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ENERGY AND ECONOMIC IMPACTS OF PROJECTED FREIGHT TRANSPORTATION IMPROVEMENTS

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16. Abstract

This study examines current and future energy impacts for each major freight mode, by commodity, and, in many cases, by vehicle types. It also discusses potential economic impacts of these anticipated changes. The study is limited to intercity freight movements of both private and for-hire carriers. The study includes a determination of base case energy scenarios for 1972, 1980, and 1985 to serve as a basis for evaluating operational and technological impacts by 1980 and 1985 for an industry change scenario (in which industry is likely to implement changes on its own), and the government influence scenario (where changes could be accelerated by changes in economic and regulatory policies). Much of the data and findings contained in this study represent original research, but based on a relatively incomplete national data base. The report discusses in detail operational and technological changes which will have energy and economic impacts on each of the freight modes included in the report. Greater emphasis was given to intercity freight transportation by truck and railroad, with less emphasis on inland, coastal, and great lakes movements, pipelines and air freight.

17. Key Words Freight energy usage, transportation energy impacts, transportation energy conservation, truck/railroad/water/pipeline/air energy usage, freight transportation improvements

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PREFACE

In anticipation of the need for government to promote energy conservation in freight transportation, a better understanding of energy consumption characteristics within each mode of the freight transportation industry is necessary to assess the sensitivity and impacts of projected operational and technological change. To develop a better understanding of energy and economic impacts of these changes and how national interests can be promoted by changes in federal policies, the Transportation Systems Center awarded a contract to Peat, Marwick, Mitchell & Co. (PMM&Co.) to assess scenario alternatives for 1980 and 1985. PMM&Co. was assisted by Battelle Columbus Laboratories in the preparation of the data base, development of a computer model to systematically prepare scenario impacts (given different input assumptions), and assessment of the meaning of the results. Mr. Alan Cripe, an engineer and energy consultant, provided extensive technical assistance in evaluating vehicle energy requirements and the impact of changes. In addition to the help provided by many people in the transportation industry, PMM&Co. wishes to acknowledge the assistance of the American Trucking Association, the Association of American Railroads, and the National Waterways Conference, Inc. for their review and comments on this study.

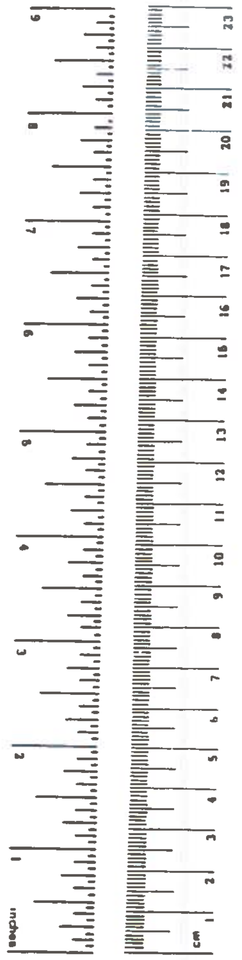
Consistent with our past experience in analyzing energy consumption in freight transportation, this study was somewhat handicapped by a lack of good source data from which to develop reliable energy consumption figures in the level of detail desired. For this reason, the accuracy and reliability of some estimates may be low. Where this is true, it reinforces the need to systematically collect base-data information in much the same manner that national economic sector data are collected.

Nevertheless, this study provides an extensive level of detail of estimated energy consumption in all modes of freight transportation, by commodity, and in many cases even vehicle types. It cannot be overemphasized that the accuracy and reliability of these detailed numbers decreases with lower levels of disaggregation. In any event, this study provides a wealth of original data and information upon which to construct additional research efforts to improve the understanding of energy consumption and energy conservation alternatives in freight transportation. The information contained in this report, when used in its proper perspective, can be helpful to government and industry planners in preparing policy changes that promote the national interest, yet preserve the economic and competitive structure of our nation's excellent freight transportation system.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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

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EXECUTIVE SUMMARY

STUDY OBJECTIVES AND SCOPE (SECTION 1)

Section 1 of this report provides an overview of the study. The general objectives of this study were to assess current and future energy usage for each major freight mode by major commodity and to identify potential economic impacts of anticipated changes in freight systems under varying assumptions about freight transportation for 1980 and 1985. This study has attempted to probe deeper into energy consumption characteristics by transportation mode, by commodity, and even by certain vehicle types than any previous published study. Information sources were limited to previous studies, existing data bases of energy consumption and freight transportation, theoretical energy consumption relationships, transportation characteristics as determined from federal statistics summaries, and trade publications of industry associations. This information was supplemented by interviews with people in the freight transportation industry and its associations. This study provides the best available information on freight energy consumption characteristics and their potential changes in future years. However, much of the data used in this study cannot be verified and many of the study determinations are based on judgment assumptions. Specific limitations include:

> Census of Transportation data are the prime source for nonregulated truck fuel estimates and other selected motor carrier transportation estimates.
>
> Although railroads appear to be statistically more fuel efficient on a net ton-mile basis than motor carriers, it cannot be assumed that the use of railroads in lieu of motor carriers results in fuel savings or that it is necessarily economically desirable and in the nation's best interest. A similar limitation exists when comparing rail versus water.
>
> Data sources for other modes, particularly water and pipeline, are incomplete and their reliability may be questioned.

Base case data were computed for 1972 (adjusted for 55 miles per hour speed limits) and projected to 1980 and 1985 with the assumption that no energy conservation measures would be implemented beyond 1972 levels. Projections for 1980 and 1985 include scenarios for "industry changes" assumptions, i.e., past trends in energy conservation will continue and transportation carriers will implement other operational and technological changes without new incentives or other stimulus. Other scenarios for 1980 and 1985 were based on a series of government incentive and regulation assumptions that relate to the implementation of new or additional operational and technological changes. Data for the scenarios described above were entered into an intercity freight transportation energy consumption model (TRANSEN), which systematically details energy consumption and energy intensiveness patterns for the base year and projected scenarios based on specific data inputs, assumptions, and energy use relationships.

Basic projections of traffic growth are assumed to closely follow the historical trend of constant dollar growth in the gross national product.

INTERCITY FREIGHT TRANSPORTATION ENERGY MODEL FRAMEWORK (SECTION 2)

Energy impact scenarios were developed for the following specific modes:

trucks;

railroads;

inland waterways (non-self-propelled vessels);

coastal and Great Lakes ships (self-propelled and non-self-propelled vessels);

pipelines; and

air freight.

Freight was divided into 19 commodity categories based on combinations of major two-digit standard transportation commodity code groupings. Energy conservation measures addressed in this study included only the impacts of operational change, technological change, and modal shift from motor carriers to rail. Changes in freight characteristics, markets, industry location, etc., were not included.

An analysis of the energy conservation impacts of different operational and technological changes and policy options requires an understanding of how traffic and transportation operating characteristics are translated to energy consumption. To analyze the multiplicative impact of many different alternatives and opportunities, PMM&Co. and Battelle developed the TRANSEN model, which converts traffic data by commodity and mode to energy consumption estimates. The model relates transportation performance parameters to energy utilization, which permits analysis of the way in which changes in operating conditions and technology affect transportation performance and, consequently, energy consumption. The model calculates energy intensity values for each mode under input conditions relating to operating practices and technology in use. The model is not deterministic but is a descriptive tool which analyzes the impacts of alternative operating policies and uses of technological improvements to alter the energy intensity of different modes.

Truck

For truck movement, variations in fuel consumption by commodity group reflect differences in truck-fleet makeup to carry each commodity as well as differences in commodity density. Truck-mile estimates by commodity group and truck type form the basis for the fuel consumption calculations. To develop the necessary truck data base, vehicle miles for commodity group categories were allocated based on statistics for Class I common and contract carriers. A second adjustment to truck-mile data involved defining the study truck-type categories and then classifying vehicle-miles by commodity according to truck types. The combination of three body types, five weight classes, and two fuel types resulted in 24 generalized truck types.

To estimate load capacity for each truck category, tare and gross vehicle weights were estimated for representative trucks in each category. Fuel consumption rates were calculated based on handbook formulas.

Because of the lack of data on motor carrier tonnage by commodity group shipped by truck in intercity service, a two-stage procedure was also used to estimate truck tons by commodity. The first stage involved developing estimates from information in the Census of Transportation Commodity Survey. The second stage involved modifying and extending that estimate by multiple regression analysis against ICC commodity statistics for regulated carriers.

The product of estimated average hauls times tons by commodity group produced some values which were inconsistent with vehicle ton-mile capacity estimates. Therefore, to assure consistency between data obtained from independent sources, some adjustments to data were made, as discussed in Appendix A.

Railroads

Energy intensity for railroad movements differs for each of the 19 commodity groups because of variations in load per car, length of haul, and the mix of equipment used to transport each commodity. Thus energy intensity was estimated for rail movements by commodity for seven car-type categories. Because of regulatory reporting requirements, statistical information in the railroad industry was superior to all other modes and provided the study team with control totals to reconcile energy statistics and traffic statistics.

Inland Waterways

Since energy consumption varies for different waterway systems due to differences in the number of locks and dams, water current speed, and the size of tows, the inland-waterway system was divided into six segments. The average length of haul per ton was developed by dividing reported ton-miles by reported tons. Subsequent commodity specific average haul values for each waterway were estimated and adjusted so that the sum of ton-miles on each waterway equalled the national total. The modified Howe Formula (see Appendix C) was used to calculate water speed under a variety of tow configurations and towboat horsepower. Then, using brake-horsepower specific fuel consumption factors, it was possible to estimate energy consumption for specified average waterway current velocity, miles traveled, allowances for locking and other delays, towboat horsepower, draft per tow, engine load factor, length and width of tow, tons per tow, channel depth, channel width, and number of locks per mile by waterway.

Coastal and Great Lakes Shipping

An accurate analysis of coastal shipping was extremely difficult because of the lack of summary data on ships engaged in coastal trade and the intermingling of international with domestic cargos on many ships. The methods and assumptions for this transportation sector are based on available published data and are intended to give a general indication of this mode in relation to other modes and to permit analysis of the effects of changes in speed and ship size on energy consumption. Three typical ship types were selected for analysis: dry bulk, break bulk, and tanker. The procedures used to estimate energy consumption are similar for ships and for barges. The keys to energy consumption are running hours per trip, tons, horsepower hours, and idle time.

Pipelines

To estimate energy consumed for crude and products pipelines movements, the following information was used:

> barrels per day by products and crude;
>
> average length of haul per barrel (ratio of annual barrel-miles to annual barrels);
>
> miles of pipeline for products and crude by pipeline size;
>
> inside diameters by pipeline size;
>
> barrels per ton for products and crude; and
>
> friction factors.

A value for energy conversion efficiency was estimated based on the efficiency of the four types of pumping stations involved in pipeline transportation: electric motors, gas turbine, liquid fuel turbine, and diesel engine. For this study, a level of 30 percent was selected for pipeline thermal energy conversion efficiency.

The most sensitive assumption in pipeline methodology was that for a particular commodity (i.e., product or crude) and pipeline size, a single velocity figure was used. In spite of numerous discussions with industry experts and a search of the literature, no good estimates of weighted average pumping velocities could be found. Because pipeline resistance per unit of measure decreases significantly with large diameter, a low "nominal" velocity was assumed for a 2-inch line, and a higher "nominal" velocity assumed for a 48-inch line, with linear interpolation applied to pipeline diameters in between.

Air Cargo

Air cargo moves in all cargo aircraft or in the underbelly of passenger aircraft. The energy intensity for cargo moving in passenger aircraft was computed based on two alternative assumptions:

> Marginal Approach - Passenger aircraft will move with or without cargo since its primary purpose is to transport passengers. Thus freight should bear only the incremental fuel usage associated with the weight of the freight itself.

Pro-Rata Approach - The cargo in passenger aircraft consumes its weight-proportional share of the energy used in flight.

The basis for calculating energy intensity is the distribution of tons by commodity. The energy values selected for the TRANSEN model calculations were based on load factor and stage-length assumptions corresponding to the aircraft mix included in the study. No allowances were made for ground movements associated with air freight.

Summary

The summary of 1972 base case traffic and energy statistics is included in Table 1, for each of the different modes included in the study.

ENERGY CONSERVATION MEASURES (SECTION 3)

Research and interviews with motor carrier industry experts suggest that as long as fuel is readily available, radical operating changes are not likely to occur in the next 10 years in trucking. Progress is expected to be evolutionary and to center on reducing circuity and empty truck-miles and improving trip productivity (net tons per truck-mile). The fleet mix of truck sizes is not expected to vary significantly except that, when possible, trailer size is expected to continue to increase due to increased legal limits. The three factors which could result in energy conservation through operating changes include changes in:

capacity utilization (both proportion of truck capacity utilized and proportion of total truck miles operated with load);

speed; and

fleet makeup.

For a given capacity utilization factor, fuel consumption will be greater if the proportion of empty miles is increased and the load factor is correspondingly decreased. This is because fuel consumption increases at a marginally lower rate with increases in load, while back-haul fuel consumption varies directly with the number of empty vehicle-miles. At low speeds, rolling resistance of trucks is greater

TABLE 1

SUMMARY OF 1972 BASE CASE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS ($x10^6$)	AVERAGE HAUL PER TON (Miles)	NET TON-MILES ($x10^9$)	TOTAL BTUs ($x10^{12}$)	BTUs PER NET TON (1) ($x10^3$)	BTUs PER NET TON-MILE (1)
Truck	1,525	238	363	850	557	2,343
Rail	1,447	523	756	519	370	687
Inland Waterway	507	350	177	48	96	272
Coastal & Great Lakes Ship	384	1,095	420	70	264	226
Coastal & Great Lakes Barge				17	211	281
Pipeline (4)	879	414	363	102	116	158
Air	2	620	2	21 (2) 60 (3)	8,782 (2) 24,726 (3)	14,188 (2) 39,949 (3)
Total/Average	4,744	439	2,081	1,665 (3)	351 (3)	800 (3)

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

than air resistance. At a speed of approximately 70 miles an hour, air resistance is roughly equal to rolling resistance for a large, fully loaded truck (and greater for a smaller truck with approximately the same frontal area). As a general rule, energy efficiency per net ton-mile increases with vehicle size (capacity). For instance, switching from a 57,500-pound gross vehicle weight, 40-foot semi-trailer to a 73,280-pound gross vehicle weight, 27-foot twin trailer for light and bulky freight can save approximately 2,800 gallons of diesel fuel per million net ton-miles, or 386 Btus per ton-mile.

Changes in truck technology include:

engine optimization;

parasitic-load reduction;

drive-train optimization; and

aerodynamic improvements.

Engine optimization involves choosing an engine size that satisfies service requirements while operating at the lowest possible fuel consumption rate. It is a relatively common practice in the motor carrier industry to overpower trucks to improve acceleration, speed, hill-climbing ability, and engine life. With the increasing cost of energy, motor carriers are becoming more cognizant of the benefits to be achieved by reducing engine size and power to more closely match service requirements.

Many engine accessories are driven directly from truck engines with no intermediate modulating device. Others are indirectly powered using electricity generated by the alternator. Of all the parasitic loads, the engine fan draws the most power--as much as 36 horsepower for a large engine at highway speeds. Since this cooling power is needed only rarely, a potential savings of 8 percent can be realized with the use of fan clutches. Since 1973, the use of clutched fans has become quite common.

Drive train optimization includes the use of transmissions that permit the engine to operate at its optimum speed and throttle range over a wide variety of operating conditions. Radial tires, as the final link of the drive train, can also contribute significantly in reducing energy consumption compared to conventional bias-ply tires.

The most significant technological truck fuel-efficiency improvement is aerodynamic streamlining. Opportunities range from simple cabmounted air foils to complete streamlining of tractor and trailer, including a flexible diaphragm between the tractor and trailer to reduce air turbulence. Energy savings up to 30 percent at highway speeds can be realized with a fully aerodynamically streamlined truck.

Rail

A number of operating changes can be instituted by railroads to save energy, including:

reductions in circuity;

reductions in empty backhauls;

increases in load per car;

reductions in operating speeds;

reductions in delays and stops;

changes in train configuration;

reductions in yard handling;

reductions in locomotive idling;

elimination of cabooses; and

tighter control of fuel use and accounting.

Average circuity of rail movements is estimated to be between 11 and 18 percent of published-tariff short routes. Eliminations of circuitous routings save energy directly proportionate to the number of circuitous miles eliminated. Such high circuity exists in the railroad industry because shippers can often specify competitive routings other than the short-haul carrier, and many carriers which originate traffic attempt to keep cars on line for the greatest distance to maximize divisions of revenue. Cars returning empty often move via reverse routing instead of the most direct route back to the owning road. Reduction in circuity is an industry problem which should best be attacked on an industry basis.

Many empty backhauls are not incurred because of traffic imbalances, but because of restrictions applicable to equipment now owned by an originating carrier. Car-service rules require that certain types of equipment be returned home empty, regardless of the opportunity to load that car in a direction towards the owning carrier (unless permission is first obtained from that owner). The trend to empty backhauls is increasing due to greater use of specialized equipment, which is subject to special rules and is less suitable for general-commodities loading. The increasing use of dedicated equipment and private-line equipment also contributes to increased empty backhaul. By attacking the many problems which cause empty backhaul, the industry could possibly significantly reduce empty backhaul and improve equipment utilization. This major problem is now being studied by the industry and the Association of American Railroads.

The benefit of increased load per car is similar to the benefits of increasing load factor in motor carriers.

Reductions in line speed can be accomplished by reducing the horsepower per gross-ton ratio, which results in the need for fewer locomotives and a general overall increase in net tons to gross-tons ratio. Since so much of transit time from origin to destination is consumed in yards and terminals, reductions of times spent in these areas can reduce the need for high line speeds and preserve schedule connections and customer service.

The elimination of avoidable slow orders, delays, and stops will reduce the need to accelerate and decelerate trains (as well as save time) with some attendant savings in energy. In today's railroads, crew districts approximately 100 miles in length are no longer necessary, but are a holdover from steam-engine days.

In some cases, changes in train composition or configuration to provide a more uniform, aerodynamically smooth shape can contribute to energy savings. Although this may not be practical in most cases due to blocking requirements, this area has not received attention in the past. Computer simulation studies have shown that for a 30-car TOFC train with four empty spaces, up to 6 percent more energy may be required than if the train were fully loaded.

Yard operations currently consume approximately 11 percent of total railroad transportation fuel. Reducing yard handling requirements can save energy. Energy saving steps include:

increasing use of run-through trains and eliminate intermediate blocking requirements;

reducing handling within terminals;

increasing flexibility between line and yard crews for industry switching activities;

reducing special handling of shipments;

improving planning and supervision; and

modernizing and consolidating yards and terminals.

It is estimated that approximately 2.4 percent of transportation fuel is consumed by idling locomotives. Diesel engines are typically left running to avoid coolant freezing in winter, potential engine damage by moisture condensation within cylinders, and thermal stress to the engine block. Engine damage can be prevented by adherence to proper operating procedures when starting diesels and the use of block heaters in cold weather.

The value of the caboose in today's railroad environment has diminished. The use of improved signaling on high-speed main lines and the technological development and improvement of wayside detection devices has reduced the need for human observation of the rear of a train for protection from following trains. European roads and the Florida East Coast Railroad operate successfully without the use of cabooses. Elimination of cabooses on today's trains could save 1 to 2 percent of transportation fuel.

Tighter control of fuel accounting and use can reduce losses due to undelivered fuel, misuse, and theft.

Technological improvements in railroad transportation include:

locomotive streamlining;

car tare-weight reduction;

car streamlining;

other changes in car technology; and

electrification.

Wind resistance at 40 to 70 miles an hour consumes from 6 to 20 percent of the horsepower output of a modern, 3,000-horsepower, diesel-electric locomotive. Previous studies have shown that this wind resistance can be reduced by up to 50 percent by streamlining. Other possible technological improvements that could save energy include automatic locomotive control which takes units "off the line" when not needed, the increased use of turbo-chargers (already 10 percent on high-horsepower road locomotives), and additional clutching mechanisms for parasitic loads (such as air compressors).

