynamic shape, etc. are not treated separately. Similarly, operational and environmental variables which include such factors as speed (average, maximum), terrain (grade, elevation), climate (temperature, road conditions) and highway congestion are not disaggregated. While information is available to include the effects of some of these on fuel consumption, this has not been done. The added complexity is not necessary because the supply variables used in planning the routes and services are not identified in sufficient detail to warrant use of other than system averages. A balance is attempted between the detail which is available and can be handled analytically and the specificity and accuracy needed to be useful. Vehicle and system characteristics of the modes and services of this study are given in Table A-1.

Appendix A references given on page A-23.

TABLE A-1. INTERCITY FREIGHT TRANSPORTATION VEHICLE AND PAYLOAD WEIGHT (TONS) CHARACTERISTICS AND AVERAGE EMPTY BACKHAUL CORRECTION FACTORS[1]

SERVICE	TARE WEIGHT[2]	CHARACTERISTICS[1] PAYLOAD[3] AVERAGE	MAXIMUM	MAXIMUM GROSS WEIGHT	EMPTY BACKHAUL CORRECTION FACTOR
Standard Rail	30	50	77	107	1.6
Standard TOFC	22.6	15	23	45.6	1.4
Dedicated TOFC	22.6	15	23	45.6	1.4
Lightweight TOFC	18.3	15	23	41.3	1.4
Motor Carrier Single 40 Ft. trailer	13.3	15	23	36.3	1.11
Private Truck Single 40 Ft.	13.3	15	23	36.3	1.33
Motor Carrier Double 27 Ft. trailers	15.65	15	20.65	36.3	1.11
Motor Carrier Double 40 Ft. trailers	19.85	30	46	65.85	1.11

[1]Characteristics given here are based on material in Reference 7. (See page A-23) The values shown are representative of general commodity traffic.

[2]Tare weight calculations are given in text and in Table A-5.

[3]Payload weights are for commodities whose densities are above the critical density.

Fuel consumption values for planning purposes can be expressed in different ways. In this note, fuel consumption factors are shown for the following measures:*

1. Fuel consumption rate in terms of gallons per vehicle mile,
2. Gross fuel intensiveness per ton-mile in terms of gallons per mile per gross vehicle weight, and
3. Net fuel intensiveness per ton-mile in terms of gallons per mile per payload weight carried.

When the fuel consumption rate factor is multiplied by line-haul distance, the line-haul fuel consumption is given. In a similar manner, when the fuel intensiveness factors are multiplied by both the line-haul distance and either the gross vehicle weight or payload weight, the line-haul fuel consumption is given.** Empty backhaul correction factors are included which account for those vehicles moved empty to another location to pick up a shipment. The tare (or empty weight) of the vehicles is included in the basic equations.

Factors are given in equation form where fuel consumption is expressed as a function of payload weight and a constant. The constant term accounts for fuel used to overcome tare weight and other non-payload related resistances to vehicle movement. The constant term also includes the empty backhaul correction factor. Vehicle and shipment data is substituted into the equations and the resultant factors are given in Table A-2. Derivation of the fuel consumption factors is shown so that new factors can be calculated when other input variables are used. Both the gross fuel

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* Gross fuel intensiveness, expressed in gallons per mile per gross ton (tare weight plus payload weight), is used when investigating fuel use and gross vehicle weight changes. Net fuel intensiveness expressed in gallons per mile per net ton (payload weight), is used when investigating relationships between shipment weight change and fuel consumption.

* See equations A-2 and A-3 in text.

TABLE A-2. INTERCITY FREIGHT SYSTEMS FUEL CONSUMPTION FACTORS[1]

SERVICE	FUEL CONSUMPTION RATE (GPM)[2]	FUEL INTENSIVENESS: GROSS FUEL INTENSIVENESS (GPM/TON)		FUEL INTENSIVENESS: NET FUEL INTENSIVENESS (GPM/TON)	
		Max. Payload	Ave. Payload	Max. Payload	Ave. Payload
Standard Rail	0.072 + 0.0015 (P)	0.00175	0.00183	0.00244	0.00294
Standard TOFC	0.0475 + 0.0015 (P)	0.00179	0.00185	0.00354	0.00463
Dedicated TOFC	0.056 + 0.0020 (P)	0.00239	0.00247	0.00474	0.00620
Lightweight TOFC	0.0512 + 0.0020 (P)	0.00235	0.00244	0.00423	0.00541
Motor Carrier Single 40 ft.	0.1616 + 0.0030 (P)	0.00635	0.00720	0.01003	0.01377
Private Truck	0.1936 + 0.0030 (P)	0.00723	0.00834	0.01142	0.01591
Motor Carrier Double 27 ft.	0.1694 + 0.0030 (P)	0.00637	0.00722	0.01120	0.01429
Motor Carrier Double 40 ft.	0.1834 + 0.0030 (P)	0.00489	0.00549	0.00697	0.00909

[1]Fuel consumption factors are derived from tests and adjusted to system average conditions.

[2]Equations give fuel consumption for individual vehicle in each type service (i.e. box car, TOFC trailer, highway combination rig). Equation includes tare weight and an empty backhaul correction factor. "P" is payload in tons.

intensive and the net fuel intensiveness are given in terms of maximum payload weight and national system average payload weight. Other payload weights may be substituted in the equations.

The fuel consumption factors and fuel intensiveness values shown here are developed by the following procedure;

1. Field tests are selected which are considered most representative of national systems operations.
2. Selected field fuel consumption rates are corrected from the test conditions to system average operating conditions.
3. Incremental fuel consumption rates per unit weight are calculated.
4. Empty vehicle fuel consumption is calculated.
5. Vehicle fuel consumption factor as a function of payload weight is then expressed in linear equation form.
6. Fuel consumption intensiveness per gross ton-mile is found by dividing vehicle fuel consumption by total vehicle weight (tare or empty weight plus payload weight).
7. Fuel consumption intensiveness per net ton-mile is found by dividing vehicle fuel consumption by payload weight.

Derivation of fuel consumption and fuel intensiveness equations are given below.

1. Fuel Consumption Factor Per Vehicle Mile

Fuel consumption per vehicle mile is the sum of the fuel used to move the empty (tare) vehicle (surface rolling resistance and aerodynamic drag resistance) and the fuel used to move the payload.

This can be expressed as

$$GPM = (GPM)_{tare} + (GPM)_{payload}$$

Both terms can be expressed in terms of sensitivity of fuel consumed to weight change (GPM/Gross ton).

$$GPM = (GPM/Gross\ ton)(tare\ wt.) + (GPM/Gross\ ton)(payload)$$

For a system wide analysis the tare component includes an empty corrections factor to correct the tare weight by assigning a portion of all the empty vehicle fuel consumed to the load carrying vehicles:

Eq A-1. ... $GPM = (GPM/Gross\ ton)\ (tare\ wt)\ (EF) + (GPM/Gross\ ton)\ (payload)$

where EF is the empty backhaul correction factor (Table A-1).