Although railroading in the United States is significantly different from that in Europe, many U.S. railroads operate high-speed trains where locomotive weight is not essential. In high-speed operating situations, locomotives of reduced weight could conserve energy. In heavy-drag service, weight is essential for tractive effort at low speeds. Improved wheelslip control devices can reduce the weight needed for traction by improving the effective-adhesion ratio.

Freight-car streamlining and weight reduction can contribute to significant energy savings ranging up to 20 percent on empty car movements. Other areas currently being researched include technological improvements to reduce truck "hunting" (oscillations which increase wheel/track friction and wear) and devices to help steer trucks in curves.

Electrification is an alternative only because it reduces dependence on the use of petroleum fuels. However, the overall thermal efficiency of electrification is not significantly different from the thermal efficiency of a diesel-electric locomotive. In heavy-grade territory or where substantive regeneration can be achieved (such as where frequent starts and stops are made), electrification could save energy.

Inland Waterways

Operating changes in the inland waterways are highly dependent on technological changes to the waterway systems, locks, and dams. Larger tows at optimized speeds (influenced by river current) are not always practical. Because of the already relatively efficient modal use of energy, potential operational and technological changes in the inland waterways were not assumed to be overly significant.

Coastal and Great Lakes Shipping

Potential operating and technological changes in this transportation mode were not examined and are assumed to be relatively insignificant in terms of energy conservation potential by 1980 and 1985.

Pipelines

Improvements to pipeline energy efficiency can occur by reduced pumping velocities over longer periods of time, larger diameter of pipes, and a continued shift towards more efficient turbine-driven pumps. No significant operating or technological improvements were assumed for this mode by 1980 and 1985.

Air Cargo

Operational and technological changes in air freight include the use of larger aircraft with larger load factors, use of turboprop aircraft at slower speeds, higher-altitude flights, and use of smaller aircraft where load factors cannot be increased.

Because energy costs are such a large portion of air freight costs, it is anticipated that airlines will be making substantial reductions to energy intensities of air freight in the next 10 years. Because the total volume of energy consumed in air freight is so small relative to other modes, however, a thorough review of the potentials by 1985 was not conducted.

Modal Shifts

Some freight shipments by virtue of shipment size, length of haul, and nature of origin and destination served, could reasonably move by either truck or rail. Service and economics are generally governing factors. In some cases, railroads could be in a position to provide line-haul service to motor carriers at an advantage to both with the potential additional benefits of energy savings. Growth in intermodal movements can be encouraged by:

> operating cost reductions in terminal areas (such as by dedicated shuttle TOFC trains);
>
> joint marketing efforts on the part of rail carriers and motor carriers to achieve mutual benefits;
>
> potential governmental assistance in expanding TOFC/COFC capabilitites and facilities; and
>
> regulatory reforms to encourage intermodal coordination.

The greatest opportunity for intermodal cooperation lies in traffic moving over 400 miles. One study estimated that only 4 percent of potential motor carrier freight moving in the 400- to 1,200-mile range was actually moving by TOFC/COFC.

ENERGY CONSERVATION SCENARIOS (SECTION 4)

Section 3 of this report describes a series of scenarios which project freight transportation and energy consumption by each freight transportation mode in 1980 and 1985 under varying conditions of energy conservation. The section combines energy conservation measures discussed in Section 3 to evaluate the relative potential energy impacts in each mode under assumed rates of implementation. Given the amount and quality of data available, we believe the assumptions contained in this study to be a reasonable expectation for the future. We also believe that the findings and determinations can be improved upon as better, more reliable data become available and perhaps as clearer industry trends develop.

For each mode, three sets of scenarios were developed:

projections which assume increases in traffic consistent with expected growth of the economy with no changes in 1972 levels of energy efficiency or modal shifts;

projections which assume that each transportation mode will implement changes to conserve energy (relative to 1972 energy intensity levels), and that there is some modal shift between truck and rail; and

projections which assume government influence (voluntary or involuntary) to achieve greater energy conservation measures over and above what industry would do without government incentives.

Tables 2 through 8 provide a summary for each of the scenarios in 1980 and 1985 traffic and energy statistics. Since adjustments for different circuity factors that are peculiar to each mode are excluded, direct comparisons between modes are not appropriate. The nature of the product transported, the type of service rendered, and the service (average haul) are different for each mode. Details for each of the 19 study commodities by mode are contained in Section 3. Modal comparisons by commodity may be more relevant than whole industry comparisons except that these comparisons should include adjustments for circuity, shipment size, length of haul, and consider quality of service rendered.

TABLE 2

SUMMARY OF 1980 BASE CASE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS (x10^6)	AVERAGE HAUL PER TON (Miles)	NET TON-MILES (x10^9)	TOTAL BTUs (x10^{12})	BTUs PER NET TON (1) (x10^3)	BTUs PER NET TON-MILE (1)
Truck	2,282	238	543	1,246	546	2,294
Rail	2,130	522	1,111	760	357	684
Inland Waterway	746	350	261	74	99	278
Coastal & Great Lakes Ship	619	1,052	651	110	253	226
Coastal & Great Lakes Barge				25	209	274
Pipeline (4)	1,261	414	522	147	116	281
Air	4	605	2	32 (2) 95 (3)	8,267 (2) 24,650 (3)	13,667 (2) 40,753 (3)
Total/Average	7,042	439	3,090	2,457 (3)	349 (3)	795 (3)

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

TABLE 3

SUMMARY OF 1980 INDUSTRY CHANGE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS $(x10^6)$	AVERAGE HAUL PER TON (Miles)	NET TON-MILES $(x10^9)$	TOTAL BTUs $(x10^{12})$	BTUs PER NET TON (1) $(x10^3)$	BTUs PER NET TON-MILE (1)
Truck	2,179	232	506	1,071	492	2,119
Modal Shift (Truck to TOFC/COFC)	103	352	37	58	559	1,589
Rail	2,130	517	1,101	668	314	617
Inland Waterway	746	350	261	70	94	265
Coastal & Great Lakes Ship }	619	1,052	651	108	252	225
Coastal & Great Lakes Barge }				25	206	271
Pipeline (4)	1,261	414	522	138	110	265
Air	4	605	2	{ 31 (2) { 93 (3)	8,072 (2) 24,211 (3)	13,345 (2) 40,028 (3)
Total/Average	7,042	437	3,080	2,232 (3)	317 (3)	725 (3)

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

TABLE 4

SUMMARY OF 1980 GOVERNMENT INFLUENCE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS ($x10^6$)	AVERAGE HAUL PER TON (Miles)	NET TON-MILES ($x10^9$)	TOTAL BTUs ($x10^{12}$)	BTUs PER NET TON (1) ($x10^3$)	BTUs PER NET TON-MILE (1)
Truck	2,127	229	487	992	466	2,036
Modal Shift (Truck to TOFC/COFC)	1,055	352	54	79	515	1,462
Rail	2,130	514	1,095	624	293	570
Inland Waterway	746	350	261	70	94	265
Coastal & Great Lakes Ship	619	1,052	651	108	252	225
Coastal & Great Lakes Barge				25	206	271
Pipeline (4)	1,261	414	522	138	110	265
Air	4	605	2	31 (2) 93 (3)	8,072 (2) 24,241 (3)	13,345 (2) 40,028 (3)
Total/Average	7,042	436	3,072	2,129 (3)	302 (3)	693 (3)

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

TABLE 5

SUMMARY OF 1985 BASE CASE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS (x10^6)	AVERAGE HAUL PER TON (Miles)	NET TON-MILES (x10^9)	TOTAL BTUs (x10^{12})	BTUs PER NET TON (1) (x10^3)	BTUs PER NET TON-MILE (1)
Truck	2,675	238	637	1,456	544	2,287
Rail	2,504	519	1,299	886	354	682
Inland Waterway	880	350	308	87	99	280
Coastal & Great Lakes Ship	751	1,048	787	132	254	226
Coastal & Great Lakes Barge				30	209	274
Pipeline (4)	1,500	414	620	174	116	281
Air	5	591	3	36 (2) 113 (3)	7,748 (2) 24,573 (3)	13,118 (2) 41,601 (3)
Total/Average	8,315	439	3,654	2,879 (3)	346 (3)	788 (3)

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

TABLE 6

SUMMARY OF 1985 INDUSTRY CHANGE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS ($x10^6$)	AVERAGE HAUL PER TON (Miles)	NET TON-MILES ($x10^9$)	TOTAL BTUs ($x10^{12}$)	BTUs PER NET TON (1) ($x10^3$)	BTUs PER NET TON-MILE (1)
Truck	2,418	225	544	1,096	453	2,014
Modal Shift (Truck to TOFC/COFC)	256	348	89	136	529	1,522
Rail	2,505	511	1,280	692	276	540
Inland Waterway	880	350	308	84	95	270
Coastal & Great Lakes Ship	751	1,048	787	126	249	223
Coastal & Great Lakes Barge				29	205	269
Pipeline (4)	1,500	414	620	165	110	265
Air	5	591	3	34 (2) 109 (3)	7,388 (2) 23,712 (3)	12,508 (2) 40,143 (3)
Total/Average	8,315	437	3,631	2,437 (3)	293 (3)	671 (3)

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

TABLE 7

SUMMARY OF 1985 GOVERNMENT INFLUENCE SCENARIO TRAFFIC AND ENERGY STATISTICS

MODE	TONS (x10^6)	AVERAGE HAUL PER TON (Miles)	NET TON-MILES (x10^9)	TOTAL BTUs (x10^{12})	BTUs PER NET TON (1) (x10^3)	BTUs PER NET TON-MILE (1)
Truck	2,290	218	499	951	415	1,904
Modal Shift (Truck to TOFC/COFC)	384	348	134	149	388	1,117
Rail	2,505	504	1,263	558	223	442
Inland Waterway	880	350	308	83	94	267
Coastal & Great Lakes Ship	751	1,048	787	126	249	223
Coastal & Great Lakes Barge				29	205	269
Pipeline (4)	1,500	414	620	165	110	265
Air	5	591	3	34 (2) 109 (3)	7,388 (2) 23,712 (3)	12,508 (2) 40,143 (3)
Total/Average	8,315	435	3,614	2,170 (3)	261 (3)	600

(1) Excludes adjustments for different circuity factors peculiar to each mode.

(2) Based on incremental energy requirements for the portion of freight moving in passenger aircraft.

(3) Based on pro-rata share of fuel consumption for portion of freight moving in passenger aircraft.

(4) Regulated pipelines only.

TABLE 8

RECAP OF TOTAL FREIGHT TRANSPORTATION BTUs
(10^{12})

	Base Case			Industry Change		Gov. Influence	
	1972	1980	1985	1980	1985	1980	1985
Truck	850	1,246	1,456	1,071	1,096	992	951
Modal Shift	0	0	0	58	136	79	149
Rail	519	760	886	668	692	624	558
Inland Water	48	74	87	70	84	70	83
Coastal & G.L.	87	135	162	133	155	133	155
Pipeline[1]	102	147	174	138	165	138	165
Air[2]	60	95	113	93	109	93	109
Total	1,666	2,457	2,879	2,232	2,437	2,129	2,170

Regulated pipelines only.

Based on pro rata share of fuel consumption.

For the industry change scenarios in 1980, we have assumed a 20 percent shift from truck to rail of the relatively small amount of total traffic which is competitive to both truck and rail. By 1985, we have assumed a shift of 40 percent. Appendix A describes the calculations of the shift in more detail. It was assumed that where modal shift from truck to rail occurs, the average length of haul of the freight shifted is 50 percent longer than the average haul by truck for that particular commodity.

Government influence scenarios center chiefly on providing incentives, technical assistance, or capital assistance to implement change beyond that which industry would likely achieve on its own behalf. Some of these influences include intermodal cooperation (or outright traffic shift) between truck and rail. Influence on other modes is negligible.

In developing the results of energy conservation measures, it was necessary to consider both the rate of adoption of operating and technological change and the penetration that these changes have had on the population of vehicles within each transportation mode. Section 4 discusses in detail assumed impacts on base case input variables, that is, the net weighted-average change to input variables entered into the TRANSEN model.

Economic Impacts

Economic implications of energy conservation alternatives are quite complex. Compared to energy conservation studies, there is an even more serious lack of data upon which to base estimated industry impacts. As a general rule, operating changes which save energy are accompanied by other direct and corresponding reductions in incremental cost--usually labor. For motor carriers, these incremental savings will vary between approximately 30 to 35 cents per trailer mile not operated (70, 000-pound gross vehicle weight). For lighter (smaller) trucks, savings are not corresponding less since labor costs, about 75 to 85 percent of incremental costs, are not materially less for smaller vehicles.

On a long-term basis, operating savings which promote energy conservation also tend to promote greater equipment productivity, utilization of capacity, and hence the need for fewer vehicles. In these cases, fully allocated operational costs may be considered to be a proper basis for savings and range between 35 cents per truck mile for smaller vehicles and up to 75 cents per truck mile for large, expensive rigs which average 70,000 miles per year.

Railroad economic impacts are more difficult to evaluate and range from as little as the cost of fuel saved to as high as $10.00 per train mile.

The evaluation of technological change is greatly impacted by the order, or procession, of the adoption of changes. For instance, the economic impact of two technological alternatives which have the same capital and maintenance costs and useful life, which both result in the same percentage savings of energy, is affected by which improvement is applied first. The absolute amount of energy saved will be greater for the first improvement applied than for the second technological alternative, due to the effects of compounding. For example, thus to analyze economic impacts of new truck technology, it is generally preferable to analyze alternatives as a "package." One approach to determine economic impact is to analyze the impact on a single vehicle and extend this impact to the appropriate number of vehicles in a fleet (adjusted for age, utilization, etc., as appropriate). A break-even determination of the adoption of a technological "package" or engine substitution may be calculated using procedures included in Section 4.

Similar procedures can be used for the evaluation of technological change in the railroad industry. Section 4 illustrates how these evaluations can be made. Since so many assumptions are required for evaluating what the total economic impact will be in both the motor carrier and rail models, the study focused on prescribing this simplified methodology which can be used under many different assumptions.

CONCLUSIONS (SECTION 5)

An important conclusion of the study is the need for an improved national data base on freight-transportation-energy consumption, particularly for unregulated elements of the transportation sector. Although studies such as this can provide useful and valuable information for the purpose of establishing national policies and priorities, an improved data base can result in improving the confidence and reliability of assessing alternatives and their potential impacts on freight transportation and, subsequently, national interest.

The study concludes that substantial opportunities exist for energy conservation in the freight transportation industry. The greatest opportunity for conservation lies with the industry itself. Indeed, return-on-investment opportunities are sufficiently attractive in many specific instances that we believe the transportation industry will continue to explore and adopt changes to realize energy conservation. Government influence to improve energy conservation practices is not as potentially significant as opportunities currently available to industry. The primary influence of government is to accelerate industry trends by making change financially attractive (or, conversely, failure to change more expensive). Other changes, of course, could include regulatory changes that can have a direct effect on transportation energy conservation. The danger in major regulatory changes, however, includes adverse econnomic side effects in the transportation sectors and for users of transportation. Major regulatory changes could also cause restructuring in the transportation industry and result in major capital needs in one area and excess capacity in another, to the point where economic consequences outweigh the benefits of energy conservation. Because of the many unknowns and the problems associated with implementing regulatory changes, no major changes to government regulatory policies were assumed in this study.

Tables 5-2 through 5-6 summarize the change in Btus per ton-mile by mode and scenario, total Btu consumption by mode and scenario, percent of ton-miles relative to percent of energy used, total Btu consumption by commodity and scenario, and net ton-miles and energy consumption by mode and scenario.

The government influence scenarios suggest that the marginal energy saving influence of government is half that of the trucking industry itself, and equal to about 60 percent of what the railroad industry can do on its own behalf by 1980. Short of draconian measures we have also concluded that government influence can double the 1985 contribution to truck but still amount to only half the percentage impact that carriers themselves can achieve. For railroads, however, government influence can almost equal the impact of the industry itself. Except for inland waterways (where even their government influence is small), no significant savings are anticipated as a result of industry acceptable levels of government influence.

In absolute terms, motor and rail carriers offer the greatest potential for energy savings. Changes in inland, coastal, and Great Lakes waterway modes are not as potentially significant as opportunities in rail and truck and therefore were not studied. Energy conservation opportunities in air cargo are relatively large in terms of potential percentage reduction in energy requirements but very small in the total picture of freight transportation energy. The amount of savings is also largely influenced by whether freight is considered to be an add-on to passenger traffic, or whether freight carried in passenger planes should assume its pro-rata share of energy consumption.

Although modal shift may be desirable from an energy conservation viewpoint, it may not be advantageous from an economic or shipper's viewpoint. For a modal shift to occur and be effective, it should be voluntary on behalf of the users of transportation and sufficiently attractive to carriers to provide mutual economic benefits. In lieu of a pure modal shift, opportunities exist for carriers to work together in a cooperative environment without one mode suffering at the expense of another.

Motor carriers are generally more responsive to opportunities to change. Investment requirements are usually substantially less, and turnover rates among motor carrier equipment are highly relative to rail. In addition, trucking companies are generally smaller than railroad companies and thus motor carrier management can often respond more quickly to opportunities to change.

The availability of cash and other financing alternatives is also important in promoting the adoption of energy conservation measures.

1. INTRODUCTION

1.1 OVERVIEW

In anticipation of the need for government to establish policies which promote energy conservation in freight transportation, a better understanding is needed of the future energy costs for each freight mode under a range of assumptions regarding anticipated technological and operational improvements. This need led to the award of a contract to Peat, Marwick, Mitchell & Co. (PMM&Co.) by the Transportation Systems Center (TSC) to study the energy and economic impacts of projected freight transportation improvements. The primary objectives of this study were to assess current and future energy costs for each major freight mode and identify potential economic and environmental impacts of anticipated changes in freight systems under varying assumptions about freight transportation for 1980 and 1985.

The scope of study was limited to intercity freight movements of both private and for-hire carriers. Although urban freight transportation consumes about as much fuel as intercity truck transportation, too little is known about this fragmented and widely diversified industry to conduct a meaningful analysis.

The intercity freight transportation modes included were:

trucks;

railroads;

inland waterways (non-self-propelled vessels);

coastal and Great Lakes shipping (self-propelled and non-self-propelled vessels);

pipelines; and

air.

The study draws on recent and historical studies, data, and publications, where available. In addition, the study team has performed mathematical analyses where necessary and sensitivity analyses on some of the relevant parameters.

This study assessed the energy conservation and the economic implications of alternative technologies and operational conditions which can be implemented within the next decade. Alternative possibilities were analyzed individually, and their impacts were combined into a set of scenarios which estimate energy consumption over the next 10 years under varying sets of assumptions. Specifically, the study team developed:

> data for a base case to serve as the foundation from which the impacts of energy conservation measures can be assessed. Base case data include information on traffic movements and energy consumption for each of the six modes studied, with traffic separated into selected commodity groups. Base case data were computed for 1972 and projected to 1980 and 1985 with the assumption that no energy conservation measures would be implemented beyond 1972 levels. (Adjustments were made, however, for the 55 mph highway speed limits.)
>
> projections for 1980 and 1985 based on a series of "industry change" assumptions, i.e., that past trends in energy conservation will continue and that transportation carriers will implement other operational and technological changes without new incentives or other stimulus.
>
> projections for 1980 and 1985 based on a series of government incentive and regulation assumptions which result in the implementation of new or additional operational and technological changes.

The scenarios identified above were calculated by an Intercity Freight Transportation Energy Consumption (TRANSEN) model, which is described in the next section. The TRANSEN model systematically details energy consumption and energy intensiveness patterns for the base year 1972 and calculates the energy and economic impacts of specific assumptions for projected changes in technology and operating conditions in 1980 and 1985.

The results of the model do not represent conclusive findings. They are based on the best available information obtained within the scope of this study and serve as indicators of trends under varying assumptions. Furthermore, the energy consumption estimates are not intended to provide a basis for intermodal comparisons. The values do not reflect differences in the quality of service between modes and, as the national averages, they do not indicate differences in individual situations or the incremental energy cost of shifting movements from one mode to another. These numbers are intended primarily to provide a basis for making comparisons within a mode and over time.

1.2 GROWTH OF INTERCITY FREIGHT TRAFFIC

As shown in Table 1-1, the volume of intercity freight transportation expressed in ton-miles has increased by 232 percent from 1940 to 1972. The annual compound growth rate in this 33-year period averaged 3.7 percent (compared to a constant dollar growth rate of 3.9 percent per year in the nation's gross national product during the same period).

The distribution of growth among the transportation modes has not been even. Rail tonnage, with an average annual growth rate of 2.2 percent, showed the least growth, followed by inland waterways (3.2 percent), trucks (6.3 percent), oil pipelines (6.5 percent), and air (18.5 percent). The uneven growth rate among modes significantly altered modal shares. In 1945, railroads comprised more than two-thirds of the intercity freight market in terms of ton-miles. This share steadily declined to a level of only 38 percent, where it appears to have stabilized.

The share of the market for trucks and oil pipelines more than doubled during the 1940-1972 period, with each reaching a level of nearly 23 percent of intercity ton-miles in 1972. Speed, flexibility, and reliability of service contributed to the growth of motor carrier traffic. Growth in oil pipeline transportation has followed the growth in the production of and demand for petroleum, gas, and petrochemicals. The share of traffic moving on inland waterways has remained reasonably steady at approximately 15-17 percent. Although the share of the market served by air freight is relatively low compared to the other modes, it has registered the most dramatic increase (but from a low base).

1.3 MODAL DIFFERENCES IN ENERGY INTENSIVENESS

The concept of energy efficiency quantitatively relates transportation outputs to energy inputs. For this study, energy inputs to the intercity freight transportation sector are expressed in British thermal units (Btus). The outputs of the intercity freight transportation are

TABLE 1-1

DISTRIBUTION OF TON-MILES AMONG INTERCITY FREIGHT CARRIERS[1]

(Including for-hire and private carriers)

Year	Railroads		Motor Trucks		Inland Waterways		Pipelines (oil)		Airways		Total
	Millions of Ton-Miles*	% of Total	Millions of Ton-Miles	% of Total	Millions of Ton-Miles@	% of Total	Millions of Ton-Miles	% of Total	Millions of Ton-Miles#	% of Total	Millions of Ton-Miles**
1940	379, 201	61. 30	62, 043	10. 03	118, 057	19. 08	59, 277	9. 58	14	. 00	618, 592
1945	690, 809	67. 26	66, 948	6. 52	142, 737	13. 90	126, 530	12. 32	91	. 01	1, 027, 115
1950	596, 940	56. 17	172, 860	16. 27	163, 344	15. 37	129, 175	12. 16	331	. 03	1, 062, 650
1955	631, 385	48. 53	223, 254	17. 51	216, 508	16. 98	203, 244	15. 94	465	. 04	1, 274, 856
1960	579, 130	44. 06	285, 483	21. 72	220, 253	16. 76	228, 626	17. 39	891	. 07	1, 314, 383
1965	708, 700	43. 25	359, 218	21. 92	262, 421	16. 01	306, 393	18. 70	1, 911	. 12	1, 638, 643
1967	731, 216	41. 43	388, 500	22. 01	281, 400	15. 95	361, 041	20. 46	2, 590	. 15	1, 764, 747
1968	756, 800	41. 16	396, 300	21. 55	291, 409	15. 85	391, 300	21. 28	2, 916	. 16	1, 838, 725
1969	780, 000	41. 02	404, 000	21. 25	302, 901	15. 93	411, 000	21. 61	3, 574	. 19	1, 901, 475
1970	771, 012	39. 83	412, 000	21. 28	318, 560	16. 46	431, 000	22. 26	3, 295	. 17	1, 935, 867
1971	746, 000	38. 11	445, 000	22. 73	315, 030	16. 09	448, 000	22. 89	3, 500	. 18	1, 957, 530
1972	784, 300	37. 8	470, 000	22. 60	338, 700	16. 3	480, 000	23. 1	3, 700	. 2	2, 076, 700
1973	857, 600	38. 4	505, 000	22. 60	358, 222	16. 1	507, 000	22. 7	3, 943	. 2	2, 231, 765
1974	885, 700	38. 6	495, 000	22. 30	354, 882	16. 1	506, 000	22. 8	3, 910	. 2	2, 215, 492
1975e	761, 000	37. 0	441, 000	21. 40	343, 000	16. 9	510, 000	24. 8	4, 000	. 2	2, 059, 000

* Includes express and mail until 1970.

@ Including Great Lakes but excluding deep sea ton-miles between mainland and Alaska, Hawaii, and territories.

\# Domestic revenue service, including express, mail and excess baggage, Intra-Alaska and Intra-Hawaii ton-miles included beginning in 1959. Effective January 1, 1970, operations between the 48 states and Alaska/Hawaii were reclassified as domestic operations. Data for the years after 1969 has been adjusted in accordance with the new definition.

** Components may not add to total due to rounding.

e-- Estimated.

Sources: Interstate Commerce Commission, U.S. Corps of Engineers, Association of American Railroads, Civil Aeronautics Board, and American Trucking Associations.

(1) 1972 data from above does not reconcile with 1972 base case data due to different sources and data included in study.

expressed in short-tons and ton-miles. However, the output of one mode of the transportation system is not the same as the output of another. The nature of the service and the quality of service differ from mode to mode and may require different energy inputs to produce the same statistical measures of transportation output, such as ton-miles. The definition of energy efficiency in the intercity freight transportation, however, makes no allowance for these differences in service, and relates only to tons and ton-miles per Btu. Thus efficiency comparisons between modes are not necessarily meaningful, unless freight and other service parameters are also similar. Energy intensiveness (EI) is defined as the inverse of energy efficiency, i.e., Btus per ton and ton-mile.

Energy intensiveness shows considerable variation among transport modes. A number of studies have been undertaken in the past to measure the energy intensiveness of intercity freight transportation modes.[1] One source gives the following order of energy intensity by intercity freight transportation mode:[2]

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[1] See, for example, E. Hirst, Energy Consumption for Transportation in the U.S. (Oak Ridge National Laboratory: NSF Environmental Program, March, 1972); E. Hirst, Energy Intensiveness of Passenger and Freight Transport Modes: 1950-1970 (Oak Ridge National Laboratory: NSF Environmental Program, April, 1973); E. Hirst, Transportation Energy Use and Conservation Potential (Oak Ridge National Laboratory: NSF Environmental Program, February, 1973); W. E. Mooz, Energy in the Transportation Sector, paper presented at the Florida Governor's Conference on Energy Supply and Use (Tallahassee, Florida, March, 1973); Office of Emergency Preparedness, The Potential for Energy Conservation: A Staff Study (Washington, D.C.: U.S. Government Printing Office, October, 1972); W. P. Goss and J. G. McGowan, "Transportation and Energy--A Future Confrontation," Transportation, Volume 1, Number 3 (November, 1972); R. L. Strombotne and A. L. Malliaris, Demand for Energy by the Transportation Sector and Opportunities for Energy Conservation (Washington, D.C.: U.S. Department of Transportation, undated); W. L. Savery, "Future Energy Sources for Transportation," Traffic Quarterly, Volume 26, Number 6 (October, 1972); R. A. Rice, "System Energy as a Factor in Considering Future Transportation," MIT Technology Review (January, 1972); C. M. Cope, The Effect of Speed on Truck Fuel Consumption Rates (Washington, D.C.: Federal Highway Administration, August, 1974).

[2] E. Hirst, February 1973, op. cit.

Mode[1]	Average Btus/ton-mile*
Pipeline	450
Railroads	670
Water	680
Truck	2,800
Air	42,000

* Does not recognize character of freight or service performed.

Recent trends in modal shifts conflict with the recent national goal of energy conservation. This conflict has been amplified by changes in operating conditions and transportation technology, which have affected the energy intensity of the different modes. For example, due to the shifts from coal-burning steam locomotives to diesel engines, the energy intensity of intercity rail transportation has been reduced by almost five-fold from 3,200 to 670 Btus per ton-mile in the 1950-1970 period.[2] During the same period, the EI of air freight increased from approximately 23,000 to 42,000 Btus/ton-mile and trucks from 2,500 to 2,800 Btus/ton-mile. Thus, at a time when railroads were making significant improvements in EI, a significant tonnage shift was made toward the more energy intensive truck and air modes whose EI was increasing.

The combined passenger and freight transportation sector of the United States is already using 31 percent of the nation's energy, and about 52 percent of its petroleum products.[3] Energy resources will continue to be scarce and expensive during at least the next decade. Therefore, the ability of our nation to meet the energy challenges of the future will depend largely on the development and implementation of more energy efficient technologies and operations.

1.4 ORGANIZATION OF REPORT

The remainder of this report is organized into four sections. Section 2 discusses the study methodology and includes a description of

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[1] Source: E. Hirst, Energy Conservation for Transportation in the U.S. Oak Ridge National Laboratories, March 1972.

[2] Ibid.

[3] Walter G. Dupree, Energy Consumption in the Transportation Sector, Effects of Energy Constraints on Transportation Systems, Schenectady, New York, Union College, 1975.

the TRANSEN model and model outputs for the 1972 base case. Section 3 describes the operational and technological changes which could reasonably be implemented to conserve energy. Section 4 describes the results of combining the impacts of several energy conservation changes into a series of scenarios. Finally, Section 5 summarizes the findings of the study overall and discusses the conclusions. Appendices A-F give the details of the model for each mode, including methodology and sources of data.

2. INTERCITY FREIGHT TRANSPORTATION ENERGY MODEL FRAMEWORK

As described in the preceding section, energy intensiveness for a freight transportation mode is a means of relating energy inputs, expressed in Btus, to transportation outputs, expressed in tons and ton-miles, for a specified commodity. This section describes the framework for this study within which estimates of freight transportation were developed and converted to energy intensity measures. Details of the actual computations and data sources appear in Appendices A-F.

2.1 GENERAL DESCRIPTION

This study of energy efficiency in the intercity freight transportation market began with a consideration of:

transportation mode;

commodity;

time; and

geographic area.

The transportation mode reference encompassed all intercity freight for the following modes:

trucks;

railroads;

inland waterways (non-self-propelled vessels);

coastal and Great Lakes ships (self-propelled and non-self-propelled vessels);

pipelines; and

air freight.

Freight transportation was subdivided into the 19 commodity categories listed in Table 2-1, based on the major two-digit Standard Transportation Commodity Code (STCC) groupings. In some cases, based on similarity

TABLE 2-1

COMMODITY GROUPS SELECTED FOR ANALYSIS

GROUP NUMBER	STANDARD TRANSPORTATION COMMODITY CODE (2 Digit Level)	COMMODITY
1	01-09	Agricultural products
2	10	Metallic ores
3	11, 29914	Coal, coke produced from coal
4	13, 29	Crude oil, petroleum
5	14	Nonmetallic minerals
6	20, 21	Food, kindred products, tobacco
7	22, 23, 31	Textiles, apparel, leather
8	24, 25	Lumber, wood products, furniture
9	26	Pulp, paper, allied products
10	28	Chemicals, allied products
11	30	Rubber, plastic products
12	32	Clay, concrete, glass, stone
13	33	Primary metal products
14	34	Fabricated metal products
15	35	Nonelectrical machinery
16	36	Electrical machinery
17	37	Transportation equipment
18	38, 39	Instruments, photographic goods, miscellaneous products of manufacturing
19	40	Waste, scrap materials

of commodity groups or availability of data needed to construct the base case, two or more codes were combined. The base year was 1972, and 1980 and 1985 were selected as the future points of reference. Since reliable data by geographic area are not available, the geographic scope of reference is restricted to the United States as a whole, except for inland water transport where the influence of specific waterways on transportation is great and data are available.

Energy conservation means reducing the amount of energy consumed to perform a service of given size and characteristics. Each mode in the transportation sector can conserve energy by adopting new technologies, modifying operating practices, or a combination of both. Within the overall transportation sector, some energy conservation can be achieved by a shift of carefully selected traffic to less energy intensive modes. The government can affect the conservation process by introducing appropriate policy measures directed at the technology and operating characteristics of individual modes.

An analysis of the impacts of different policy options on energy conservation requires a clear understanding of the way in which traffic and transportation operating characteristics are converted to energy consumption. Although detailed national data on energy consumed and traffic moved are available, a systematic framework was not available to relate traffic and energy. Thus, to analyze the effects of conservation policy options, PMM&Co. and Battelle developed the TRANSEN model which converts traffic data, by commodity and mode, to energy consumption estimates to help fill this void in the published literature.

2.2 THE TRANSEN MODEL

TRANSEN is a computer model which was developed to quantify mode- and commodity-specific energy intensiveness under different assumptions about future energy consumption by the different modes. The model relates transportation performance parameters to energy utilization, which permits analysis of the way in which changes in operating conditions and technology affect transportation performance and, consequently, energy consumption. The model calculates energy intensiveness values for each mode under input conditions relating to operating policy and transportation technological development. The model is not deterministic; it does not purport to describe what the optimum energy intensity output should be under given conditions. Rather, the model is a descriptive tool which analyzes the impacts of alternative operating policies and use of technological improvements to alter the energy intensity of different modes, either singly or in combinations.

Figure 2-1 illustrates the conceptual design of the TRANSEN model and its integrating links. The model permits an analysis of the following conservation scenarios:

> No changes in the energy intensity of each mode. This alternative involves projecting future intercity freight transportation output in terms of tons and ton-miles without any modal shift change or change in energy intensity. Total energy consumption is a linear determinant of commodity volumes.
>
> Selective changes in the energy conversion system. For these projections, the energy intensity of each mode is altered from the base year case to reflect changes which occur due to economic and regulatory forces now in effect. These energy changes can be superimposed upon different growth rates of each commodity by mode.
>
> Additional changes in energy conversion which can be attributed to specific new or contemplated government policies.

The measures of energy consumption estimated from the model represent national averages. Differences in the relative performance of individual modes can vary significantly in individual situations. Furthermore, the model does not account for changes to average length of haul associated with modal shifts when circuity factors are different.

Results from the use of the model are not intended to suggest that transfer of commodity movements from one mode to another (in specific situations) could result in implied energy savings. What may be true on a national average basis, cannot be construed to be applicable in specific situations, since many factors can cause energy intensity in specific instances to vary widely from national averages. Energy intensity values are intended primarily to highlight differences in each mode's overall energy consumption to provide a basis for assessing the relative impacts of implementing operating and technological changes for each mode to conserve energy.

For each of the six modal components, traffic inputs were converted to energy consumption outputs. The remainder of this section summarizes each component in terms of the sources of data for the analysis and the way in which traffic measures for each mode were converted to energy consumption estimates. Specific conversion logic and data sources for calculations are described in Appendices A-F.

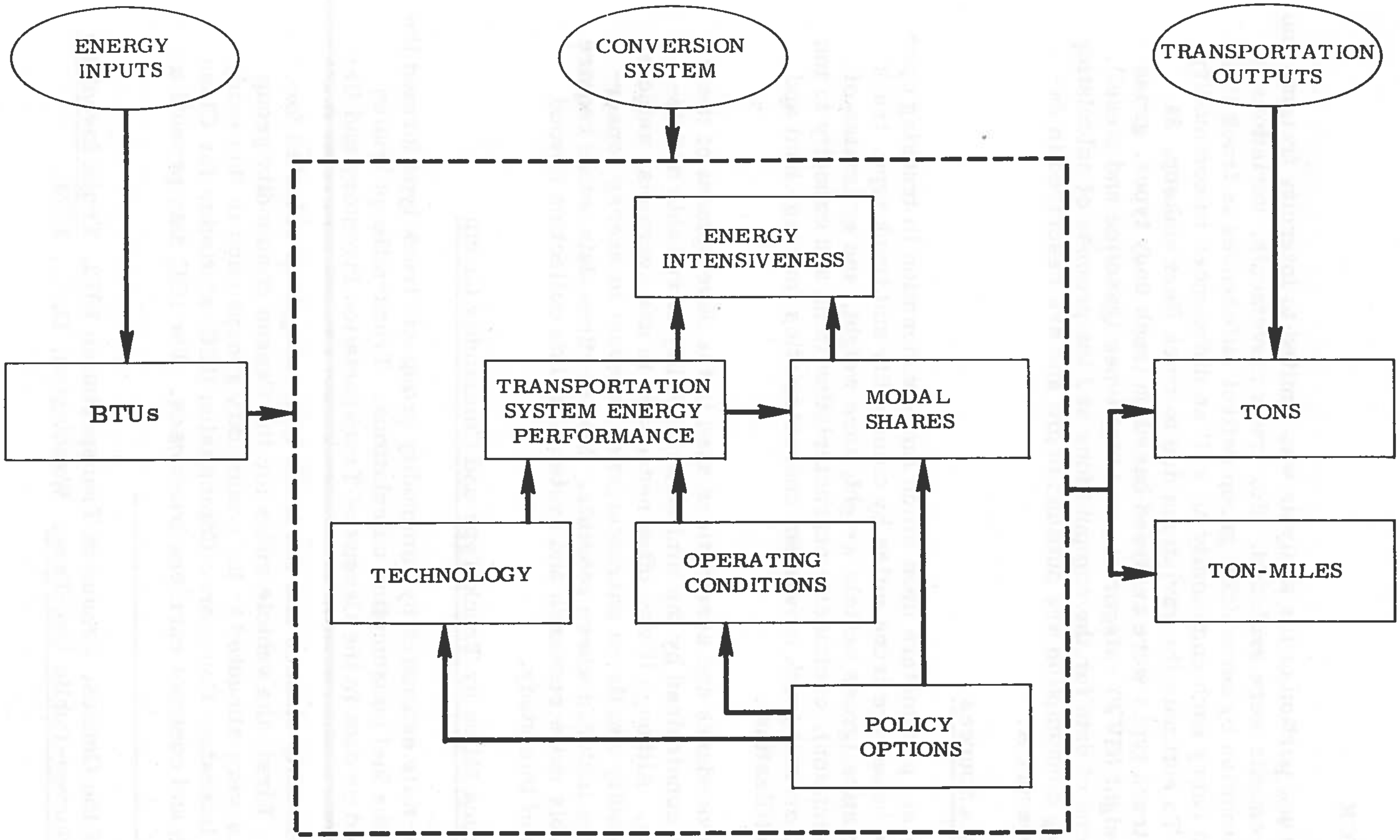

FIGURE 2-1: CONCEPTUAL DESIGN OF THE TRANSEN MODEL

2.3 TRUCK

The truck portion of the analysis was limited to intercity freight, and local movements were excluded. For truck movements, variations in fuel consumption by commodity group reflect differences in truck fleet makeup to carry each commodity as well as differences in commodity density. To estimate the variations due to truck fleet makeup, 24 different truck types were analyzed based on truck body types, gross vehicle weight (GVW) categories, and fuel types (gasoline and diesel). The sources of data for the computations and the process of calculating fuel energy consumption are outlined below and are described in detail in Appendix A.

2.3.1 Data Sources

The basic parameters upon which fuel consumption in trucking operations are based are truck miles by commodity and truck type, truck characteristics (gross vehicle weight, tare weight, and estimates of fuel consumption), commodity characteristics (tons and capacity to ton ratio) and overall truck movement characteristics (average haul and capacity utilization).

The procedures and assumptions used in the development of these data were constrained by the limited availability of reliable and detailed data. Although it was often necessary to use averages, vehicle and commodity details on characteristics relevant to energy conservation were included where possible. More refined data would require considerably more research and systematic data collection beyond the scope of this study.