2. Gross Fuel Intensiveness Factor

Gross fuel intensiveness is the fuel consumed per mile divided by the gross vehicle weight:

Eq A-2. ... $$GPM/Gross\ ton = \frac{(GPM)_{tare}(EF) + (GPM)_{payload}}{Gross\ vehicle\ weight}$$

3. Net Fuel Intensiveness Factor

Net fuel intensiveness is the fuel consumed per mile divided by the payload weight:

Eq A-3. ... $$GPM/Net\ ton = \frac{(GPM)_{tare}(EF) + (GPM)_{payload}}{Payload\ weight}$$

The vehicle line-haul fuel consumption factors and the fuel intensiveness values are given in Table A-2.

A-2. DERIVATION OF RAIL FUEL CONSUMPTION FACTORS

Intercity rail freight fuel consumption factors are based on actual rail fuel tests. The fuel consumption factors are derived below following the steps described before.*

* The stepwise procedure is shown for the "standard" boxcar transportation fuel consumption. Fuel consumption factors are also given for standard TOFC, dedicated TOFC, lightweight TOFC.

A-2.1 STANDARD RAIL

Step 1. Basic fuel consumption rates.

Field tests considered most representative of national rail system average fuel consumption are tests reported by Hopkins (ref. 1.[†] These are summarized in Table A-3. However, the data is for the test conditions and must be adjusted for assumed "national average" conditions.

TABLE A-3. FIELD TEST AND ESTIMATED RAIL SYSTEM AVERAGE* HIGHWAY FUEL CONSUMPTION

SERVICE	TEST CONDITIONS			ESTIMATED SYSTEM AVERAGE CONDITIONS	
	HP/TON	AVE. SPEED (MPH)	Gal/Gross ton-mile	AVE. SPEED (MPH)	Gal/Gross ton-mile
All Box	2.1	33	0.00151	20	0.00150
Mixed	3.0	41	0.00179	20	0.00150
All TOFC	4.6	45	0.00273	30	0.00200

*Values given have aggregated from Hopkins, Reference 5.

Step 2. Correcting test conditions speed to national system average speed conditions.

Test results are corrected from average test performance conditions to the system average performance by the relationships given by Hopkins (Reported by Murphy, Ref. 2). This is done graphically as shown in Figure A-1, where it is assumed that the

[†]Data reported includes: railroad, test location, total horsepower, number and type boxcars, number of trailers, gross trailing and net weight, test distance, average speed, fuel consumed.

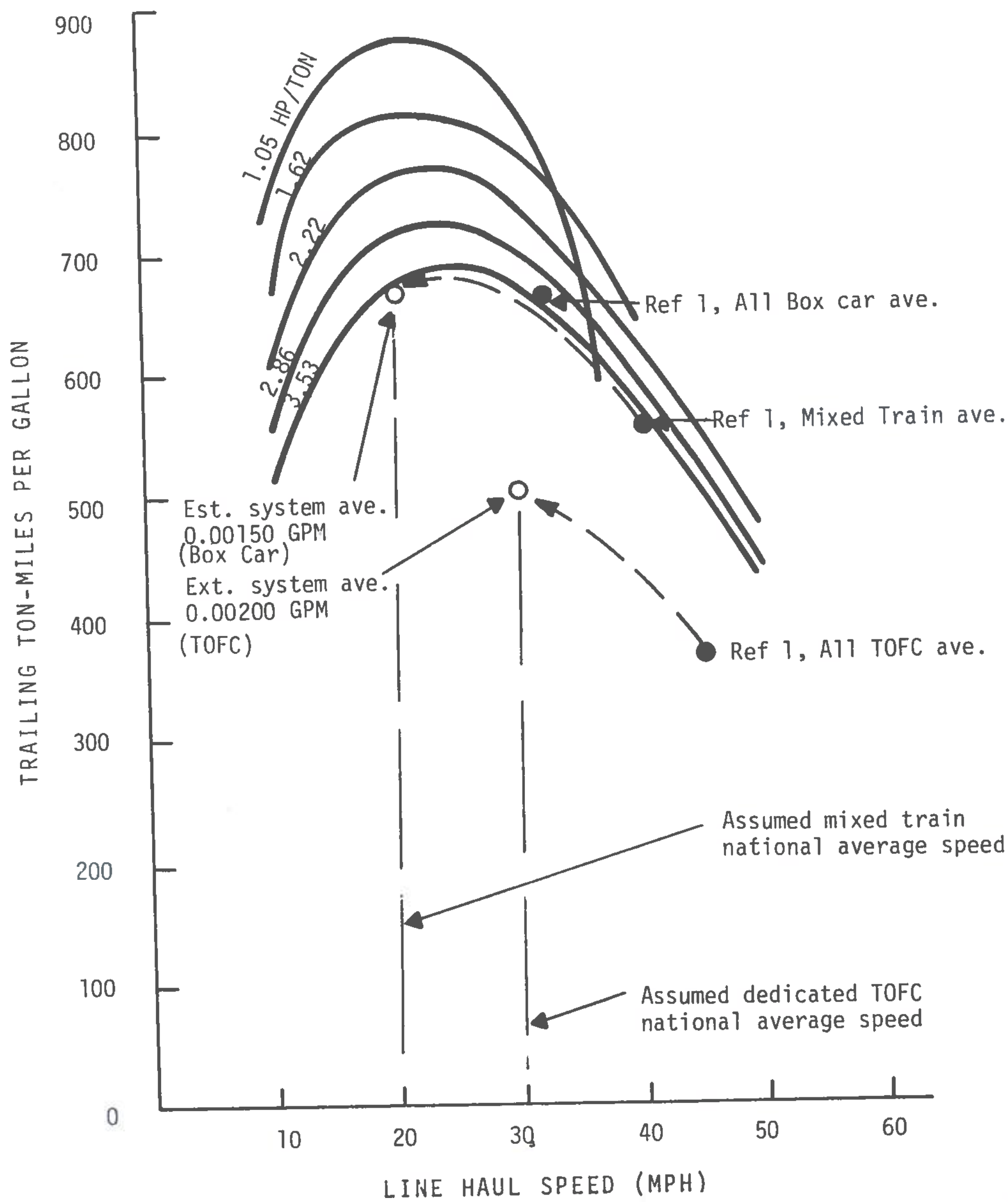


FIGURE A-1. ILLUSTRATION OF METHODOLOGY TO CONVERT FUEL CONSUMPTION AT AVERAGE TEST SPEEDS TO ASSUMED SYSTEM AVERAGE SPEEDS isobars of constant HP/ton follow the trends indicated on the map. The field test and the adjusted fuel consumption values are given in Table A-3.

Step 3. Sensitivity of locomotive fuel consumption to changes in train weight.

Values given by this method for trailing ton-miles per gallon are the inverse of the fuel consumption per gross trailing ton-mile values. Fuel consumption per gross-ton-mile value is also the sensitivity value per incremental change in fuel required per payload ton.

Step 4. Empty Backhaul Correction

Empty rail backhaul correction factors are given in Table A-1. The box car empty correction factor is 1.6.

Step 5. Fuel Consumption Rate Per Vehicle Mile

The fuel consumption factor as shown in Eq. A-1 is expressed in terms of fuel consumed per freight car.

$$\text{GPM} = (\text{GPM/Gross ton} \times \text{tare wt.})(\text{EF}) + (\text{GPM/Gross ton})(\text{payload})$$

$$= (0.0015)(30)(1.6) + (0.0015)(P)$$

$$= 0.072 \times (0.0015)(P) \text{ gal per mile}$$

Step 6. Gross fuel intensiveness and net fuel intensiveness for both maximum payload weight and average payload weight.

Gross Fuel Intensiveness (from Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (Max)} = \frac{(0.072) + (0.0015)(77)}{107}$$

$$= 0.00175 \text{ GPM/ton}$$

where max. payload is 77 tons, and gross vehicle weight is 77 tons plus tare wt. (i.e. 77 + 30 = 107 tons)

At 50 ton payload

$$\text{GPM/Gross ton (50t)} = \frac{(0.072) + (0.0015)(50)}{80}$$

$$= 0.00183 \text{ GPM/ton}$$

Net Fuel Intensiveness (From Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.072) + (0.0015)(77)}{77}$$

$$= 0.00244 \text{ GPM/ton}$$

where maximum payload is 77 ton

At 50 ton Payload

$$\text{GPM/Net ton (50t)} = \frac{(0.072) + (0.0015)(50)}{50}$$

$$= 0.00294 \text{ GPM/ton}$$

A-2.2 STANDARD TOFC

Standard TOFC fuel consumption factors are calculated in a similar manner. Average tare weight is however, more complicated because there are both empty trailers and flatcars which are not loaded to capacity. The average flatcar carries 1.9 trailers and the overall system empty trailer backhaul is 40%.

The tare weight per loaded flatcar is,

flatcar	33.6 tons
1 trailer	6.1 tons
1 trailer (90% of time)	5.5 tons
	45.2 tons

the tare weight per trailer is:

$$\frac{45.2}{2} = 22.6 \text{ tons}$$

Fuel Consumption Rate (Eq. A-1)

$$\text{GPM} = (0.0015)(22.6)(1.4) + (0.0015)(p)$$

$$= 0.0475 + 0.0015(p) \text{ gal per mile}$$

Gross Fuel Intensiveness (Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (max)} = \frac{(0.047) + (0.0015)(23)}{45.6}$$

$$= 0.00179 \text{ GPM/ton}$$

where maximum payload is 23 tons and gross vehicle weight is 23 tons plus tare weight (23 + 22.6 = 45.6 tons)

At 15 ton Payload

$$\text{GPM/Gross ton (15t)} = \frac{(0.047) + (0.0015)(15)}{37.6}$$

$$= 0.00185 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.047) + (0.0015)(23)}{23}$$

$$= 0.00354 \text{ GPM/ton}$$

At 15 ton payload

$$\text{GPM/Net ton (15t)} = \frac{(0.047) + (0.0015)(15)}{15}$$

$$= 0.00463 \text{ GPM/ton}$$

A-2.3 DEDICATED TOFC

Fuel consumption of dedicated TOFC carried on through trains is calculated in a similar manner. Tare weight and empty load factor are the same as that used for standard TOFC. The only difference is that the fuel consumption per gross ton-mile is higher due to the greater locomotive power (HP per ton) required for the higher average speed of the through train (30 mph) over that of the standard train (20 mph).

Fuel Consumption Rate (Eq. A-1)

$$\text{GPM} = (0.002 \times 22.6)(1.4) + (0.002)(p)$$

$$= 0.0633 + (0.002)(p) \text{ gal per mile}$$

Gross Fuel Intensiveness (Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (max)} = \frac{(0.063) + (0.0002)(23)}{45.6}$$

$$= 0.00239 \text{ GPM/ton}$$

At 15 ton payload

$$\text{GPM/Gross ton (15t)} = \frac{(0.063) + (0.002)\ (15)}{37.6}$$

$$= 0.00247 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.063) + (0.002)\ (23)}{23}$$

$$= 0.00474 \text{ GPM/ton}$$

At 15 ton payload

$$\text{GPM/Net ton (15t)} = \frac{(0.063) + (0.002)(15)}{15}$$

$$= 0.00620 \text{ GPM/ton}$$

A-2.4 LIGHTWEIGHT TOFC

Lightweight TOFC fuel consumption factors are based on a lighter weight flatcar while all other variables are held the same as for the dedicated TOFC.

The tare weight per loaded flatcar is:

flatcar	25.0 tons
1 trailer	6.1
1 trailer (90% of time)	5.5
	36.6 tons

The tare weight per trailer is:

$$\frac{36.6}{2} = 18.3 \text{ tons}$$

Fuel Consumption Rate (Eq. A-1)

$$GPM = (0.0020)(18.3)(1.4) + (0.002)(p)$$
$$= 0.0512 + (0.002)(p) \text{ gal per mile.}$$

Gross Fuel Intensiveness (Eq. A-2)

At Minimum Payload

$$\text{GPM/Gross ton (max)} = \frac{(0.0512) + (0.002)(23)}{41.3}$$
$$= 0.00235 \text{ GPM/ton}$$

where maximum payload is 23 tons and gross vehicle weight per trailer is 23 tons plus tare weight (23+18.3 = 41.3 tons).

At 15 ton payload

$$\text{GPM/Gross ton (15t)} = \frac{(0.0512) + (0.002)(15)}{33.3}$$
$$= 0.00244 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.0512) + (0.002)(23)}{23}$$
$$= 0.00423 \text{ GPM ton}$$

At 15 ton payload

$$\text{GPM/Net ton (15t)} = \frac{(0.0512) + (0.002)(15)}{15}$$
$$= 0.00541 \text{ GPM/ton}$$

A-3. HIGHWAY

Intercity tractor-trailer fuel consumption factors are based on actual highway fuel tests. System average fuel consumption factors are derived from the highway tests as described below.* The methodology is shown schematically in Figure A-2.

A-3.1 MOTOR CARRIER SINGLE 40 FT.

Step 1. Basic fuel consumption rates.