2.3.2 Truck Miles by Truck Type and Commodity Group

Truck-mile estimates by commodity group and truck type formed the basis for the fuel consumption calculations. Truck-mile estimates were based on data in the Census of Transportation Inventory and Use Survey.[1] The survey results required several adjustments to fit the study commodity classes and the truck type categories selected for analysis. First, the vehicle miles for the Census commodity group categories were allocated to the commodity groups used in this study based on Interstate Commerce Commission (ICC) statistics for Class I common and contract carriers truckloads. The ICC data provide a

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[1] Bureau of the Census, Census of Transportation 1972, Truck Inventory and Use Survey-Public Use Tape. Washington, D.C., 1974.

commodity breakdown fine enough to apply to Census and STCC definitions. This basis of allocation reflects the lack of any satisfactory data base for calculating truck-miles by commodity type.

The second adjustment to the Census truck-mile data involved defining the study truck type categories and then classifying vehicle miles by commodity according to the truck types. The truck type definitions are based on three truck characteristics:

Body Type. The Census provided 21 body types, which were condensed into five basic types: light bodies, box bodies, irregular bodies, tank bodies, and nonfreight. Nonfreight and light body trucks were considered outside the scope of this study and were excluded from further analysis. The other three categories were established to reflect similarity of truck types with respect to the effect of body type on fuel consumption due to aerodynamic drag and the susceptibility to specific aerodynamic improvements.

Gross Vehicle Weight. The gross vehicle weights were condensed into five categories:

10,000 to 19,000 pounds;

19,000 to 32,000 pounds;

32,000 to 50,000 pounds;

50,000 to 70,000 pounds; and

over 70,000 pounds.

Fuel Type (Gasoline and Diesel). Fuel type categories were determined from the public use tape which shows vehicle miles of gasoline, diesel, and liquid petroleum gas (LPG) trucks by weight class and principal product. LPG was combined with gasoline because, in terms of Btus per horsepower hour, an LPG engine is closest to a gasoline engine. All trucks over 70,000 pounds were assumed to run on diesel fuel.

The first gross vehicle weight category (10,000 to 19,000 lbs.) was excluded, since most vehicles in this class are used for other than strictly intercity freight transportation. The remaining combination of three body types, four weight classes, and two fuel types results in the 24 generalized truck types used in this study. Vehicle miles by commodity group were assigned to the body and weight classes used in the study and were split according to the relevant gasoline and diesel percentages for those truck types requiring a split. Finally, vehicle miles were adjusted, where necessary, to correspond to the commodity group truck-miles developed from the Census data.

2.3.3 Truck Specific Data

To estimate load capacity for each truck category, tare and gross vehicle weights were estimated for a representative truck for each truck category. Data in making the tare weight assumptions were obtained from a Federal Highway Administration report[1] and discussions with several truck dealers.

Fuel consumption rates were calculated for each truck type category for empty and loaded movements. The basis for these calculations was the horsepower requirements of each truck type at different operating speeds and the specific fuel consumption rate of the engine. The method used was taken from the Society of Automotive Engineers Handbook.[2] The theoretical calculations have a high correlation with actual road tests of fuel consumption. The calculations for standard or benchmark trucks in each weight class in the study were plotted on a graph, and values for empty vehicles were interpolated for 45, 50, 55, 60, 65, and 70 miles per hour. From these values the changes in miles per gallon with each additional ton of load were computed by dividing the difference between the empty-mile per gallon curve and the loaded-mile per gallon curve by the maximum ton capacity of the truck. Benchmark trucks for each weight class were indexed to match the 24 truck type categories based on a series of assumptions which are outlined in Appendix A.

2.3.4 Commodity Data

Because of the scarcity of data on the tonnage of each commodity group shipped by truck in intercity service, a two-stage procedure was used to estimate truck tons by commodity. The first stage involved

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[1] Federal Highway Administration, Road User Property Taxes on Selected Motor Vehicles, 1973, U. S. Government Printing Office, Washington, D. C., pp. 10-11.

[2] Society of Automotive Engineers, "Truck Ability Prediction Procedure - SAE J-688" pp. 790-2. 1962 SAE Handbook, Society of Automotive Engineers, Inc., New York, 1962.

developing estimates from information in the Census of Transportation Commodity Survey.[1] The second stage involved a modification and extension of that estimate by multiple regression analysis using ICC statistics for regulated carriers.

The Transportation Commodity Survey reports tonnage by commodity and by mode. These figures are estimates of total shipments from manufacturing plants by the principal mode used to points beyond the local area. The shipments are classified according to the Standard Industrial Classification (SIC) codes which correspond to the Standard Transportation Commodity Codes in this study within the accuracy required for this analysis.

The Census estimates of tons and ton-miles by commodity represent only shipments from manufacturing plants. The Census estimates were extended to the total movements for those commodity groups surveyed by comparing the Census estimates for rail and water to known data for these modes and then using an average of the water and rail coverage proportions to scale Census truck estimates to the total population of truck movements.

To improve these estimates and compute values for the commodities not covered in the Census, second-stage estimates were made of truck tons, by commodity group, to maximize the use of available information. The second stage procedure was based on the assumption that total tons for a commodity group carried by all trucks varies with (1) the total mileage of trucks carrying that commodity (available from the Census of Transportation) and (2) the tons carried by regulated carriers, as reported by the ICC. For the second-stage analysis, vehicle miles and Class I tons by commodity group were regressed as independent variables against the first-stage estimates previously computed. The resulting regression formula (see Appendix A) was used in this analysis as a predictor for only those five commodity groups not covered by the Census. For the remaining commodity groups, this procedure was viewed as an averaging process to weight the first-stage estimates with known variables.

Finally, for each commodity group, the commodity full-load weight to net weight limit ratio was computed to account for density variations between commodities. The ratio reflects whether a vehicle is "cubed out" before the net weight capacity of the truck is reached. Values

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[1] Bureau of the Census, Census of Transportation 1972, Transportation Commodity Survey, U.S. Government Printing Office, Washington, D.C., 1975.

of this measure for the different commodities were based on estimates by experienced operators and the study team. More precise determination by using sampling techniques was beyond the scope of this study.

2.3.5 Overall Truck Movement Characteristics

The product of estimated average hauls times tons by commodity group produced some values inconsistent with capacity ton-mile estimates. Therefore, the commodity-specific length of haul was estimated indirectly. Commodity-specific length of haul was estimated using (1) truck fleet average vehicle capacity utilization, (2) commodity-specific ton-mile truck capacity, and (3) commodity-specific tons transported, as explained in detail in Appendix A.

2.3.6 Methodology

The TRANSEN methodology involves calculating empty and loaded vehicle-miles and empty and loaded miles per gallon ratios and combining them to determine truck energy consumed.

The distribution of truck-miles by empty and loaded movements was based on estimates of capacity utilization. Truck ton capacity was estimated by commodity group and truck type based on the difference between truck gross and tare weights, as adjusted by the capacity-to-ton ratio which reflects commodity density. Ton capacity was then combined with vehicle-mile estimates to obtain total ton-mile capacity by commodity group and truck type. Next, actual tons were combined with overall average haul to estimate actual ton-miles. Actual ton-miles, compared with ton-mile capacity, produced an estimate of overall capacity utilization. The capacity utilization ratio reflects two measures of capacity use:

how fully trucks are loaded on the average; and

how much of the time trucks move empty.

Given an assumption regarding the first measure, the "equivalent" backhaul ratio can be computed from the capacity utilization ratio. The equivalent backhaul ratio, thus computed, was used to distribute truck miles by truck type and commodity group between empty and loaded movements.

Empty and loaded miles per gallon fuel use rates were then applied to the corresponding vehicle-mile estimates by truck type and commodity group and were summed by commodity group to compute energy consumed, in Btus, for each commodity in trucking movements. Finally, total energy consumption was divided by ton and ton-mile commodity estimates to compute energy intensity for each commodity group.

2.3.7 Output

Tables 2-2 and 2-3 show the results of these calculations for 1972 estimates of truck traffic and energy consumption by commodity group.

2.4 RAILROADS

The energy intensity of railroad movements differs for each of the 19 commodity groups in this study, because of variations in load per car, length of haul, and the mix of equipment used to transport each commodity. For the latter reason, energy intensity for rail movements was estimated by commodity separately for seven car type categories:

- boxcar;
- covered hopper;
- flat car (including TOFC/COFC traffic);
- gondola;
- open-top hopper;
- tank car; and
- miscellaneous (including auto rack, refrigerator, and stock cars).

Traffic (in ton-miles) was estimated by commodity group and car type category, and the estimated ton-miles were then converted to energy consumed in Btus. This process was done separately for loaded and for empty movements. The data sources and calculation process for computing ton-mile and energy consumption estimates are described below. Appendix B provides backup detail.

TABLE 2-2

TRUCK TRAFFIC MEASURES

1972

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	246451	295	72780
METALIC ORES	7628	135	1036
COAL & COKE	6573	84	558
PETROLEUM	153713	206	317[illegible]7
NONMET MINERAL	27449	221	6033
FOOD PRODUCTS	165293	266	44104
TEXTILES	68379	232	1590[illegible]
LUMBER & FUR.	62355	208	12975
PULP & PAPER	44701	184	8234
CHEMICALS	105504	248	26222
RUBBER&PLASTI	53874	224	12098
STONE & GLASS	128590	181	23291
PRIMARY METAL	63736	268	17080
FABRIC. METAL	77074	319	24640
NON-ELEC MACH.	48821	315	15415
ELECTRIC MACH.	52133	216	11277
TRANSPORT EQUI	125120	196	24636
INSTRUMENTS	76186	176	13467
SCRAP	11596	120	1396
TOTAL/AVERAGE	1525173	232	362990

TABLE 2-3

TRUCK BTU CONSUMPTION

1972

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	38917	134533	173450	703	2383
METALIC ORES	258	1823	2082	272	2006
COAL & COKE	149	1066	1215	185	2183
PETROLEUM	4525	54671	59197	385	1862
NONMET MINERAL	1831	10611	12443	453	2045
FOOD PRODUCTS	25541	83445	108986	659	2471
TEXTILES	5428	37105	42534	622	2674
LUMBER & FURN	10044	25171	35215	564	2714
PULP & PAPER	4424	14586	19010	425	2308
CHEMICALS	5489	50304	55793	526	2127
RUBBER&PLASTIC	3566	27793	31360	582	2592
STONE & GLASS	11885	50878	62764	488	2694
PRIMARY METAL	3208	31504	34712	544	2032
FABRIC. METAL	6214	49556	55770	723	2263
NON-ELEC MACH.	5768	27131	32899	673	2134
ELECTRIC MACH.	3218	21856	25075	481	2223
TRANSPORT EQUI	13046	46336	59383	474	2410
INSTRUMENTS	10158	24819	34977	459	2597
SCRAP	1708	1894	3602	310	2579
TOTAL/AVERAGE	155385	695092	850477	557	2343

2.4.1 Ton-Mile Estimates

The Interstate Commerce Commission publishes annual rail freight traffic data in tons by commodity.[1] These data, aggregated into the 19 selected commodity groups, form the basis of the rail freight traffic commodity computations. Originated tonnage has been selected as the most reliable measure of rail freight traffic, because it has the fewest duplications or omissions.

Freight traffic data for each car type by commodity have been computed in a special computer run from the Federal Railroad Administration (FRA) based on data from the 1972 Department of Transportation (DOT) 1-percent waybill sample. Statistics obtained from the sample included tons per car, haul per car, and haul per ton, with the latter two statistics measured in short-line miles. In addition, percentages of each commodity moving in each car type were computed as a basis for distributing aggregate commodity data by car type.

Other data obtained to compute rail traffic measures were:

> average tare (weight of car) and circuity for each car type, obtained from an ICC Bureau of Accounts report;[2] and
>
> the ratio of empty to loaded car miles for each car type, obtained from special studies conducted by the ICC Bureau of Accounts.[3]

These statistics, disaggregated by car type and averaged over all commodity groups, represent the best available measures of this information.

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[1] Freight Commodity Statistics - Class I Railroads, ICC Bureau of Accounts, Washington, D.C.

[2] Bureau of Accounts, Interstate Commerce Commission, Rail Carload Cost Scales - 1972, Washington, D.C., October 1974.

[3] Bureau of Accounts, Interstate Commerce Commission, Ratios of Empty to Loaded Freight Car-Miles by Type of Car and Performance Factors for Way, Through, and All Trains Combined, Washington, D.C., December 1973.

Using these data, net commodity ton-miles were computed as the product of net tons and average haul per ton, adjusted for circuity. Total ton-miles for all commodities were divided by the corresponding total published by the Association of American Railroads (AAR).[1] This value was used as a constant ratio to adjust all commodity statistics in order that statistical errors in the measurement of the components would be forced to agree with the control total ton-miles.

Tare ton-miles by car type and commodity group were estimated by using the following four-step approach:

> Net tons originated by commodity group and car type were converted to carloads based on corresponding average 1-percent waybill load per car values.
>
> Loaded car-miles by car type and commodity group were calculated by multiplying carloads for each car type and commodity group by average length of haul per car by car type and commodity group.
>
> Empty car-miles by car type and commodity group were computed by multiplying loaded car-miles by the empty to loaded car-mile ratio for each car type.
>
> Empty car-miles, by car type and commodity group, were multiplied by average car tare weight to produce tare ton-miles.

2.4.2 Energy Consumption Estimates

Estimates of energy consumption (in Btus per ton-mile) by commodity group and by car type were obtained after analysis of published and unpublished studies and discussions with the Federal Railroad Administration (FRA), Transportation Systems Center (TSC), and the AAR. The basis for the calculations began with the use of the modified Davis formula, to develop average train resistance estimates, which were converted to resistance of the "average" car in the "average" train. Preliminary values were then assigned to car types and average loads based on gross weights relative to the average. Base calculations were adjusted to account for headwinds, grades, curve resistance, braking, train composition, and switching operations.

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[1] Association of American Railroads, Yearbook of Railroad Facts, Washington, D.C., 1973.

The resultant estimates of energy consumption for each car type were then further adjusted (again somewhat arbitrarily), for each commodity group based on average load factors and assumptions regarding the average speed of the commodity/car type classification. The results (i.e., estimates of energy consumption in Btus per ton-mile) were developed separately for loaded and empty movements for each car type and commodity classification.

Based on the energy consumption and ton-mile estimates, total Btu consumption was computed in the TRANSEN model by commodity group and then compared with rail freight fuel consumption as reported by the ICC.[1] The computed Btu estimates per ton-mile by commodity group were adjusted to reconcile to control totals of fuel consumption reported by the ICC.

2.4.3 Outputs

Tables 2-4 through 2-8 show the resulting traffic and energy consumption estimates for rail movements for 1972.

2.5 INLAND WATERWAYS

The inland waterways component of the analysis computed total Btus and Btus per ton and ton-mile for inland waterway movements for each of the 19 commodity groups. An inland waterway movement is assumed to consist of a tugboat and a tow of barges. Since energy consumption varies for different waterway systems due to differences in the number of locks and dams and water current speed, the United States inland waterway system was divided into six segments:

Ohio River System;

Upper Mississippi River System;

Lower Mississippi River System;

Gulf Intracoastal Waterway;

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[1] ICC Bureau of Accounts, Transport Statistics in the United States, Year Ended December 31, 1972, Second Release, Washington, D.C., May 1974.

TABLE 2-4

RAIL NET TON-MILES BY CAR TYPE(1)

1972

10**6

COMMODITY	CAR TYPE BOXCAR	 COVER HOPPER	 FLAT CAR *	 GON-DOLA	 OPEN HOPPER	 TANK CAR	 MISC @	 TOTAL
AGRICULTURE	22693.	43746.	2087.	1018.	521.	0.	14390.	84455.
METALIC ORES	736.	6179.	0.	2004.	9653.	0.	1908.	20479.
COAL & COKE	0.	0.	0.	7560.	133881.	0.	0.	141441.
PETROLEUM	1130.#	0.	261.	0.	0.	14716.	307.	16414.
NONMET MINERAL	4554.	10995.	0.	5645.	13959.	3006.#	494.	38652.
FOOD PRODUCTS	25347.	19829.	4422.	0.	0.	9440.	36384.	95422.
TEXTILES	1402.	0.	467.	0.	0.	0.	0.	1869.
LUMBER & FURN	52575.	9395.	16703.	5448.	325.#	0.	7660.	92106.
PULP & PAPER	41056.	0.	875.	0.	0.	284.	1741.	43956.
CHEMICALS	14247.	32866.	1449.	0.	0.	29886.	3111.	81563.
RUBBER&PLASTIC	3465.	0.	393.	0.	0.	0.	185.	4043.
STONE & GLASS	13832.	17761.	2363.	722.	2367.	0.	1781.	38827.
PRIMARY METAL	12284.	680.#	6534.	15229.	794.#	0.	1794.	37316.
FABRIC. METAL	2099.	0.	1156.	3401.	0.	0.	383.	7039.
NON-ELEC MACH.	961.	0.	3114.	247.	0.	0.	0.	4323.
ELECTRIC MACH.	3493.	0.	1287.	168.	0.	0.	199.	5147.
TRANSPORT EQUI	14506.	387.#	14809.	481.	0.	149.#	0.	30333.
INSTRUMENTS	900.	0.	172.	0.	0.	0.	0.	1072.
SCRAP	4144.	236.	0.	5216.	902.	411.	146.	11055.
TOTAL	219425.	142077.	56094.	47135.	162401.	57893.	70483.	755509.

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

(1) Based on actual miles, not adjusted for circuity.

TABLE 2-5

RAIL BTUs FOR LOADED CAR MOVEMENTS(1)
BY CAR TYPE
1972

10**9

COMMODITY	CAR TYPE							
	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC @	TOTAL
AGRICULTURE	9351.	12645.	1861.	363.	244.	0.	12655.	37118.
METALIC ORES	240.	1710.	0.	481.	2137.	0.	739.	5307.
COAL & COKE	0.	0.	0.	1813.	34581.	0.	0.	36395.
PETROLEUM	611.#	0.	233.	0.	0.	4978.	157.	5979.
NONMET MINERAL	1736.	3043.	0.	1944.	3090.	721.#	191.	10726.
FOOD PRODUCTS	13094.	7561.	4079.	0.	0.	3088.	18349.	46171.
TEXTILES	1336.	0.	416.	0.	0.	0.	0.	1753.
LUMBER & FURN	30717.	3467.	12327.	2278.	144.#	0.	3580.	52513.
PULP & PAPER	19947.	0.	753.	0.	0.	94.	878.	21673.
CHEMICALS	6834.	9703.	1292.	0.	0.	9448.	1454.	28731.
RUBBER&PLASTIC	3729.	0.	353.	0.	0.	0.	139.	4221.
STONE & GLASS	5955.	4915.	1744.	262.	655.	0.	833.	14364.
PRIMARY METAL	4382.	146.#	2371.	5339.	181.#	0.	706.	13125.
FABRIC. METAL	2117.	0.	1031.	1548.	0.	0.	250.	4946.
NON-ELEC MACH.	798.	0.	2796.	129.	0.	0.	0.	3724.
ELECTRIC MACH.	4512.	0.	1187.	70.	0.	0.	178.	5947.
TRANSPORT EQUI	11597.	229.#	15410.	237.	0.	104.#	0.	27577.
INSTRUMENTS	1129.	0.	162.	0.	0.	0.	0.	1292.
SCRAP	2141.	87.	0.	1925.	211.	127.	72.	4562.
TOTAL	120227.	43506.	46018.	16388.	41243.	18561.	40180.	326122.

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

(1) Based on actual miles, not adjusted for circuity.