Reference 3 gives intercity truck fuel consumption rates most useful to this study; these data, aggregated by speed are shown in Table A-4 and as Step 1 in Figure A-2.** These values are for vehicles having average speeds of 44.5 mph, 48.9 mph and 52.5 mph; traversing rolling and mountainous terrain carrying payloads of 13.85 tons.

TABLE A-4. INTERCITY HIGHWAY TRUCK FUEL CONSUMPTION REPORTED

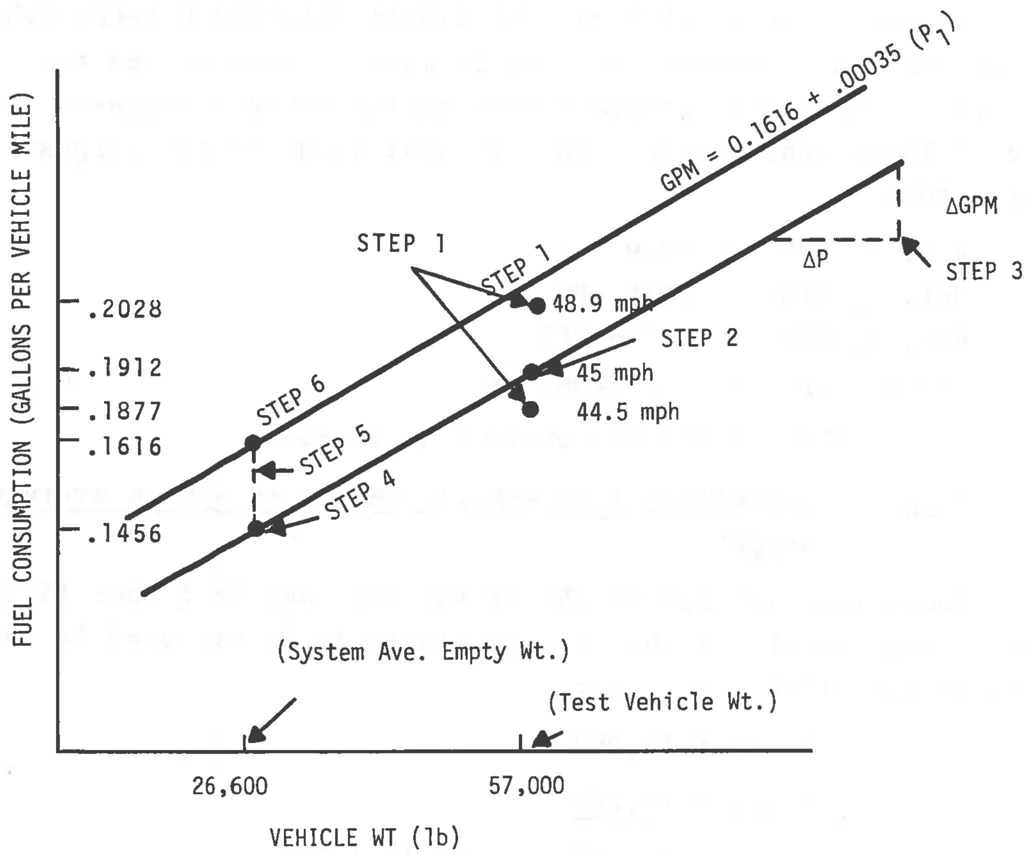
MAX. SPEED (MPH)	AVE. SPEED (MPH)	TOTAL DISTANCE (MILES)	TOTAL GALLONS	MILES PER GALLON (MPG)	GALLONS PER MILE (GPM)
50	44.5	2290.9	429.9	5.33	0.1877
55	48.9	2336.3	473.7	4.93	0.2028
60	52.5	2505.3	530.4	4.72	0.2117

Step 2. Correcting test speed conditions to system average speed conditions

A linear interpolation is made between the fuel consumption rates at the test speeds of 44.5 mph and 48.9 mph to find the fuel consumption rate at 45 mph, i.e., 0.1912 GPM.

*The stepwise procedure is shown for motor carrier single trailer service. Fuel consumption factors are also given for private truck, motor carrier double 27 ft. service, and motor carrier double 40 ft. service.

**The test data used here is from Reference 3. The test vehicle weight is converted from the test weight to system average weight.



Note: This figure shows the steps used in correcting the fuel consumption of the test vehicle to that of the system average vehicle.

FIGURE A-2. ILLUSTRATIONS OF METHODOLOGY TO CONVERT HIGHWAY TEST FUEL CONSUMPTION TO SYSTEM AVERAGE FUEL CONSUMPTION

Step 3. Sensitivity of vehicle fuel consumption to changes in weight*

To convert the fuel consumption at the test condition vehicle weights to system average vehicle weights, it is necessary to determine sensitivity of fuel consumption to changes in vehicle weight.

Several sources give an approximate relation between vehicle weight and fuel consumption. While many factors act on the relation, the close agreement between the sources suggests that use of these approximate values is justified for the purposes of this study.

Ref. 4, GPM = 0.0029 (P)
Ref. 5, GPM = 0.0031 (P)
Ref. 6, GPM = 0.00306 (P)
The average value assumed is:

GPM = 0.003 (P) where P is in tons

Step 4. Correcting test vehicle weight to system average empty weight.

Gross vehicle test weight of the rigs was 28.5 tons (57,000 lbs). Tare weight of the average single 40 ft rig used in inter-city freight (Table A-5) is:

Tractor	16,000 lb.
Trailer	10,600
Total tare	26,600 lb. (or 13.3 ton)

*The test data used here is from Reference 3. The test vehicle weight is converted from the test weight to system average weight.

TABLE A-5. HIGHWAY TRUCK WEIGHT BREAKDOWN (lb)

SERVICE	MGVW	Tractor[1]	Trailer 1	Trailer 2[4]	Maximum Payload	Empty Weight
System Ave. Vehicles[2]						
Motor Carrier Single 40 Ft trailer	72,380	16,000	10,600		46,000	26,600
Private Truck Single 40 Ft	72,380	16,000			46,000	26,000
Motor Carrier Double 27 Ft. trailers	72,380	16,000	6,400	8,900	41,300	31,300
Motor Carrier Double 40 Ft. trailers	131,700	16,000	10,600	13,100	92,000	39,700
Test Vehicles[3] (Ref. 3)		16,500	12,800		27,700	29,300

[1] Est. ave. trailer 15,000 lb plus 1000 lb for 2 drivers and 100 gal. fuel at 7.24 lb per gal.

[2] Data taken from (Ref. 7).

[3] Data taken from (Ref. 3).

[4] Trailer 2 weight = trailer 1 weight plus dolly weight (2500 lb).

Therefore, fuel consumption of the average empty rig (GPM_E) is found by reducing the fuel consumption of the test vehicle by the expression:

GPM_E = (Test average GPM at 45 mph)
-(Gross vehicle test weight - ave. vehicle tare wt.) (0.003)

= 0.1912 - (28.5 - 13.3)(0.003)

= 0.1456 gal per mile (for empty vehicle).

Step 5. Empty backhaul correction.

The empty vehicle fuel consumption rate is adjusted to include a factor for the fuel used in moving the empty trailers to another location. Industry system average values shown in Table A-1 are used. For the motor carrier for this sample calculation the empty backhaul correction factor is 1.11.

Step 6. Fuel consumption rate.

The fuel consumption factor as shown in Eq. A-1, can therefore be expressed with the values derived in the previous steps.

GPM = (GPM_E)(EF) + 0.003 P

= (0.1456)(1.11) + 0.003 P

= 0.1616 + (0.003)(P) gal per mile.

Step 7. Gross fuel intensiveness and net fuel intensiveness for both maximum payload weight and average payload weights.

Gross fuel intensiveness and net fuel intensiveness are calculated using equations A-2 and A-3 and with the values for vehicle weight and payload weights shown in table.

Gross Fuel Intensiveness (Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (max)} = \frac{(.1616) + (0.003)(23)}{36.3}$$

$$= 0.00635 \text{ GPM/ton}$$

where max. payload is 23 tons, and Gross vehicle weight is payload plus tare wt. (23 + 13.6 = 36.3 tons)

At 15 ton payload

$$\text{GPM/Gross ton (15t)} = \frac{(.1616) + (0.003)(15)}{28.6}$$

$$= 0.00722 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.1616) + (0.0003)(23)}{23}$$

$$= 0.01003 \text{ GPM/ton}$$

where maximum payload is 23 tons

At 15 ton payload

$$\text{GPM/Net ton (15t)} = \frac{(0.1616) + (0.003)(15)}{15}$$

$$= 0.01377 \text{ GPM/ton}$$

A-3.2 PRIVATE TRUCK

Private truck fuel consumption values are calculated in a similar manner to the motor carrier values calculated before. Truck weight and performance are assumed the same as that of motor carrier. A difference in empty backhaul, however, causes a difference in system fuel consumption.

Fuel consumption rate (Eq. A-1)

$$\text{GPM} = (\text{GPM}_E)(\text{EF}) + (0.003)(P)$$

$$= (0.1456)(1.33) + (0.003)(P)$$

$$= 0.1936 + (0.003)(P) \text{ gal per mile}$$

Gross fuel intensiveness (Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (max)} = \frac{(0.1936) + (0.003)(23)}{36.3}$$

$$= 0.00723 \text{ GPM/ton}$$

At average payload

$$\text{GPM gross ton (15t)} = \frac{(0.1936) + (0.003)(15)}{28.6}$$

$$= 0.00834 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.1936) + (0.003)(23)}{23}$$

$$= 0.01142 \text{ GPM/ton}$$

At average payload

$$\text{GPM/Net ton (15t)} = \frac{(0.1936) + (0.003)(15)}{15}$$

$$= 0.01591 \text{ GPM/ton}$$

A-3.3 MOTOR CARRIER DOUBLE 27 FT. TRAILERS

Tare weight of double 27 ft. rigs is (Table A-5):

Tractor	16,000 lb
2 Trailers	15,300 lbs
	31,300 lb (15.65 Tons)

$$GPM_E = 0.1912 - (28.5 - 15.65)(0.003)$$
$$= 0.1526 \text{ gal per mile}$$

System average fuel consumption from equation A-1 is:

$$GPM = (0.1526)\ (1.11) + (0.003)\ (P)$$
$$= 0.1694 + (0.003)\ (P) \text{ gal per mile}$$

Gross Fuel Intensiveness (Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (max)} = \frac{(0.1694) + (0.003)(20.65)}{36.3}$$

$$= 0.00637 \text{ GPM/ton}$$

where max. payload is 20.65 tons, and gross vehicle weight is payload weight plus tare weight (20.65 + 15.65 = 36.3 tons)

At 15 ton payload

$$\text{GPM/Gross ton (15t)} = \frac{(0.1694) + (0.003)(15)}{30.65}$$

$$= 0.00700 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq. A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.1694) + (0.003)(20.65)}{20.65}$$

$$= .01120 \text{ GPM/ton}$$

$$\text{GPM/Net ton (15t)} = \frac{(0.1694) + (0.003)(15)}{15}$$

$$= .01429 \text{ GPM/ton}$$

A-3.4 MOTOR CARRIER DOUBLE 40 FT. TRAILERS

Tare weight of 40 ft. double rigs is (Table A-5):

Tractor	16,000 lbs
Semi-Trailer	10,600
Full Trailer	13,100 (includes extra axle)
Total rig	39,700 lbs (19.85 tons)

Empty double rig fuel consumption is calculated by the same procedure used in the single rig calculation

$$GPM_E = 0.1912 - (28.5 - 19.85)(0.003)$$

$$= 0.1652 \text{ gal per mile}$$

System Average Fuel Consumption - The empty double rig vehicle fuel consumption as a function of payload weight and average empty backhaul ratio is:

$$GPM = (0.1652)\ (1.11) + (0.003)\ (P) \quad \text{(Eq. A-1)}$$
$$= 0.1834 + (0.003)\ (P) \text{ gal per mile}$$

Gross Fuel Intensiveness (Eq. A-2)

At Maximum Payload

$$\text{GPM/Gross ton (max)} = \frac{0.1834 + (0.003)\ (46)}{65.85}$$
$$= 0.00488 \text{ GPM/ton}$$

At average payload

$$\text{GPM/Gross ton (30t)} = \frac{(0.1834) + (0.003)\ (30)}{28.6}$$
$$= 0.00548 \text{ GPM/ton}$$

Net Fuel Intensiveness (Eq.A-3)

At Maximum Payload

$$\text{GPM/Net ton (max)} = \frac{(0.1834) + (0.003)\ (46)}{46}$$
$$= 0.00699 \text{ GPM/ton}$$

At 15 ton Payload

$$\text{GPM/Net ton (15t)} = \frac{0.1834 + (0.003)\ (30)}{30}$$
$$= 0.00911 \text{ GPM/ton}$$

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APPENDIX B

CACI/DOT PHYSICAL

NETWORK MODE SHARE

MODEL RESULTS

TABLE B-1. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-AVERAGE STATISTICS BY MODE