TABLE 2-6

RAIL BTUs FOR EMPTY CAR MOVEMENTS(1) BY CAR TYPE 1972

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR *	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	4001.	6570.	1540.	195.	87.	0.	9395.	21788.
METALIC ORES	128.	1069.	0.	287.	974.	0.	329.	2788.
COAL & COKE	0.	0.	0.	1010.	14297.	0.	0.	15306.
PETROLEUM	348.#	0.	193.	0.	0.	3693.	132.	4366.
NONMET MINERAL	947.	1853.	0.	976.	1489.	501.#	136.	5901.
FOOD PRODUCTS	6128.	4356.	4307.	0.	0.	2279.	11344.	28413.
TEXTILES	679.	0.	415.	0.	0.	0.	0.	1094.
LUMBER & FURN	14268.	2176.	8243.	1385.	64.#	0.	2479.	28616.
PULP & PAPER	9394.	0.	678.	0.	0.	73.	751.	10895.
CHEMICALS	2785.	5692.	1119.	0.	0.	6431.	1067.	17094.
RUBBER&PLASTIC	1875.	0.	342.	0.	0.	0.	115.	2331.
STONE & GLASS	3333.	3166.	1239.	141.	270.	0.	614.	8763.
PRIMARY METAL	2079.	150.#	2554.	3135.	92.#	0.	553.	8562.
FABRIC. METAL	1012.	0.	1043.	1010.	0.	0.	214.	3278.
NON-ELEC MACH.	478.	0.	2711.	93.	0.	0.	0.	3282.
ELECTRIC MACH.	2374.	0.	1212.	36.	0.	0.	154.	3775.
TRANSPORT EQUI	8538.	180.#	14827.	156.	0.	105.#	0.	23806.
INSTRUMENTS	508.	0.	182.	0.	0.	0.	0.	690.
SCRAP	1022.	54.	0.	1112.	129.	84.	50.	2450.
TOTAL	59895.	25267.	40605.	9535.	17403.	13165.	27332.	193201.

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

(1) Based on actual miles, not adjusted for circuity.

TABLE 2-7

TOTAL RAIL BTU CONSUMPTION BY CAR TYPE(1)

1972

10**9

COMMODITY	CAR TYPE							
	BOXCAR	COVER HOPPER	FLAT CAR *	GONDOLA	OPEN HOPPER	TANK CAR	MISC @	TOTAL
AGRICULTURE	13352.	19215.	3401.	558.	331.	0.	22050.	58906.
METALIC ORES	368.	2779.	0.	766.	3111.	0.	1066.	8095.
COAL & COKE	0.	0.	0.	2823.	48878.	0.	0.	51701.
PETROLEUM	959.#	0.	426.	0.	0.	8671.	289.	10345.
NONMET MINERAL	2683.	4896.	0.	2920.	4580.	1222.#	327.	16627.
FOOD PRODUCTS	19222.	11917.	8386.	0.	0.	5367.	29692.	74585.
TEXTILES	2015.	0.	832.	0.	0.	0.	0.	2846.
LUMBER & FURN	44985.	5643.	20570.	3663.	208.#	0.	6059.	81130.
PULP & PAPER	29341.	0.	1431.	0.	0.	167.	1629.	32568.
CHEMICALS	9619.	15395.	2411.	0.	0.	15879.	2522.	45825.
RUBBER&PLASTIC	5604.	0.	695.	0.	0.	0.	254.	6553.
STONE & GLASS	9288.	8081.	2984.	403.	925.	0.	1446.	23127.
PRIMARY METAL	6461.	296.#	4925.	8473.	273.#	0.	1259.	21687.
FABRIC. METAL	3126.	0.	2074.	2558.	0.	0.	464.	8224.
NON-ELEC MACH.	1276.	0.	5507.	222.	0.	0.	0.	7006.
ELECTRIC MACH.	6885.	0.	2398.	106.	0.	0.	332.	9722.
TRANSPORT EQUI	20136.	409.#	30237.	393.	0.	209.#	0.	51384.
INSTRUMENTS	1638.	0.	344.	0.	0.	0.	0.	1982.
SCRAP	3162.	141.	0.	3036.	340.	212.	122.	7013.
TOTAL	180121.	68772.	86623.	25923.	58646.	31726.	67512.	519324.

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

(1) Based on actual miles, not adjusted for circuity.

TABLE 2-8

RAIL ENERGY INTENSITY MEASURES

1972

COMMODITY	RAIL BTU CONSUMPTION PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET TON 10**3
AGRICULTURE	697.	450.
METALIC ORES	395.	74.*
COAL & COKE	366.	134.@
PETROLEUM	630.	397.
NONMET MINERAL	430.	101.
FOOD PRODUCTS	782.	699.
TEXTILES	1523.	1666.
LUMBER & FURN	881.	724.
PULP & PAPER	741.	735.
CHEMICALS	562.	482.
RUBBER&PLASTIC	1621.	1623.
STONE & GLASS	596.	315.
PRIMARY METAL	581.	356.
FABRIC. METAL	1168.	877.
NON-ELEC MACH.	1621.	1869.
ELECTRIC MACH.	1889.	2137.
TRANSPORT EQUI	1694.	1638.
INSTRUMENTS	1849.	2980.
SCRAP	634.	176.
	687.	370.

* Reflects short length of haul and low energy intensity per net ton-mile (influenced heavily by two way utilization of equipment in Great Lakes ore movements).

@ Reflects heavy "drag" movements and longer hauls which are inherently more energy efficient.

Atlantic Intracoastal Waterways; and

Pacific Coast Waterways.

The calculation process for energy consumption by inland waterway movements and the sources of data are described in detail in Appendix C and are summarized below.

2.5.1 Data Sources

The primary source of information for inland waterway fuel consumption was the U.S. Army Corps of Engineers.[1] Additional information was obtained through waterway simulation studies done for the Corps of Engineers at Pennsylvania State University.[2] The sources of data inputs for this portion of the analysis are discussed under three headings:

traffic data;

tow descriptors; and

waterway descriptors.

2.5.2 Traffic Data

The calculation of fuel consumption for inland waterways requires measures of traffic volume for the nation as a whole and for each waterway system. The ton and ton-mile measures by commodity group for the nation as a whole are found in the Waterborne Commerce National Summaries.[3] Ton measures by waterway were obtained to

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[1] U.S. Army Corps of Engineers, Waterborne Commerce of the United States - Calendar Year 1972, Vicksburg, Mississippi (hereafter called WCS). 1972 Annual Report of the Chief of Engineers on Civil Works Activities, Washington, D.C.

[2] Pennsylvania State University, Waterways System Simulation, U.S.A. Corps of Engineers, North Central Division, August 1971. The Illinois Upper Mississippi River Ten Lock Subsystem, U.S.C.O.E., Chicago, Illinois, October 1971. Mississippi River 12-Foot Channel Study, U.S.C.O.E., Chicago, Illinois, February 1972.

[3] WCS, op. cit., Part 5, pp. 7-9, 126-8.

calculate the characteristics of inland waterway energy intensiveness on each waterway.

In the Waterborne Commerce Statistics, tonnage data appear by commodity group for each waterway project carrying a significant amount of traffic.[1] A project is a harbor, bay, port, canal, or stretch of river (called a "reach" of the waterway). All tons traversing the project are counted in project totals, irrespective of other project reaches over which the same shipment may have travelled. To calculate tonnage by waterway system without double counting tons included on more than one project, a project-by-project analysis was done. The analysis for each waterway was conducted in one of two ways, depending on the nature of the waterway and the organization of the reported data:

> Where a consolidated tonnage report for the main stem of a waterway system exists, the main stem totals were increased by the amount of traffic which traversed all ancillary waterways but which did not touch the main stem.
>
> Where no main stem consolidated report exists and where significant amounts of data reported in the National Summary volume were not covered by regional volumes because the traffic did not traverse a U.S. Army Corps of Engineers project, all tons listed as originating or terminating on the projects within the study waterway system were summed and the total divided by two to arrive at the commodity totals for the waterway system. Thus, the greatest amount of non-Corps traffic was captured with only that traffic which both originated and terminated on non-Corps projects excluded.

Because energy intensiveness differs by direction as well as by waterway, tonnage was allocated to upstream and downstream movements for the Ohio and the Upper and the Lower Mississippi from information in the published consolidated reports for the main stem traffic as found in the WCS, Part 2. The other waterways were assumed to have zero current and therefore, for energy calculation purposes only, the traffic was arbitrarily split in half for each direction (with no resulting influence on the average energy intensiveness).

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[1] Ibid., Parts 1, 2, and 4.

The average length of haul per ton was found by dividing the reported ton-miles by the reported tons from the National Summary data.[1] To determine commodity-specific average haul values for each waterway, average haul values were estimated by waterway and distributed among commodities according to the variation about the mean found in the national average hauls by commodity. Scaling was performed so that the sum of ton-miles on each waterway equalled the national total.

2.5.3 Tow Descriptors

The modified Howe formula[2] used to calculate water speed requires the input of the following tow descriptors:

Horsepower. Installed horsepower values represent the size of the towboat. These data were provided by the U.S. Army Corps of Engineers for the Mississippi River and Gulf Intracoastal systems, by waterway. Values for the other waterways were estimated from a series of assumptions outlined in Appendix C.

Draft per Tow. These data were obtained from the WCS, Parts 1, 2, and 4, for all waterway projects, weighted where necessary by number of trips.

Engine Load Factor. This factor modifies horsepower to reflect operating conditions and optimum running loads. These load factors were estimated after discussions with several barge operators and were calculated for movements upstream and downstream and during contingency and lock delays.

Length and Width of Tow. These values were estimated on the basis of what the average horsepower boat would typically handle on each waterway.

Tons per Tow. This value was computed from average drafts for all barges, empty and loaded, and tow length and width.

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[1] Ibid., Part 5.

[2] See Appendix C.

2.5.4 Waterway Descriptors

The modified Howe formula also requires the input of the following waterway descriptors:

Channel Depth. The values selected for this study were were based on estimates of actual pool depths provided by Corps of Engineers' district offices.

Channel Width. The project widths of various reaches of each waterway were taken from an American Waterway Operators publication.[1]

Current Velocity. The velocity of the current in a river channel is dependent on the cross-sectional area of a point on the river and the volume of water per unit of time passing through that point. The speeds thus calculated for each reach were weighted by the length of the reaches and an average current speed was found.[2] Based on discussions with barge operators, these estimates were extended to the noncoastal waterways based on a set of assumptions discussed in Appendix C.

Number of Locks per Mile by Waterway. The number of locks within each waterway segment was divided by the length of that segment and then weighted by the tons of traffic on that segment to arrive at an average. The average lock-per-mile value was multiplied by the average haul by commodity to determine the average number of locks traversed by a typical tow on the waterway. This value was multiplied by the delay time in hours to determine the total lock delay attributable to each commodity and each waterway.

Lock Delay Times. The delay times resulting from inclement weather, congestion, and other conditions used in this study were calculated from waterway simulation

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[1] American Waterway Operators, Big Load Afloat, Washington, D.C., 1973.

[2] Pennsylvania Transportation & Traffic Safety Center, Waterway Systems Simulation Vol. IV, Penn. State U., University Park, PA 1971, pp. 63-4.

studies done by Penn State University[1] and the Chicago District Office of the Corps of Engineers and increased to 1972 values based on corresponding growth in tonnage. This calculation was made for the Ohio and Upper Mississippi with adjustments made for the remaining waterways. A lockage delay time was added to these delay values to arrive at total lockage time.

2.5.5 Methodology

The process of computing energy consumed in inland waterway movements by commodity group and waterway involved computing running speeds, running and idle hours, and the resulting horsepower hour requirements. Specifically, still-water speed was computed from tow and waterway characteristics from the Howe formula, empirically modified to correlate to larger tows. To account for variations in the energy intensity between upstream and downstream operations, tow speed was computed for a typical tow going up and downstream by adding the water speed to the still-water speed for downstream trips and deducting the water speed from the still-water speed for upstream trips. A running time per trip was then computed for each commodity group and waterway for upstream and downstream movements from average haul and tow boat speeds. The total horsepower hour requirements corresponding to the trip running times were computed by multiplying each time value by the average installed horsepower of tow boats in each waterway, modified by an engine load factor reflecting the percent utilization of installed horsepower.

Delay time per trip resulting from inclement weather, congestion, and other conditions was computed and added to lock delay estimates. Average delays per mile were computed from the average number of locks per mile of waterway, the average delay per lock, and the average length of haul. Delay hours were converted to horsepower hours for idle time per trip from the appropriate horsepower factor modified by the engine load factor.

The total Btu consumption per trip for each commodity group and waterway was estimated for the total horsepower hour requirements for the trip. This estimate, when divided by the product of length of haul and tons per tow for each commodity group and waterway, yielded an estimate of Btus per ton-mile. Finally, Btu per ton values were estimated from Btus per ton-mile multiplied by average length of haul.

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[1] Ibid., pp. 38-9.

2.5.6 Outputs

Tables 2-9 and 2-10 show resulting base case energy consumption estimates for inland waterways for 1972. Since tow characteristics are assumed to vary by waterway, but not by commodity, variation in energy intensity among commodities results from the commodity mix on the different waterways. Empty hauls are presumed to be part of a mixed tow and are accounted for by the tow dimensions and the total tons carried in a mixed tow.

2.6 COASTAL AND GREAT LAKES SHIPPING

This component of the analysis was concerned with computing energy intensity values by commodity group for coastal movements in domestic deep sea shipping, including Great Lakes shipping. This shipping category also includes coastwide shipping by oceangoing tug-barge configurations which are not included in the inland waterway component of the analysis.

Because modal share for barges and coastal ships varies by commodity, this component of the analysis computed energy intensity for both shipping modes. Calculations for energy consumption for coastal shipping were similar to those for inland waterway. These calculations and the sources of data and data assumptions are outlined below and described in detail in Appendix D.

2.6.1 Data Sources

An accurate analysis of coastal shipping is extremely difficult because of the serious lack of summary data on ships engaged in coastal trade and the intermingling of international with domestic cargos on many ships. The methods and assumptions for this component are based on readily available data and are intended to give a general indication of this mode in relation to other modes and to permit analysis of the effects of changes in speed and ship size on energy consumption. Comparison of energy intensities developed in this study with those of others suggests a wide range in energy intensity and consumption estimates, as much as a 75 percent difference.

The input data for this portion of the analysis fall into three categories: commodity characteristics, ship characteristics, and barge tow characteristics. The source of the commodity related data is a report published by the U.S. Department of the Army, Corps of

TABLE 2-9

BARGE BTU CONSUMPTION

1972

COMMODITY	BTUS PER TON	BTUS PER TON-MILE *	TOTAL BTUS 10**9
AGRICULTURE	124101	172	6484
METALIC ORES	211139	263	1102
COAL & COKE	83702	296	9970
PETROLEUM	91835	321	15445
NONMET MINERAL	64878	339	4651
FOOD PRODUCTS	165597	201	1031
TEXTILES	185706	306	6
LUMBER & FURN	17906	226	310
PULP & PAPER	54598	221	137
CHEMICALS	189381	290	6245
RUBBER&PLASTIC	84501	169	0
STONE & GLASS	80698	230	508
PRIMARY METAL	216054	240	1796
FABRIC. METAL	194122	231	67
NON-ELEC MACH.	119748	284	31
ELECTRIC MACH.	259525	265	11
TRANSPORT EQUI	60250	270	1
INSTRUMENTS	9722	373	8
SCRAP	38170	310	487
	95742	272	48298

* Actual miles, not adjusted for circuity.

TABLE 2-10

BARGE BTUs PER TON-MILE BY WATERWAY

1972

WATERWAY	UPSTREAM	DOWNSTREAM
OHIO *	456	173
UPPER MISS. @	495	182
LOWER MISS. #	276	103
GIWW **	475	475
AIWW @@	330	330
PACWW ##	242	242

*	Ohio River System
@	Upper Mississippi River System
#	Lower Mississippi River System
**	Gulf Intracoastal Waterway
@@	Atlantic Intracoastal Waterway
##	Pacific Coast Waterways

Engineers.[1] This report provided data on tons, ton-miles, and the proportional split between coastal ship and barge movements for each commodity group.

Three typical ship types were selected for analysis: dry bulk, break bulk, and tanker. The most typical ship type was assigned to each commodity group. For each ship type, a set of assumptions was made to estimate values for average speed, average size, number of ports per trip, ship capacity utilization factors, delay factors, and port time. For each tow, assumptions were made to estimate tow size, speed, horsepower engine load factor, and Btus per horsepower hour. These assumptions are contained in Appendix D.

2.6.2 Methodology

The procedures used to estimate energy consumption are similar for ships and for barges. Running hours per trip are computed by commodity group from ton-miles, tons, and the speed of the typical ship used in shipping that commodity. Idle hours per trip are computed from the number of ports called per trip, the hours spent at each port, and a delay factor. Running and idle hours are then converted to Btus consumed per trip, total Btus for the year's shipping volume, and Btus per ton and ton-mile.

2.6.3 Output

Tables 2-11 and 2-12 show the 1972 base case output for the coastal and Great Lakes shipping component of the analysis. Different energy intensities for the different commodity groups result from differences in ship type, length of haul, and number of ports of call (which result in differences in the ratio of running time to idle time).

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[1] WCS, op. cit., Part 5, pp. 7-9 and 126-8.

TABLE 2-11

COASTAL AND GREAT LAKES SHIP BTU CONSUMPTION

1972

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	217933	198	340.
METALIC ORES	151420	203	10527
COAL & COKE	64659	232	1026
PETROLEUM	240082	170	42104
NONMET MINERAL	94220	215	1890
FOOD PRODUCTS	638767	313	319.7
TEXTILES	661904	312	124
LUMBER & FURN	308157	194	.748
PULP & PAPER	285003	330	268
CHEMICALS	666782	312	6685
RUBBER&PLASTIC	530640	315	52
STONE & GLASS	78318	222	443
PRIMARY METAL	564923	314	1106
FABRIC. METAL	551887	315	319
NON-ELEC MACH.	581424	314	156
ELECTRIC MACH.	626891		87
TRANSPORT EQUI	370338		227
INSTRUMENTS	476871		192
SCRAP	128216		26
	264074		6951.7

TABLE 2-12

COASTAL AND GREAT LAKES BARGE BTU CONSUMPTION

1972

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	348241	317	544
METALIC ORES	0	0	0
COAL & COKE	101819	365	1322
PETROLEUM	309704	219	7406
NONMET MINERAL	149344	342	4493
FOOD PRODUCTS	630851	309	166
TEXTILES	653957	309	1
LUMBER & FURN	493296	311	513
PULP & PAPER	277557	321	8
CHEMICALS	658829	308	816
RUBBER&PLASTIC	522867	311	1
STONE & GLASS	123779	352	742
PRIMARY METAL	557105	310	223
FABRIC. METAL	544086	310	110
NON-ELEC MACH.	573584	310	43
ELECTRIC MACH.	618991	309	7
TRANSPORT EQUI	362778	316	36
INSTRUMENTS	0	0	0
SCRAP	204000	329	44
	210931	274	16481

2.7 PIPELINES

For this study, calculation of pipeline energy intensity involved computations disaggregated by product type and pipeline size. The sources of data and methodology used in calculating pipeline energy intensity are outlined below and discussed in more detail in Appendix E.

2.7.1 Data Sources

To calculate energy consumed for crude and products pipeline movements in regulated lines (non-regulated lines have inadequate data), the following data were used:

barrels per day by products and crude - obtained from the U.S. Bureau of Mines;[1]

average length of haul per barrel - calculated as the ratio of annual barrel miles to annual barrels originated, obtained from Interstate Commerce Commission data on regulated common carrier pipelines;[2]

miles of pipeline for products and crude by pipeline size - obtained from U.S. Bureau of Mines publication of pipeline mileage reports;[3]

inside diameters by pipeline size - obtained from American Petroleum Institute reports[4] and discussions with industry engineers;

barrels per ton for products and crude - obtained from the American Petroleum Institute[5] and converted to

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[1] U.S. Department of the Interior, Bureau of Mines, Mineral Industry Surveys, Petroleum Statement Annual 1972, December 1973, p. 31.

[2] Interstate Commerce Commission, Transport Statistics in the United States, Part 6, 1972, Washington, D.C., Table 4.

[3] U.S. Department of the Interior, Bureau of Mines, Mineral Industry Surveys: Crude Oil and Product Pipelines, December 1971, p. 2.