	1972	1990
Rail		
Average Cost (Mills/Ton-Mile)	14.80	14.46
Cost w/o Fuel Cost	14.27	13.92
Average Speed (Miles/Day)	97	101
Average Time Cost (Mills/Ton-Mile)	11.36	12.19
Average Energy (BTU/Ton-Mile)	618	622
Average Fuel Cost (Mills/Ton-Mile)	0.53	1.51
Average Disutility (Mills/Ton-Mile)	26.16	27.62
Highway		
Average Cost (Mills/Ton-Mile)	53.45	55.26
Cost w/o Fuel Cost	51.43	53.28
Average Speed (Miles/Day)	380	364
Average Time Cost (Mills/Ton-Mile)	5.47	2.26
Average Energy (BTU/Ton-Mile)	2,335	2,291
Average Fuel Cost (Mills/Ton-Mile	2.02	5.56
Average Disutility (Mills/Ton-Mile)	58.92	61.10
Water		
Average Cost (Mills/Ton-Mile)	11.30	10.07
Cost w/o Fuel Cost	10.96	9.76
Average Speed (Miles/Day)	60	60
Average Time Cost (Mills/Ton-Mile)	12.61	10.69
Average Energy (BTU/Ton-Mile)	391	362
Average Fuel Cost (Mills/Ton-Mile)	0.34	0.88
Average Disutility (Mills/Ton-Mile)	23.91	21.33
Pipeline		
Average Cost ($/Ton-Mile)	2.40	2.47
Average Speed (Miles/Day)	55	65
Average Energy (BTU/Ton-Mile)	272	375
Average Fuel Cost (Mills/Ton-Mile)		
Average Disutility ($/Ton-Mile)	2.59	2.62
Total		
Average Cost	19.56	20.50
Cost W/o Fuel Cost		
Average Speed (Miles/Day)	93	99
Average Time Cost		
Average Energy (BTU/Ton-Mile)	855	838
Average Fuel Cost (Mills/Ton-Mile)		
Average Disutility (Mills/Ton-Mile)	28.22	29.38

TABLE B-2. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS - AVERAGE STATISTICS BY MODE AND BY NETWORK ELEMENT

	RAIL	HIGHWAY	WATER	PIPELINE
1972				
ACCESS LINKS				
Average Cost ($1/K TON)	1,708	2,149	1,686	53
Average Time (HRS/KTON)	20.51	6.49	43.28	18.11
Average Energy (BTU/KTON)	14,822	45,746	30,444	3,034
NODES				
Average Cost ($/KTON)	182	103	36	0
Average Time (HRS/KTON)	11.15	0.05	3.40	0
Average Energy (BTU/KTON)	2,301	3,008	868	0
LINE HAUL LINKS				
Average Cost (MILLS/TON-MILE)	6.82	37.03	3.55	2.22
Average Speed (MPH)	38.5	54.2	8.2	2.7
Average Energy (BTU/TON-MILE)	539	1,970.0	244	262
1990				
ACCESS LINKS				
Average Cost ($/TON)	1,731	2,141	1,682	54
Average Time (HRS/KTON)	19.60	6.54	47.47	18.45
Average Energy (BTU/TON)	14,238	45,012	27,541	3,090
NODES				
Average Cost ($/TON)	183	104	46	0
Average Time (HRS/KTON)	10.7	0.05	3.86	0
Average Energy (BTU/TON)	2,317	3,035	1,290	0
LINE HAUL LINKS				
Average Cost (MILLS/TON-MILE)	6.72	38.19	3.50	2.28
Average Speed (MPH	34.0	53.1	7.6	3.3
Average Energy (BTU/TON-MILE)	547	1,916	236	364

TABLE B-3. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS - TRAFFIC INCREASES BY MODE AND BY COMMODITY

	Δ BILLION TON-MILES '72-90						
	RAIL	HIGHWAY	WATER	PIPELINE	TOTAL Δ	1972 BASE	% INCREASE
1. Farm Products	+15	0	0	-	+15	99	15%
2. Forest and Marine Prod.	0	0	0	-	0	2	0
3. Coal	+50	0	-7	-	+43	149	29%
4. Crude Petroleum	+2	0	+17	+33	+52	178	29%
5. Metallic Ores	+1	0	+16	-	+17	26	65%
6. Minerals, Non-Metallic	+18	0	+5	-	+23	32	72%
7. Food and Kindred Prod.	+31	+5	0	-	+36	93	39%
8. Textiles and Apparel	0	+2	-	-	+2	8	25%
9. TOFC	+7	-	-	-	+7	14	50%
10. Chemicals	+76	+7	-1	-	+82	72	114%
11. Lumber and Furniture	+35	+3	0	-	+38	50	76%
12. Machinery Except Elec.	+6	+3	0	-	+9	10	90%
13. Elec. Machinery	+3	+6	-	-	+9	6	150%
14. Transportation Equip.	+5	+2	-	-	+7	9	78%
15. Unidentified Manufactures	+91	+15	+1	-	+107	151	71%
16. Paper and Allied Prod.	+21	+4	+3	-	+28	34	82%
17. Petroleum Products	+7	0	+19	-	+26	41	63%
18. Primary Metals	+7	0	0	-	+7	43	16%
19. Fabricated Metals	+9	+25	-	-	+34	14	243%
20. Miscellaneous Manuf.	+28	+13	0	-	+41	34	120%
ALL COMMODITIES Δ	+412	+85	+53	+33	+583	-	
1972 Base	600	195	105	167	-	1,067	
% Increase	69%	44%	50%	20%			55%

TABLE B-4. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS - 1972 AVERAGE COST MILLS/TON-MILE (INCLUDING FUEL COST)

	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	13.15	50.61	9.57	
2. Forest and Marine Prod.	12.70	-	21.13	
3. Coal	14.57	99.67	15.75	
4. Crude Petroleum	26.66	81.30	10.67	2.40
5. Metallic Ores	17.48	96.52	10.75	
6. Minerals, Non-Metallic	19.71	136.11	11.52	
7. Food and Kindred Prod.	15.30	53.34	16.25	
8. Textiles and Apparel	18.72	54.61	-	
9. TOFC	24.20	-	-	
10. Chemicals	12.65	52.65	9.43	
11. Lumber and Furniture	11.87	55.51	12.99	
12. Machinery Except Elec.	19.24	40.49	11.65	
13. Elec. Machinery	24.56	42.48	-	
14. Transportation Equip.	22.83	49.00	-	
15. Unidentified Manufactures	13.66	54.95	13.26	
16. Paper and Allied Prod.	15.59	49.20	16.00	
17. Petroleum Prod.	15.77	96.71	7.95	
18. Primary Metals	12.64	45.55	8.04	
19. Fabricated Metals	15.70	49.91	-	
20. Miscellaneous Manuf.	12.03	64.13	20.22	
ALL COMMODITIES	14.80	53.45	11.30	2.40

TABLE B-5. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-
'72-'90 1990 AVERAGE COST MILLS/TON-MILE