[4] Petroleum Extension Service, Oil Pipeline Construction and Maintenance, Texas Education Agency and American Petroleum Institute, April, 1973.

[5] American Petroleum Institute, Petroleum Facts and Figures, 1971 Annual, Washington, D.C.

specific gravity measures for use in energy consumption calculations; and

friction factors - obtained from the Standard Handbook for Mechanical Engineers.[1]

A value for energy conversion efficiency was estimated based on the efficiency of the four types of pumping stations involved in pipeline transport: electric motor, gas turbine, liquid fuel turbine, and diesel engine. The efficiency of each conversion system and power source varies and is dependent on the condition of the system and the distance from the source of power. Estimated efficiency values range from 24 percent to 37 percent. For this study, a level of 30 percent was selected for pipeline energy conversion efficiency as representative and was used to adjust the relation between horsepower and Btus.

2.7.2 Methodology

The most sensitive assumption in the pipeline methodology concerns the fluid velocity used. Interviews with knowledgeable industry personnel and a literature search could not provide good, reliable, weighted average velocity profiles by pipeline diameter and commodity. Figures 2-2 and 2-3 illustrate the basis for assuming pipeline velocities for products and crude lines for lines of various diameters. Each line represents a Btu/velocity profile curve for product or crude for each pipeline diameter. Using best estimates of 1.5 mph weighted average speed for products in a 2-inch line, and 6.5 mph in a 48-inch line, a straight line was drawn to provide the weighted average energy intensity/velocity profile for pipelines of various size. Formulas used to plot these curves are discussed in Appendix E. For crude, velocity assumptions were 1 mph for 2-inch lines and 5 mph for 48-inch lines. The "duty cycle" (time duration of various velocities, pressures, etc.) was not estimated.

Given the assumed velocity, a flow rate and pressure drop per mile of pipe were calculated for each pipeline size for crude oil and each product. The pressure drop is necessary to calculate horsepower requirements. By stating horsepower requirements by mile of pipe, assumptions concerning pump station spacing or total pump head are available. Further, when horsepower per mile of pipe is divided by the flow rate in barrels per hour, the result is horsepower hours

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[1] Theodore Baumeister, editor, Standard Handbook for Mechanical Engineers, New York: McGraw-Hill, 1967.

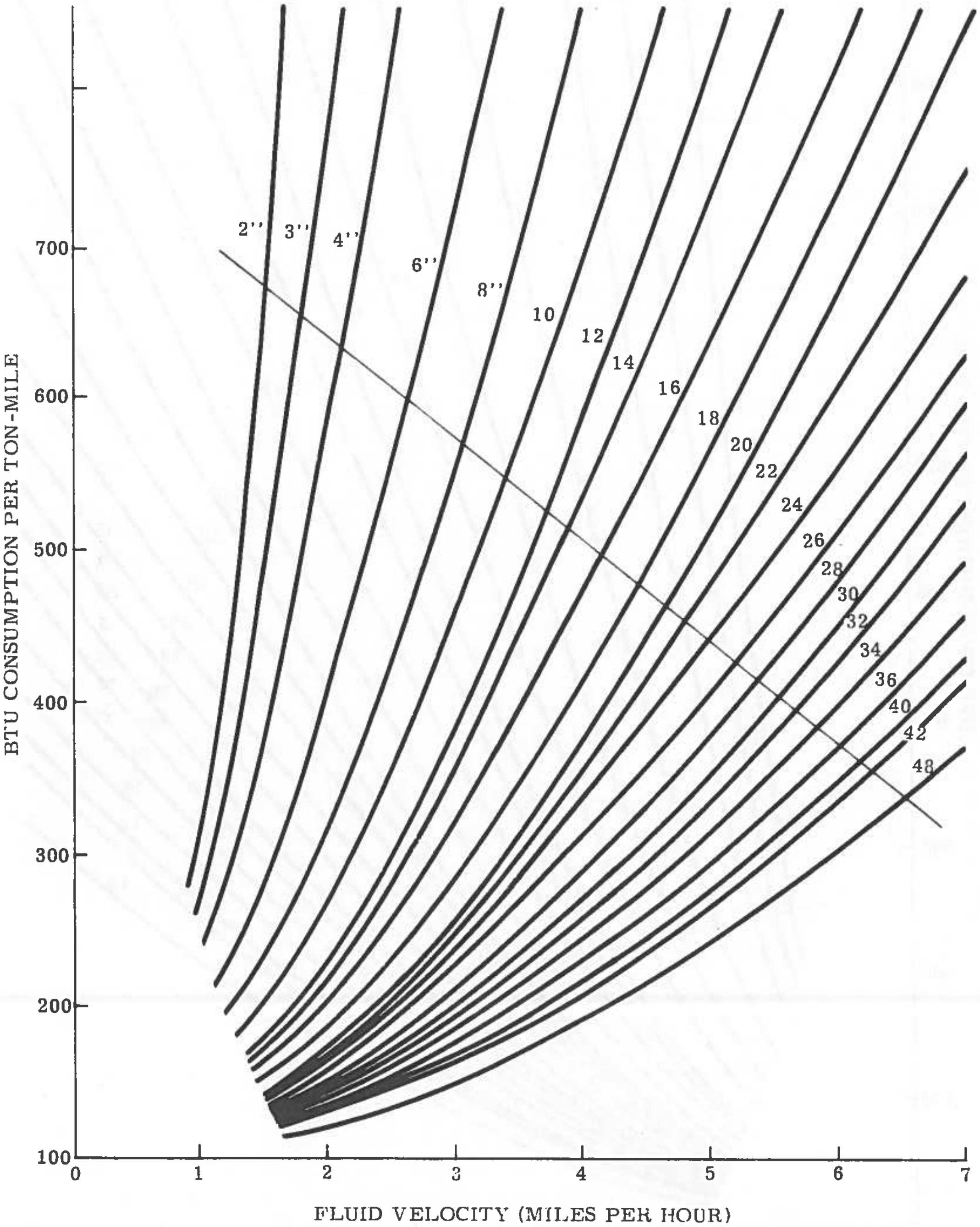

FIGURE 2-2: ASSUMED VELOCITIES BY PIPELINE SIZE FOR PRODUCTS PIPELINES

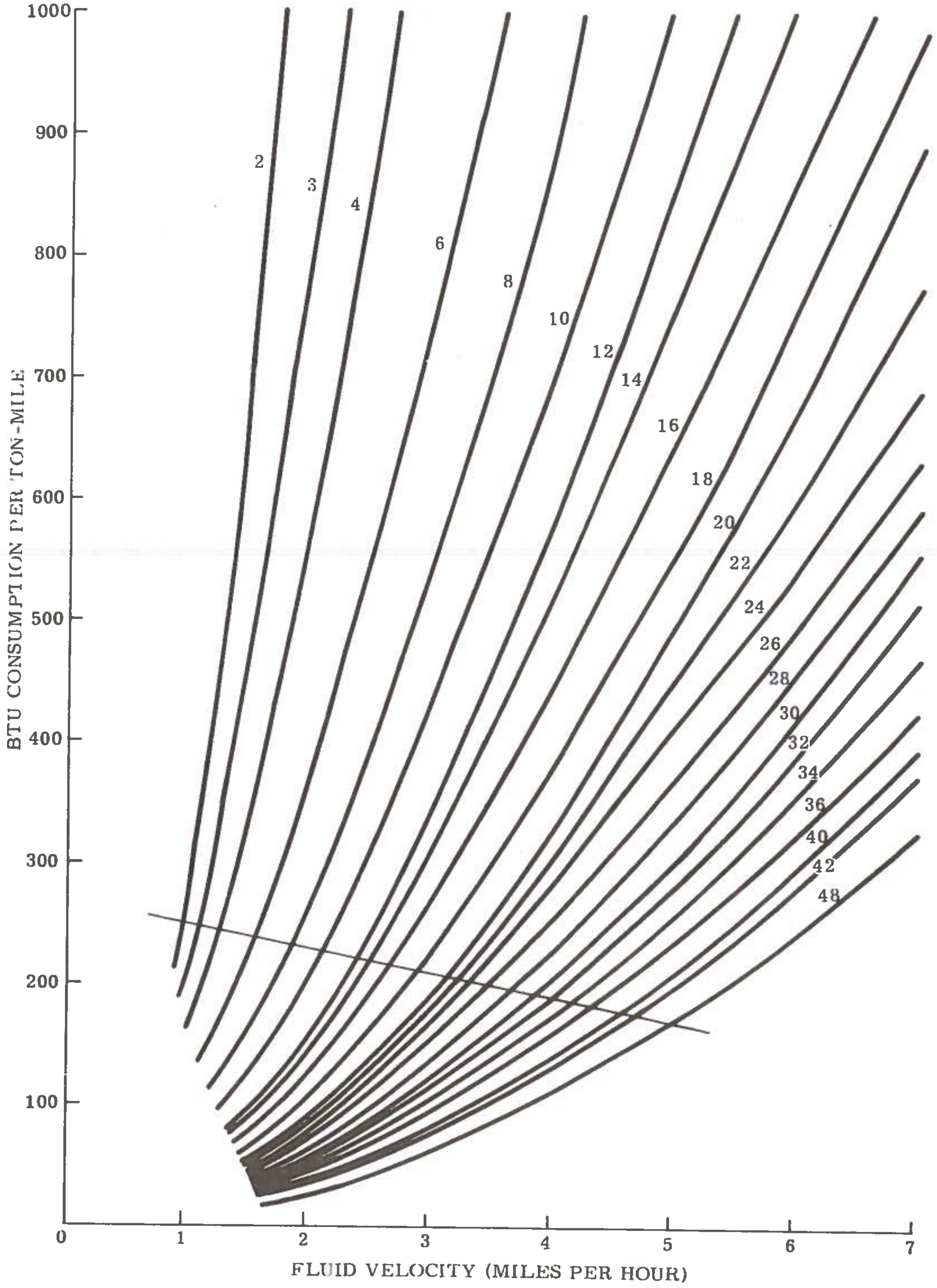

FIGURE 2-3: ASSUMED VELOCITIES BY PIPELINE SIZE FOR CRUDE LINES

per barrel-mile. One horsepower hour equals 2,547 Btus, which, when divided by the efficiency of the pump (.3) and adjusted for the number of barrels in a ton, yields the energy consumption per ton-mile. Figures thus obtained are for each pipeline size for crude oil and each product. An overall weighted average was found for crude and for products as well as total petroleum movements. To distribute actual ton-miles by pipeline size (and hence identify a corresponding total energy consumption), the assumed flow rate for each diameter line was multiplied by the corresponding miles of product or crude and divided by the sum total of ton-miles so calculated to estimate the proportion of total actual ton-miles assumed to be moved by each line (this further assumes a similar duty cycle for all lines).

In addition to differences in viscosity (friction factor), different size lines and velocities are responsible for the different energy intensities for product and crude. Because of the lack of data and assumptions in this study, more needs to be done to more accurately and reliably assess pipeline energy intensity.

2.7.3 Output

Table 2-13 shows the output of this analysis for the 1972 base case.

2.8 AIR CARGO

Air cargo moves in all-cargo aircraft or in the underbelly of passenger aircraft. The energy intensity of movements for each type of aircraft is calculated separately in the TRANSEN model. The energy intensity for cargo moving in passenger aircraft is computed in two ways based on two assumptions:

> Marginal Approach - passenger aircraft would move without cargo, since its primary purpose is to transport passengers. Therefore, the cargo share of the energy consumed is assumed to be the incremental amount of energy used to transport the cargo beyond what would be needed to transport the passengers.
>
> Pro-Rata Approach - the cargo in the passenger aircraft consumes its proportional share of the energy used in the flight.

Because of the absence of data by commodity for air cargo moves, the model computes the energy intensity of total air cargo movements but does

TABLE 2-13

PIPELINE TRAFFIC MEASURES
1972

PETROLEUM	TONS 10^3	TON-MILES 10^6	AVERAGE HAUL MILES
Crude	489,055	206,381	422
Products	389,645	157,027	403
TOTAL/AVERAGE	878,700	363,408	414

ENERGY CONSUMPTION

PETROLEUM	TOTAL BTUs 10^9	BTUs/TON	BTUs/TON-MILE
Crude	42,721	87,354	207
Products	59,513	152,737	379
TOTAL/AVERAGE	102,234	116,334	281

not allocate them to the specific commodity groups. The estimation process is described below, and the details are provided in Appendix F.

The basis for the calculation of energy intensity is the distribution of tons by commodity, with the commodity detail provided for projection purposes. The 1970 tonnage allocations by commodity[1] were upvalued to 1972 and adjusted to Civil Aeronautics Board (CAB) totals.

Data from the CAB provided the percentage distribution of cargo ton-miles for each type of movement (all cargo and passenger).[2] These data, however, were modified using special study data prepared by the Transportation Systems Center which reduced some of the data inconsistencies of CAB reported data. CAB data also reported average length of haul values on each type of movement, from which ton-mile values were computed.

Btu per ton-mile estimate for 1972 for all cargo aircraft were obtained from the value for total fuel consumed by these aircraft as reported by the CAB.[3] Passenger aircraft energy intensity measures were taken from a study conducted at TSC.[4] The TSC study examined the fuel consumed by the narrow-body, four-engine and wide-body, three-and four-engine aircrafts and measured sensitivity to passenger and cargo-load factors and flight length. The energy consumption values in the study, developed from information in manufacturers' technical performance manuals, were used in manual simulations of representative operations to compute energy consumed. The values selected from the study for the TRANSEN calculations were based on load-factor and stage-length assumptions corresponding to those reported by the CAB and on the aircraft mix reported by the Federal Aviation Administration.

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[1] Jack Faucett Associates, Inc. Transportation Projections 1970-1980, March 1973.

[2] Civil Aeronautics Board, Handbook of Airline Statistics, 1973 Edition, Washington, D.C.: CAB, 1974.

[3] CAB, op. cit.

[4] Domenic J. Maio and Michael Mui, An Analysis of Air Systems Fuel Consumption for Combination Passenger/Cargo Service, Cambridge, Massachusetts, Transportation Systems Center, 1974.

Finally, Btus per ton-mile estimates were combined with ton-mile estimates to compute Btus consumed overall and per ton-mile for the air cargo sector under both assumptions as to cargo consumption in passenger aircraft. Table 2-14 shows the resulting energy consumption estimates for air cargo movements for 1972.

TABLE 2-14

AIR CARGO TRAFFIC MEASURES
1972

COMMODITY	NET TONS
1. Agriculture	159,000
2. Metallic Ores	0
3. Coal and Coke	0
4. Petroleum	0
5. Non-Metallic Minerals	0
6. Food & Kindred Prod.	29,000
7. Textiles, Apparel & Leather	105,000
8. Lumber & Furniture	10,000
9. Pulp, Paper & Allied	25,000
10. Chemicals & Allied	132,000
11. Rubber & Plastics	108,000
12. Stone, Clay & Glass	21,000
13. Primary Metal	58,000
14. Fabricated Metal Prod.	137,000
15. Machinery ex. Elec.	210,000
16. Electrical Machinery	422,000
17. Transportation Equip.	128,000
18. Instruments & Misc. Mfg.	78,000
19. Waste & Scrap	0
20. Other	819,000
TOTAL	2,441,000

TYPE OF AIRCRAFT	NET TONS	NET TON-MILES 10**3
Cargo	683,000	772,473
Passenger/Cargo	1,758,000	738,360
TOTAL	2,441,000	1,510.833

AIR ENERGY CONSUMPTION MEASURES
1972

MEASURES		FUEL USE BASED ON: INCREMENTAL ENERGY ASSUMPTION	FUEL USE BASED ON: SHARED ENERGY ASSUMPTION
BTUs($x10^9$)			
Cargo		18,787	18,787
Passenger		2,649	41,570
Cargo and Passenger Plane Weighted Average:	TOTAL	21,436	60,357
BTUs per Ton ($x10^3$)		8,782	24,726
BTUs per Ton Mile		14,188	39,949

3. ENERGY CONSERVATION MEASURES

Freight transportation energy can be conserved by:

reducing demand for freight transportation services;

improving the energy efficiency of each transportation mode; and

substituting more energy efficient for less energy efficient transportation modes.

This study assumes a demand for transportation services which grows at a rate parallel with the GNP, as historically shown. Thus, only the second and third means of reducing transportation energy consumption are considered in this study.

This section examines potential operational and technological changes in each transportation mode that could reduce transportation energy consumption. However, a change that improves the energy efficiency of a mode may make the mode less attractive and therefore induce a transfer to another mode which is either more or less energy efficient.

The discussion of operational and technological changes to achieve energy savings includes an analysis of what each mode could achieve, with and without government assistance to reduce energy consumption. Government involvement in energy conservation can occur in the form of setting policy, providing financial incentives or rewards, changing regulatory procedures, and building public facilities.

This section concludes with a discussion of rail/truck modal shifts that could result in improved overall transportation energy efficiency. Modal shifts are discussed in terms of how shifts might be induced and what the extent of the shifts might be.

3.1 TRUCKING

Trucking is sometimes called an industry. However, its components and operations are so diverse that trucking can only be examined by components such as common carriers of regular freight, contract carriers, private carriers, special commodity carriers, etc. The use of motor vehicles to carry freight on public highways is almost the only common element. Some of the vehicles are general purpose (e.g., box or flat bed) suitable for carrying many different products. Others are specially designed (e.g., auto rack or refrigerator) and suitable for carrying only one or a few commodities. Some, like agricultural carriers (exempt from economic regulation), may go anywhere and serve anyone wishing transport of exempt commodities. Others, such as common carriers of general freight, serve anyone desiring to transport general freight along routes or within an area defined by the carrier's operating certificate. Also, contract and private carriers may go anywhere and carry anything but are restricted to serving limited, specific customers or a company's own goods.

Although the differences in trucking are recognized, this study must work with some averages and assumptions. When better and more data are available, trucking can be studied in more specific detail.

This section discusses some trends in the energy efficiency of the vehicle and some of the relationships among the vehicle, its operation, and fuel consumption.

3.1.1 Overview of Recent Trends

A survey of key engineering and management people in the trucking industry conducted by Automotive Engineering magazine[1] in 1973 may be summarized as follows:

> Government regulation of vehicle specifications will increase standardization and reduce options in truck components.
>
> Payload losses will result from additional curb weight due to federally mandated pollution and safety equipment.
>
> Pollution controls will strengthen the advantages of diesel over gasoline engines in the short-term.
>
> The gas turbine will become available for higher horsepower trucks.
>
> Automatic transmissions will be used, more often, especially in trucks used in short hauls and local service.
>
> Containerization will increase.
>
> The Wankel engine may be used in light trucks.

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[1] John P. Covington, i.e., "The Next Ten Years in Truck Technology," Automotive Engineering, V81:6, June 1973, pp. 27-82.

> Continuous improvement is expected in product handling methods and equipment.
>
> The emergence of any radical new technology is not anticipated.

This survey was conducted before the tripling of the price of imported petroleum and the Arab oil embargo. However, people were already speaking of a fuel crisis. Conservation methods mentioned included switching to diesel or multi-fuel engines and the increasing use of computers for fleet management. The use of sophisticated management techniques could mean higher fleet use and fewer empty miles. A market switch to diesel engines was predicted, and an overall trend toward higher horsepower for all trucks was cited as "becoming conspicuous."

Figure 3-1 shows a trend toward diesel engines in trucks over 33,000-pound gross vehicle weight (GVW) through 1972. This figure also shows a trend toward a greater proportion of new truck purchases in the over 33,000-pound GVW class. The increased relative demand appears to have come from the previous market for medium (26,000-33,000-pound GVW) trucks. Some increase in dieselization has occurred in the 26,000-33,000-pound GVW class, although it is not pronounced. The severe drop in 1975 sales may be attributable to two primary causes: (1) the general economic downturn and (2) an industry reaction to new federal standards for air brake design and performance, which add considerable cost and complexity to large truck-trailer combinations. Consequently, the drop in percent of diesel may be partly attributable to the air brake legislation. Carriers are continuing to replace their smaller, local delivery vehicles, which do not require a complex brake system, and are waiting for a change in regulation or a less expensive, new brake system.