	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	12.70	51.24	9.85	
2. Forest and Marine Prod.	13.75	-	21.82	
3. Coal	12.93	100.61	14.47	
4. Crude Petroleum	26.83	117.02	8.43	2.47
5. Metallic Ores	19.73	90.63	8.14	
6. Minerals, Non-Metallic	19.09	128.67	11.00	
7. Food and Kindred Prod.	15.36	54.94	19.93	
8. Textile and Apparel	19.30	56.38	-	
9. TOFC	24.09	-	-	
10. Chemicals	12.96	54.77	9.32	
11. Lumber and Furniture	12.19	54.80	15.68	
12. Machinery Except Elec.	19.09	43.62	12.61	
13. Elec. Machinery	25.15	43.86	-	
14. Transportation Equip.	23.32	52.55	-	
15. Unidentified Manufactures	13.78	56.98	17.26	
16. Paper and Allied Prod.	15.71	51.08	13.62	
17. Petroleum Prod.	16.28	105.34	7.92	
18. Primary Metals	12.39	48.11	9.77	
19. Fabricated Metals	15.35	50.59	-	
20. Miscellaneous Manuf.	11.97	65.19	18.67	
ALL COMMODITIES	14.46	55.26	10.07	2.47

Note: (Including '72 Fuel Cost but Excluding Fuel Cost Increases)

TABLE B-6. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-'72-'90
Δ AVERAGE COST MILLS/TON-MILE OTHER THAN FUEL

	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	-0.45	0.63	0.28	
2. Forest and Marine Prod.	1.05	-	0.69	
3. Coal	-1.64	0.94	-1.28	
4. Crude Petroleum	0.17	35.72	-2.24	0.07
5. Metallic Ores	2.25	-5.89	-2.61	
6. Minerals, Non-Metallic	-0.62	-7.44	-0.52	
7. Food and Kindred Prod.	0.06	1.60	3.68	
8. Textiles and Apparel	0.58	1.77	-	
9. TOFC	-0.11	-	-	
10. Chemicals	0.31	2.12	-0.11	
11. Lumber and Furniture	0.32	-0.71	2.69	
12. Machinery Except. Elec.	-0.15	3.13	0.96	
13. Elec. Machinery	0.59	1.38	-	
14. Transportation Equip.	0.49	3.55	-	
15. Unidentified Manufactures	0.12	2.03	4.00	
16. Paper and Allied Prod.	0.12	2.88	-2.38	
17. Petroleum Prod.	0.51	8.63	-0.03	
18. Primary Metals	-0.25	2.56	1.73	
19. Fabricated Metals	-0.35	0.68	-	
20. Miscellaneous Manuf.	-0.06	-1.06	-1.55	
ALL COMMODITIES	-0.34	1.81	-1.23	0.07

TABLE B-7. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-AVERAGE FUEL COST MILLS/TON-MILE 1972 (@ $0.12 GAL)

	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	0.50	2.04	0.29	
2. Forest and Marine Prod.	0.53	-	0.51	
3. Coal	0.40	2.62	0.45	
4. Crude Petroleum	0.66	2.45	0.23	0.24
5. Metallic Ores	0.48	2.84	0.34	
6. Minerals, Non-Metallic	0.49	4.33	0.34	
7. Food and Kindred Prod.	0.64	1.88	0.40	
8. Textiles and Apparel	0.96	2.14	-	
9. TOFC	1.00	-	-	
10. Chemicals	0.50	1.97	0.34	
11. Lumber and Furniture	0.60	2.16	0.45	
12. Machinery Except Elec.	0.96	1.84	0.33	
13. Elec. Machinery	1.19	1.91	-	
14. Transportation Equip.	0.92	2.23	-	
15. Unidentified Manufactures	0.53	2.02	0.36	
16. Paper and Allied Prod.	0.64	1.95	0.46	
17. Petroleum Prod.	0.48	3.07	0.27	
18. Primary Metals	0.50	1.92	0.27	
19. Fabricated Metals	0.72	2.00	-	
20. Miscellaneous Manuf.	0.50	2.31	0.45	
ALL COMMODITIES	0.53	2.02	0.34	0.24

TABLE B-8. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-AVERAGE FUEL COST MILLS/TON-MILE 1990 (@ $0.337 /GAL)

	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	1.40	5.51	0.86	
2. Forest & Marine Prod.	1.48	-	1.47	
3. Coal	0.98	7.40	1.19	
4. Crude Petroleum	1.86	6.85	0.81	0.91
5. Metallic Ores	1.44	7.19	0.74	
6. Minerals, Non-Metallic	1.41	11.52	0.90	
7. Food and Kindred Prod.	1.81	5.22	1.26	
8. Textiles and Apparel	2.78	5.93	-	
9. TOFC	2.82			
10. Chemicals	1.43	5.47	0.86	
11. Lumber and Furniture	1.69	5.96	1.17	
12. Machinery Except Elec.	2.68	5.05	0.94	
13. Elec. Machinery	3.39	5.13		
14. Transportation Equip.	2.64	5.98		
15. Unidentified Manufactures	1.50	5.54	1.19	
16. Paper and Allied Prod.	1.83	5.23	1.13	
17. Petroleum Prod.	1.40	8.62	0.76	
18. Primary Metals	1.41	5.25	0.87	
19. Fabricated Metals	2.04	5.54		
20. Miscellaneous Manuf.	1.42	6.23	1.02	
ALL COMMODITIES	1.50	5.55	0.88	0.91

TABLE B-9. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-
Δ AVERAGE FUEL COST MILLS/TON-MILE '72-'90 (12¢/GAL → 33.7 ¢/GAL)

		RAIL	HIGHWAY	WATER	PIPELINE
1.	Farm Products	0.90	3.47	0.57	
2.	Forest and Marine Prod.	0.95	-	1.06	
3.	Coal	0.58	4.78	0.64	
4.	Crude Petroleum	1.20	4.40	0.58	0.67
5.	Metallic Ores	0.96	4.35	0.40	
6.	Minerals, Non-Metallic	0.92	7.19	0.56	
7.	Food and Kindred Prod.	1.17	3.34	0.86	
8.	Textiles and Apparel	1.82	3.79	-	
9.	TOFC	1.82	-	-	
10.	Chemicals	0.93	3.50	0.52	
11.	Lumber and Furniture	1.09	3.80	0.72	
12.	Machinery Except Elec.	1.72	3.21	0.59	
13.	Elec. Machinery	2.20	3.22	-	
14.	Transportation Equip.	1.72	3.75	-	
15.	Unidentified Manufactures	0.97	3.52	0.83	
16.	Paper and Allied Prod.	1.19	3.28	0.67	
17.	Petroleum Prod.	0.92	5.55	0.49	
18.	Primary Metals	0.91	3.33	0.60	
19.	Fabricated Metals	1.32	3.54	-	
20.	Miscellaneous Manuf.	0.92	3.92	0.57	
	ALL COMMODITIES	0.97	3.53	0.54	0.67