Figure 3-1 presents a mixed and inconclusive picture of trends in the size and dieselization of the truck fleet. The general belief that the price of fuel will lead to greater adoption of diesel power is not yet strongly supported. Because of mitigating circumstances, however, the study team supports the belief that diesel engines will increase their dominance. This belief is reflected in fleet projections for the industry analysis case.

Another important change to the basic operating conditions affecting trucking in recent years is the reduction of speed limits to 55 miles per hour (mph). As a result of this change in the law, the average speed on major rural roads decreased by 2.6 mph.[1] However, average

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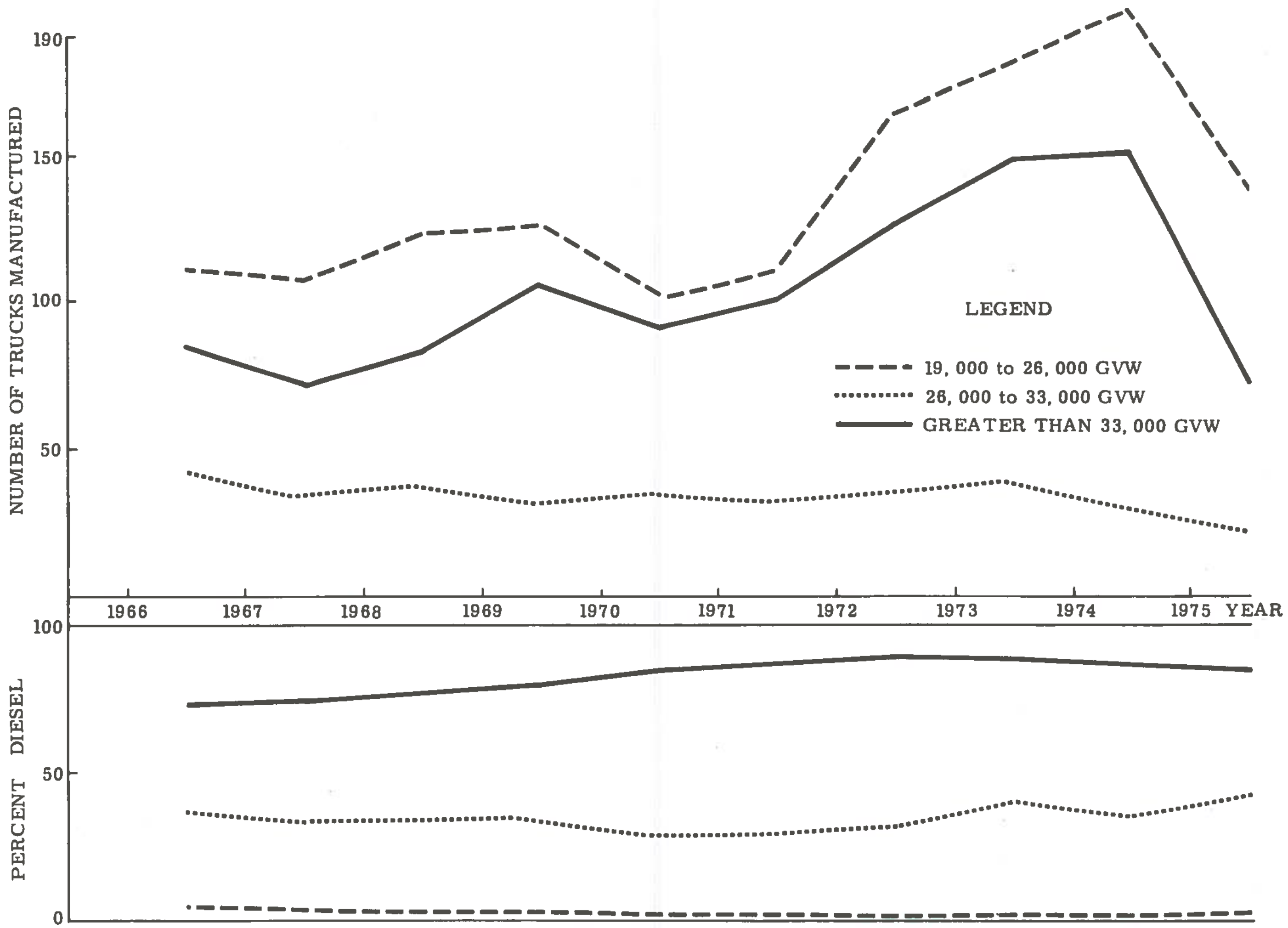
[1] See Table 3-1.



SOURCE: Motor Vehicle Manufacturers Association, Motor Truck Facts, 1975. (Domestic Factory Sales) (1974 and 1975 data obtained by telephone from the MVMA office in Detroit).

FIGURE 3-1: NUMBER OF TRUCKS MANUFACTURED AND PERCENT DIESEL BY WEIGHT CLASS speed does not reflect the true importance of the change. Examination of the percent of trucks exceeding 55, 60, and 65 mph shows the impact of the change in the law on truck operations. Table 3-1 gives speed data for major rural roads. The pattern or dispersion of speeds seems to have been narrowed. Thus, the average speed is not so greatly affected as the standard deviation, or the frequency of trucks and other vehicles traveling at speeds greatly different from the average. Two things may be inferred: (1) fewer vehicles are traveling at very high (over 60 mph) and very energy inefficient speeds and (2) traffic flow is smoother with fewer variations in speed per mile of travel, which is also energy efficient.

The effect of operating speed on truck fuel consumption is discussed below. Since the average speeds are close to 55 mph for the 1972 base year and are assumed to be constant for 1980 and 1985, the TRANSEN model does not attribute any savings from the base case due to changes in operating speeds. A more detailed analysis based on frequency distribution of prevailing speeds was beyond the scope of this study.[1]

Trends are not readily identifiable in an industry as diversified as trucking. Therefore, the development of future year scenarios is based on a more intuitive sense of what is happening and an analysis of the various relationships among factors (parameters) that affect truck fuel consumption.

3.1.2 Operational Changes

Research and interviews with industry experts suggest that as long as fuel is readily available, radical operating changes are not likely to occur in the next ten years. Progress is expected to continue to be evolutionary and to center on reducing circuity and empty truck-miles and improving trip productivity (net-tons per truck-mile). The fleet mix of truck sizes is not expected to vary significantly except that, where possible, trailer size is expected to continue to increase to the limits of the law. For economic reasons, including higher fuel costs, all carriers are working to improve net ton-mile productivity per truck mile. Three major potential changes in trucking operating--capacity utilization, speed, and fleet makeup--are discussed below.

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[1] The TRANSEN model could be modified to perform this analysis with the introduction of new data.

TABLE 3-1

PREVAILING SPEEDS ON MAJOR RURAL ROADS

YEAR	AVERAGE SPEED (MPH)		PERCENT OF VEHICLES EXCEEDING:					
			55 MPH		60 MPH		65 MPH	
	ALL VEHICLES	TRUCKS	ALL VEHICLES	TRUCKS	ALL VEHICLES	TRUCKS	ALL VEHICLES	TRUCKS
1973	60.3	56.6	70%	58%	50%	33%	31%	15%
1974	55.3	54.0	51%	44%	21%	N/A	6%	N/A
1975	55.8	54.8	55%	49%	21%	N/A	6%	N/A

Source: Federal Highway Administration, Highway Facts and Figures: 1973, (1974 and 1975 data provided by FHWA via telephone).

3.1.3 Changes in Capacity Utilization

Truck capacity utilization, as used in this study, consists of two components:

> proportion of truck capacity loaded (i.e., load factor, h); and
>
> proportion of total miles carrying a load (1-b, where b is the proportion of total miles which are traveled empty).

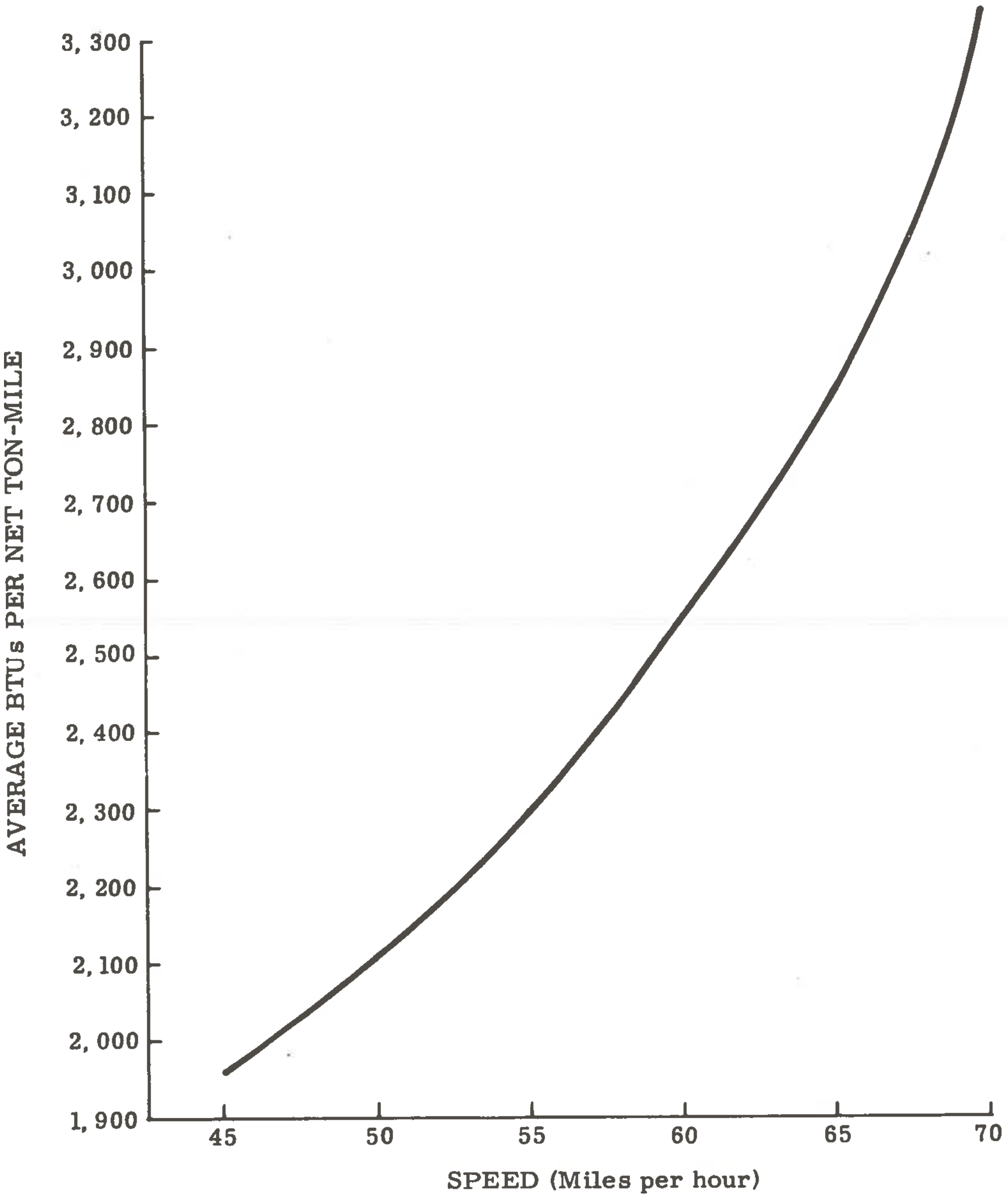
Load factor may be weight-limited or volume-limited depending upon the density of the commodity carried. Overall, capacity utilization can be defined as (1-b)h.

For a given capacity utilization factor, fuel consumption will be less if the proportion of empty miles is decreased and the load factor correspondingly increased. This is because fuel consumption increases marginally (at a lower rate of change) with increases in load, while backhaul fuel consumption rate decreases at a much larger rate directly in proportion to empty miles saved. In the TRANSEN model, however, the simplifying assumption was made that fuel consumption rates vary linearly with load, the effect of changing either b or h on fuel consumption is equivalent in the model. This assumption does not introduce a large error and reduces the complexity of calculations considerably.

3.1.4 Changes in Speed

Resistance forces increase with increased speed--some linearly and some exponentially. Therefore, for any distance traveled, the work (defined as the product of resistance times distance) required increases with increasing speed. The incremental energy consumed as speed increases is a function of energy efficiency, that is, the ability to convert potential chemical energy (Btus) into useful work.

Figure 3-2 shows the relationship between average Btus per ton-mile at different speeds for the total fleet. These relationships were developed by computing the average values of all commodities and all truck types. The figure illustrates that the amount of energy consumed in trucking increases with increased speed at an increasing rate. Thus, at 55 miles per hour, a 1 percent reduction in speed will be expected to yield a 0.877 percent reduction in fuel use, while a 1 percent increase in speed will result in approximately an 1.218 percent increase in fuel use.



Source: Based on calculations from the TRANSEN Model for 1980.

FIGURE 3-2: ILLUSTRATION OF TRUCKS BTUs PER NET TON-MILE VERSUS SPEED AVERAGED FOR ALL COMMODITIES AND ALL OVER-THE-ROAD TRUCKS

Figure 3-3 illustrates the increasing energy requirements for higher speeds. The horsepower required to overcome the different resistances to which trucks are subject increases with higher speeds. Figure 3-3 shows the cumulative requirement by type of resistance. Mechanical resistance (i.e., the internal friction of the engine and drive train) increases linearly with speed. Rolling resistance (i.e., the friction of tires on the road surface) increases at a slightly greater rate with increasing speed, and air resistance (i.e., the friction of air against the truck body--mostly frontal area) increases at an increasing rate with speed. The air resistance computed assumed a zero wind velocity.

At low speeds, rolling resistance is the greatest portion of total resistance. At 70 miles per hour, air resistance is equal to rolling resistance for a large, fully loaded truck. The dashed line in Figure 3-3 indicates the rolling resistance due to the empty truck.

3.1.5 Changes in Fleet Make-Up

Fleet make-up effects fuel consumption in a very direct fashion. A savings of from 114 to 170 Btus per net ton-mile may be realized by switching from a large, semitrailer truck (over 70,000 lbs. GVW) to a twin trailer ("double bottom"), according to the data used in the TRANSEN model.[1] According to the American Trucking Association, a switch from a 57,500 lb. GVW, 40-foot semitrailer to a 73,280 lb. GVW, 65-foot twin trailer for light and bulky freight can save 2,812 gallons of diesel fuel per one million net ton-miles[2] or 386 Btus per net ton-mile. This comparison does not correspond exactly to the type of analysis for which the TRANSEN model was designed. However, it further illustrates the great potential for conserving energy by increasing cubic capacity of some commodities.[3]

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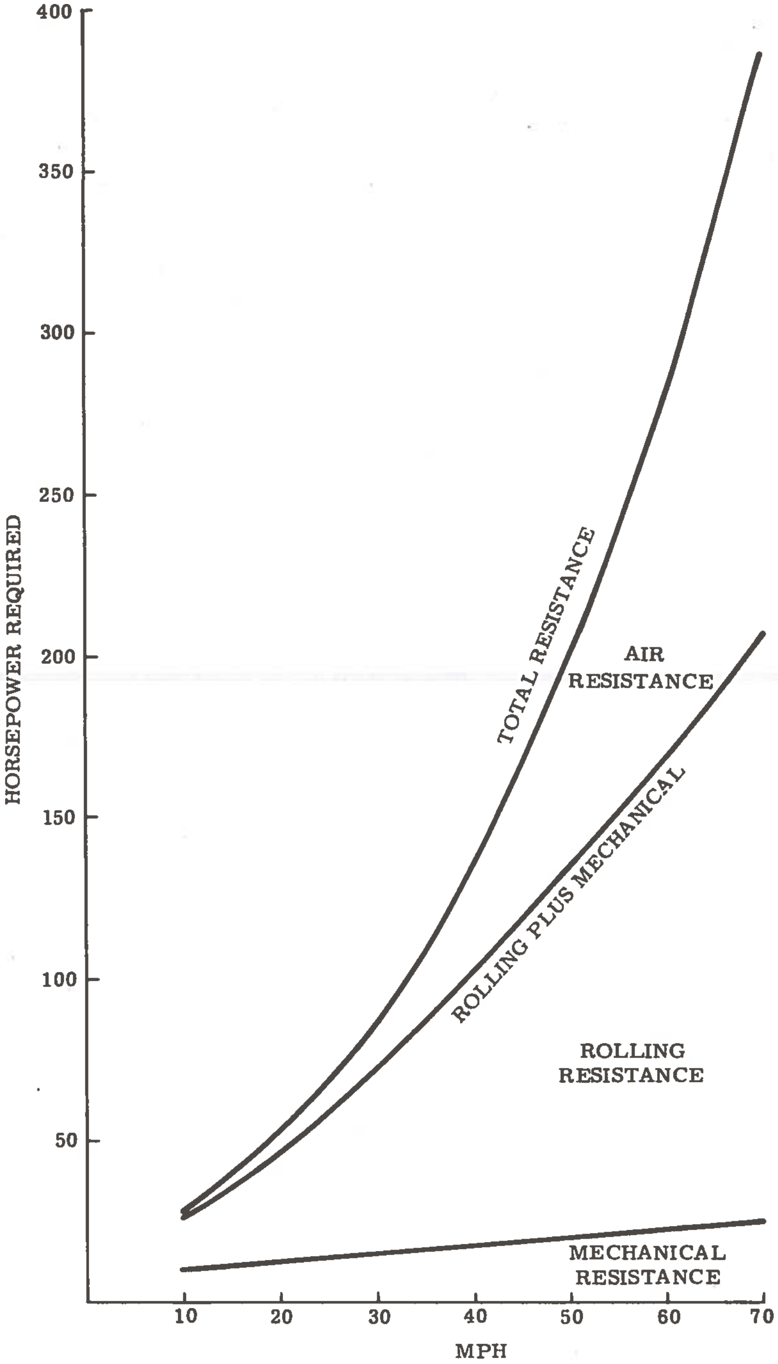
[1] See Appendix A for capacities and fuel consumption rates used in the TRANSEN model.

[2] American Trucking Association, American Trucking and Energy Crisis, Washington, D.C., April 1973, p. 9.

[3] This problem could be solved by characterizing truck types by cubic volume as well as weight limits. Doing so would add considerably to the complexity of the model, and could not have been done within the scope of the study.



*70, 000-lb. GVW,
5 axle, 109 sq. ft. frontal area

Source: Calculated from SAE Method J-688, Truck Ability Prediction.

FIGURE 3-3: TOTAL HORSEPOWER REQUIREMENT BY TYPE OF RESISTANCE AND SPEED*

Table 3-2 shows the Btus per net ton-mile implied in the model assumptions for the full range of trucks studied and at the three commodity density factors used.[1] If load factors can be maintained, any shift of operations from a light-capacity truck to a high-capacity truck will result in a fuel savings.

3.1.6 Changes in Technology

This study considered changes in truck technology related to the engine, the drive train, and the vehicle itself. Technological changes affect thermal efficiency, rolling resistance, air resistance, parasitic loads, and other sources of energy losses.

3.1.7 Engine Optimization

As discussed above, slower speeds require less horsepower, which in turn requires less fuel to move a given load a given distance. The relationship between engine horsepower output and fuel input is not linear, as indicated in Figure 3-4. This graph shows fuel consumption curves for a typical supercharged diesel engine. The horizontal axis is measured in percent of governed engine rpm for engines governed according to industry standards. If this engine were derated, the effect would be to lower the maximum governed engine speed without shifting the fuel consumption curves. The vertical axis is measured in percent of rated power. Rated power depends upon cubic displacement and the air intake capabilities (supercharging) of the engine.