TABLE B-10. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-UNCONSTRAINED 1972 ENERGY INTENSIVENESS (BTU/NET TON-MILE)

		RAIL	HIGHWAY	WATER	PIPELINE
1.	Farm Products	581	2,362	340	
2.	Forest and Marine Products	576	-	570	
3.	Coal	458	3,291	519	
4.	Crude Petroleum	757	2,330	268	272
5.	Metallic Ores	562	2,940	397	
6.	Minerals, Non-Metallic	573	5,267	395	
7.	Food and Kindred Prod.	745	2,175	476	
8.	Textiles and Apparel	1,106	2,472	-	
9.	TOFC	1,153	-	-	
10.	Chemicals	579	2,292	388	
11.	Lumber and Furniture	694	2,511	457	
12.	Machinery Except Elec.	1,115	2,150	365	
13.	Elec. Machinery	1,354	2,223	-	
14.	Transportation Equip.	1,060	2,568	-	
15.	Unidentified Manufactures	610	2,336	415	
16.	Paper and Allied Prod.	744	2,263	544	
17.	Petroleum Products	554	3,850	318	
18.	Primary Metals	579	2,220	318	
19.	Fabricated Metals	841	2,313	-	
20.	Miscellaneous Manuf.	580	2,671	506	
	ALL COMMODITIES	618	2,335	391	272

TABLE B-11. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-
1990 ENERGY INTENSIVENESS (BTU/NET TON-MILE)

	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	577	2,272		
2. Forest and Marine Prod.	612			
3. Coal	404	3,053	490	
4. Crude Petroleum	768	2,825	335	375
5. Metallic Ores	593	2,967	304	-
6. Minerals, Non-Metallic	582	4,750	370	-
7. Food and Kindred Prod.	745	2,155	522	-
8. Textiles and Apparel	1,145	2,445	-	-
9. TOFC	1,164	-	-	-
10. Chemicals	590	2,258	355	-
11. Lumber and Furniture	698	2,457	482	-
12. Machinery Except Elec.	1,105	2,084	390	
13. Elec. Machinery	1,400	2,115	-	-
14. Transportation Equip.	1,088	2,469	-	-
15. Unidentified Manufactures	618	2,284	490	-
16. Paper and Allied Prod.	756	2,158	466	-
17. Petroleum Prod.	579	3,557	314	-
18. Primary Metals	582	2,164	359	-
19. Fabricated Metals	840	2,284	-	-
20. Miscellaneous Manuf.	584	2,569	420	-
ALL COMMODITIES	621	2,291	361	375
Δ1972-1990 (Change from 1972)	+3	-44	+30	103

TABLE B-12. CACI/DOT PHYSICAL NETWORK MODE SHARE MODEL RESULTS-RELATIVE MODAL ENERGY INTENSIVENESS (RATIO OF BTU/NET TON-MILE)

	1972				1990			
	RAIL	HIGHWAY	WATER	PIPELINE	RAIL	HIGHWAY	WATER	PIPELINE
1. Farm Products	1.0	4.06	0.58	-	1.0	3.94	0.61	
2. Forest and Marine Prod.	1.0	-	0.99	-	1.0	-	0.99	
3. Coal	1.0	7.18	1.13	-	1.0	7.56	1.21	
4. Curb Petroleum	1.0	3.08	0.35	0.36	1.0	3.68	0.44	0.49
5. Metallic Ores	1.0	5.23	0.71	-	1.0	5.00	0.51	-
6. Minerals, Non-Metallic	1.0	9.19	0.69	-	1.0	8.16	0.64	-
7. Food and Kindred Prod.	1.0	2.92	0.64	-	1.0	2.89	0.70	-
8. Textile and Apparel	1.0	2.24	-	-	1.0	2.14	-	-
9. TOFC	1.0	-	-	-	1.0	-	-	-
10. Chemicals	1.0	3.96	0.67	-	1.0	3.83	0.60	-
11. Lumber and Furniture	1.0	3.62	0.66	-	1.0	3.52	0.69	-
12. Machinery Except Elec.	1.0	1.93	0.33	-	1.0	1.88	0.35	-
13. Elec. Machinery	1.0	1.64	-	-	1.0	1.51	-	-
14. Transportation Equip.	1.0	2.42	-	-	1.0	2.27	-	-
15. Unidentified Manufactures	1.0	3.83	0.68	-	1.0	3.70	0.79	-
16. Paper and Allied Prod.	1.0	3.04	0.73	-	1.0	2.85	0.62	-
17. Petroleum Prod.	1.0	6.95	0.57	-	1.0	6.14	0.54	-
18. Primary Metals	1.0	3.83	0.55	-	1.0	3.72	0.62	-
19. Fabricated Metals	1.0	2.75	-	-	1.0	2.72	-	-
20. Miscellaneous Manuf.	1.0	4.60	0.87	-	1.0	4.40	0.72	-
ALL COMMODITIES	1.0	3.78	0.63	0.36	1.0	3.69	0.58	0.49

APPENDIX C

MIT/DOT/FEA CITY-PAIR LOGISTICS MODEL RESULTS

TABLE C-1. MIT/DOT/FEA CITY-PAIR LOGISTICS MODEL RESULTS-TON-MILES BY MODE BY CITY-PAIR-MILLIONS

SCENARIOS	MODES	CLEVF. TO PHILA.	PHILA. TO CLEVE.	HOUS. TO CHIC.	CHIC. TO HOUS.	LOS ANG. TO SAN FRAN.	SAN FRAN. TO LOS ANG.	TOTAL
		(426 MILES)		(1280 MILES)		(383 MILES)		
BASE CASE	TOFC	1	0	71	38	121	105	336
	RAIL CARLOAD	53	54	209	142	82	71	611
	HIGHWAY	146	98	123	126	734	643	1,870
IMPROVED TOFC	TOFC	33	27	276	133	287	282	1,030
	RAIL CARLOAD	37	42	45	58	66	38	286
	HIGHWAY	128	84	82	115	584	503	1,496
DOUBLE 40s	TOFC	0	0	54	31	11	12	108
	RAIL CARLOAD	29	23	71	74	20	7	224
	HIGHWAY	170	129	278	201	906	802	2,486
IMPROVED TOFC AND DOUBLE 40s	TOFC	29	24	136	67	144	160	560
	RAIL CARLOAD	16	16	35	56	20	7	150
	HIGHWAY	154	112	231	182	773	653	2,105

Source: Developed from preliminary results of M.I.T. Study documented in Ref. 14

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