Engine optimization involves choosing an engine size which satisfies service requirements while operating at the lowest possible fuel consumption rate. Figure 3-4 shows a fairly wide range of horsepower and engine speeds near the optimum fuel consumption rate. The degree to which a particular operator can optimize will depend upon the consistency and predictability of his operating conditions. If the vehicle operates most of the time at a given speed, over a given terrain, with a given load, the needed horsepower can be computed. An engine can be chosen so that the needed horsepower is 80 percent of the rated horsepower and a cruising gear exists at 65 percent of governed maximum engine rpm. Thus, operation will be on the lowest specific fuel consumption curve (in this case, a point at .355 lbs./brake-horsepower-hour). However, if greater flexibility is needed to meet a variety of

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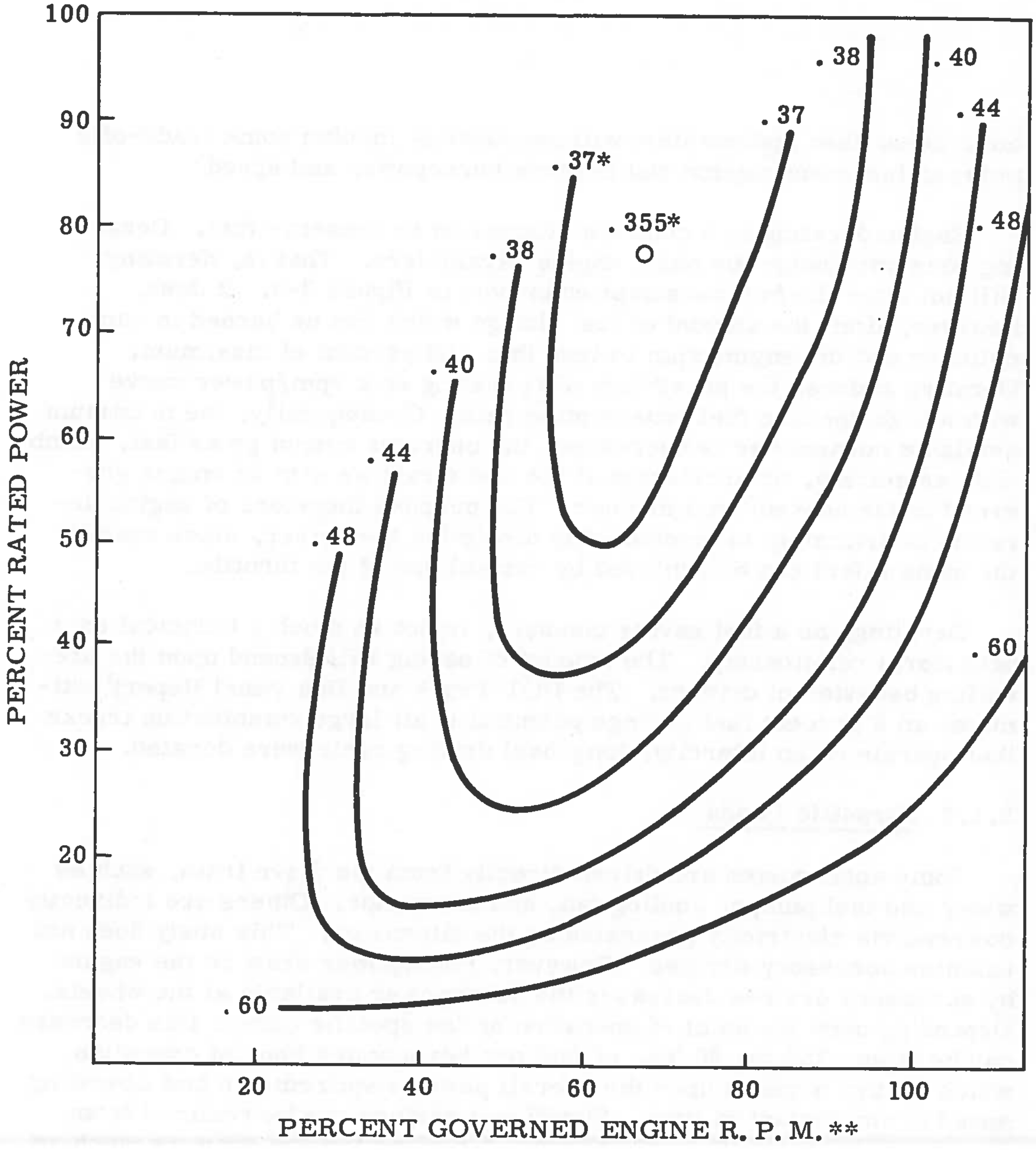
[1] See Appendix A for listing of density factors by commodity.

TABLE 3-2

TRANSEN MODEL BTUs PER NET TON-MILE BY TRUCK TYPE AND COMMODITY DENSITY FACTOR

TRUCK TYPE	BODY	MAXIMUM CAPACITY (Tons)	COMMODITY DENSITY FACTOR			
			FUEL	1.0	.9	.75
1.	Box	2.8	G	9,288	10,240	12,164
2.	Box	2.8	D	8,409	9,293	11,046
3.	Box	7.3	G	4,377	4,794	5,639
4.	Box	7.3	D	3,935	4,316	5,088
5.	Box	14.1	G	2,861	3,080	3,532
6.	Box	14.1	D	2,396	2,594	3,006
7.	Box	17.4	G	2,414	2,613	3,001
8.	Box	17.4	D	2,032	2,204	2,554
9.	Box	23.1	D	1,778	1,926	2,219
10.	Twin Box	26.1	D	1,664	1,793	2,049
11.	Irregular	4.2	G	6,416	7,054	8,332
12.	Irregular	4.2	D	5,791	6,371	7,539
13.	Irregular	8.1	G	4,001	4,383	5,257
14.	Irregular	8.1	D	3,593	3,935	4,626
15.	Irregular	14.0	G	2,875	3,096	3,557
16.	Irregular	14.0	D	2,410	2,613	3,019
17.	Irregular	17.8	G	2,381	2,564	2,945
18.	Irregular	17.8	D	1,999	2,165	2,507
19.	Irregular	23.4	D	1,762	1,904	2,194
20.	Twin Irr.	26.4	D	1,652	1,775	2,033
21.	Tank	12.5	G	2,865	3,101	N/A
22.	Tank	12.5	D	2,417	2,629	N/A
23.	Tank	17.3	G	2,233	2,412	N/A
24.	Tank	17.3	D	1,878	2,039	N/A
25.	Tank	22.9	D	1,646	1,784	N/A

Source: Based on assumed .31 backhaul; .9 load factor; 55 mph.



* SPECIFIC FUEL CONSUMPTION LBS. /BHP/HOUR (BHP = brake horsepower, or the engine drive shaft power output).

** BASED ON MANUFACTURER'S MAXIMUM GOVERNED SPEED

Source: Cummins Diesel

FIGURE 3-4: TYPICAL FOUR CYCLE DIESEL ENGINE PERFORMANCE CHARACTERISTICS (Fuel Consumption Curves) conditions, then optimization will necessarily involve some trade-offs between fuel consumption and reserve horsepower and speed.

Engine derating is a common suggestion to conserve fuel. Derating does not change the basic engine parameters. That is, derating will not alter the fuel consumption curves in Figure 3-3. It does, however, limit the amount of fuel charge which can be burned in each cylinder and the engine rpm to less than 100 percent of maximum. Derating reduces the possibility of operating on a rpm/power curve with a high specific fuel consumption rate. Consequently, the maximum available horsepower is decreased, the operator cannot go as fast, climb hills as quickly, or accelerate at the same rate as with an engine governed in the conventional manner. The purpose therefore of engine derating is primarily to involuntarily discipline the driver, since exactly the same effect can be achieved by careful use of the throttle.

Derating, as a fuel saving measure, is not so much a technical as a behavioral relationship. The amount of saving will depend upon the prevailing behavior of drivers. The DOT Truck and Bus Panel Report[1] estimates an 8 percent fuel savings potential if all large combination trucks that operate on an intercity, long-haul driving cycle were derated.

3.1.8 Parasitic Loads

Some accessories are driven directly from the drive train, such as water and fuel pumps, cooling fan, and alternator. Others are indirectly powered via electricity generated by the alternator. This study does not examine accessory devices. However, horsepower draw on the engine by accessory devices decreases the horsepower available at the wheels. Depending upon the point of operation on the specific curve, this decrease can be from .355 to .60 lbs. of fuel per horsepower hour of operation, which in turn depends upon the overall power requirements and operating speed at any instant in time. Significant savings can be realized from the use of thermostatic cooling fans. A cooling fan can draw as much as 36 horsepower during highway operation at 1,800 to 2,200 engine rpm.[2] This kind of cooling power is needed on the average only 3 to 5 percent of

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[1] DOT, EPA, Study of Potential for Motor Vehicle Fuel Economy, Report No. 7, January 10, 1975.

[2] Larry Givens, "Fan Clutches: A 'Must' for Heavy Trucks," Automotive Engineering, April 1975, p. 31.

the time. The DOT, EPA Truck and Bus Panel Report estimates a potential savings of 8 percent if large trucks use fan clutches. Cummins' own research suggested a 3.3 percent improvement. This study assumed a 6 percent improvement to large trucks fitted with a modulated or clutched cooling fan. (Such fans have been a relatively common installed option since 1973.)

3.1.9 Drive Train Optimization

Engine optimization depends upon proper selection of gears. Many drivers, either because of inadequate training, or more likely, because they operate different kinds of vehicles, are not properly matching transmission gear selection to engine characteristics. One improvement suggested is the introduction of automatic transmission in large trucks. Though there are energy losses in automatic transmissions, even when equipped with a torque-converter, lock-up device, power shifting can save fuel by (1) smoothing the flow of torque to the drive train, (2) preventing the waste of fuel which is caused when the driver pumps the accelerator during clutching, and (3) making up for variation in skill among drivers. However, automatic transmissions in trucks are large, heavy, subject to maintenance problems, and expensive. The majority of respondents in a survey of the industry saw automatics increasing in new truck sales, although no consensus existed as to which class of trucks would be most affected.[1]

In this study, the effect of automatic transmissions on average fuel consumption is not explicitly accounted for because (1) much of the affect is likely to be in local urban pick-up and delivery trucks outside the scope of study and (2) the actual fuel improvement has not been demonstrated.

Radial tires are viewed as a significant improvement to the final link of the drive train. The DOT, EPA, Truck and Bus Panel Report[2] estimates an 8 percent improvement for large trucks over the conventional biased ply tire. Other estimates vary somewhat around that figure.

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[1] John P. Covington, "The Next Ten Years in Truck Technology", Automotive Engineering, June 1973, p. 30.

[2] Op. cit., p. 102.

3.1.10 Aerodynamic Improvements

The most significant technological truck fuel efficiency improvement is in aerodynamic streamlining. This study assumes varying levels of improvements to trailer-box bodies and tank bodies but not to the irregular body trucks. (See Appendix A for definition of body types.)

The many industry studies of truck design for fuel efficiency are not done under controlled conditions and often combine several types of improvements into the test vehicles. Further, these test conditions frequently do not include consideration for side-winds, but focus only on head-wind effects. Therefore, no reliable figure on the partial improvement due to low-level aerodynamic changes exists. Although General Motors claims up to 7-11 percent reduction in fuel use, this study has estimated a more conservative improvement over the base case.

At the simplest level of improvement, a cab-top foil can be added and the lower-front bumper can be removed on large tractors. Removal of the lower-front bumper reduces frontal area. The addition of an air foil sets up a "smoother" air flow over the truck.

More sophisticated technological improvements can be made primarily to the trailer. For example, rounding of the trailer corners and removal of the vertical exposed ribs were alternatives tested in a University of Maryland wind tunnel experiment.[1] At 50 mph, a standard square front trailer requires 54 horsepower just to overcome wind resistance. With an 18-inch corner radius at top and sides, the horsepower requirement is reduced to 41.3, a 23.5 percent reduction in power losses due to air resistance. Since air resistance is approximately half of the total full-load resistance at 50 mph, the reduction translates to a 12 percent potential savings in fuel (level ground, steady speed).

An even more sophisticated improvement is the streamlining of a tractor/trailer combination with the space between the cab and the trailer enclosed by a flexible wind barrier, and a bulbous nose added to the tractor to smooth air flow (and thus air turbulence). According to the University of Maryland study, this combination allows a 63 percent reduction in wind resistance, which means approximately 30 percent less fuel at 50 mph, fully loaded.

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[1] "Wind Resistance," a pamphlet published by The University of Maryland.

3.2 RAIL

3.2.1 Overview of Recent Trends

The railroads have recently introduced several measures to conserve energy. Although energy conservation was not the sole objective in most instances, the following trends have been reported in several publications:[1]

reductions in average train speeds;

reductions in service frequency on branch lines;

closer monitoring of fueling stations to prevent fuel spillage;

reduction in locomotive idling (shutting engines down, when and where possible);

changes in maintenance practices to produce improved fuel mileage;

closer matching of gross tonnage to available motive power;

increased use of computers to improve equipment utilization; and

increases in the number of trains preblocked to bypass classification yards.

A comparison of operating statistics for ten railroads in 1972 and in 1974, the first full year since the oil embargo, showed that net ton-miles per gallon of fuel increased from 198 to 212, and the net-to-tare ratio increased from .82 to .86.[2] Finally, some extra TOFC/COFC (piggyback) services have been established to offer alternative services, presumably to reduce the volume of more energy intensive long-distance highway traffic.

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[1] "Railway Age", December 10, 1973, pp. 12-3, and "Railway Gazette International", February, 1975, pp. 54-7.

[2] Emerson Consultants, Assessment of Means of Increasing the Efficiency of Fuel Usage in Rail Transportation of Freight, Cambridge, Massachusetts: Transportation Systems Center, 1975, pp. 18-19.

3.2.2 Operating Changes

Several changes in railroad operations could improve rail energy efficiency. These changes would require (1) rail carriers to alter their operating policies and increase intercarrier cooperation, and (2) the government to alter regulatory policy to both enforce fuel conservation and create incentives to conserve fuel. The operating changes considered in this study include:

reductions in circuity;

reductions in empty backhauls;

increases in load per car (where possible);

reductions in operating speeds;

reductions in delays and stops;

changes in train configuration;

improvements in yard operations;

reductions in locomotive idling;

reductions in use of cabooses; and

tighter control of fuel use and accounting.

Each of these changes is discussed below in terms of ways to implement the change, potential impacts of the change, and implementation costs and problems.

3.2.3 Circuity Reductions

Circuitous routings increase rail fuel consumption by increasing the length of haul a shipment must move to reach its destination. Currently, average circuity is estimated to range from 11 percent to 18 percent of published tariff "short routes" (i.e., the shortest rail route over which the tariff applies), depending on the type of car. Circuity varies by car type, because of the nature of commodities handled, competitive routes, and applicable tariff provisions. Fuel consumption is proportional to one plus the circuity ratio in decimal terms. Thus, a 10 percent decrease in circuity would decrease fuel consumption by 1.1 percent to 1.8 percent of the short-line energy consumption (i.e., 10 percent of 11 percent and 18 percent, respectively).

One key reason for high rail circuity factors is that originating railroads often try to keep loaded cars on-line for as long as possible to maximize their division of the through rate. In addition, some car service rules require special or equipped empty cars to be returned to the originating carrier by the same (reverse) route from which the loaded cars came.

Rail carriers could reduce overall rail circuity by modifying car service rules, routings, and tariffs which allow excessive circuity. The Interstate Commerce Commission (ICC) might reduce circuity by encouraging the development of (1) short-route trackage rights agreements and (2) tariff incentives to encourage shippers to specify less circuitous routes. Alternatively, the ICC could directly enforce reduced circuity by restricting allowable circuity to a defined percentage in excess of the shortest applicable tariff mileage. Finally, elimination of unnecessary duplicate circuitous route service between certain origins and destinations could reduce extra car miles and save fuel in most cases.

Reductions in circuity could cause some individual carriers a net loss in income from reduced rate divisions or loss of traffic altogether. However, the rail system as a whole could experience reduced variable transportation costs somewhat proportional to the decrease in mileage run. Attempts to reduce circuity will most likely encounter opposition from carriers, who are quite naturally reluctant to lose all or portions of profitable traffic just to reduce circuity. However, the institutional barriers to an apparent reduction in competition are major. In addition, shippers may not favor short routing for a variety of reasons, including service, the desire to favor the carrier furnishing the car with the longest haul, as well as many other reasons.

3.2.4 Reductions in Empty Backhauls

This study estimates that about 37 percent of total rail energy consumption is related to moving empty cars. Empty backhauls represent fuel consumption by railroads in an amount proportional to the ratio of empty to loaded car-miles experienced by each type of car. Such movements are unproductive from an energy viewpoint and should be minimized. Currently the ratio of empty to loaded car movements ranges from .59 to 1.20, depending on the type of car involved. A 10 percent reduction in the empty backhaul ratio will reduce by 10 percent the energy consumed in empty movements.

Empty backhauls exist for may reasons, including the natural imbalances in traffic. Other causes of empty backhaul movements include:

Substitutable empty car types are frequently moved in opposite directions for a variety of reasons.

Increased use of specialized equipment means that cars are more often returned empty.

Use of dedicated equipment, which generally returns empty, is increasing in response to competitive pressures to improve the attractiveness of rail service.

Equipment distribution and control can be improved by railroads.

AAR and ICC car service rules restrict loading of certain "foreign" cars (cars not owned by the originating road) and often require that these cars be sent home to the originating carrier, often by a circuitous route.

Currently, empty rail car moves are increasing because of growing use of dedicated equipment, specialized cars, private cars, and unit trains--all of which generally return empty to their points of origin.

Empty backhauls could be reduced if rail carriers:

minimize unnecessary empty car routings through better car control and distribution practices;

modify car service rules;

modifying tariffs to give shippers incentives to cooperate in programs which help carriers to improve equipment utilization and utilization planning;

decrease use of specialized equipment;

encourage the use of TOFC/COFC movements, in select situations, as a substitute for shippers now using specialized cars with empty returns;

improve car maintenance and upgrade commodity loading classifications; and increase pooling of equipment for more efficient equipment utilization.

As an example of the latter, the Missouri Pacific, Southern, and Milwaukee Railroads initiated a freight car clearinghouse experiment in which railroads were able to use any of a pooled set of cars as if they were their own.[1]

The ICC could take several steps to reduce empty freight car movements. For example, they could encourage the use of tariff incentives and coordinated rail pickup and delivery (switching) and some modification of ICC car service rules. The ICC might provide for increased allowance of private car use on loaded return moves or encourage greater use of assigned cars in controlled backhaul movements (with a proper use allowance). Finally, duplicate routes by competing carriers could be rationalized to reduce empty movements by competing carriers. However, the implementation of several of these measures could create problems. For example, changing car service rules might change incentives on car ownership. The use of less specialized equipment could diminish the attractiveness of rail service for shippers.

Reducing empty backhauls will reduce the operating costs associated with empty movements. In addition, pooling of equipment will decrease the need for some investment in equipment through improved equipment utilization. Finally, reduction of duplicate routes could reduce rail costs; however, institutional barriers to reducing such duplications (as noted earlier), are large.

3.2.5 Increased Load Per Car

Increased loading per car increases the net-to-tare ratio and decreases the number of cars to handle the same net tonnage. As a result of increasing freight car loads (in those instances where cars are not already loaded to capacity), energy consumption would be reduced. Cars may not be loaded to 100 percent of their weight capacity because of volume constraints. However, other explanations for loading cars below capacity include shippers' lack of incentive to load beyond traiff minimum weights and the use of cars larger than needed for a particular shipment. It has been estimated that current freight cars are

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[1] U.S.. Department of Transportation, <u>1974 National Transportation Report</u> (Washington, D.C.: U..S. Department of Transportation, December 1974), pp.iv-9.

loaded, on an average, to 80 percent of weight capacity and that, due to volume limitations, a 5 percent systemwide increase in load per car is the maximum which could probably occur.[1]

Rail carriers could increase their-net-to-tare ratios by encouraging heavier loadings from shippers through tariff incentives to either increase minimum loads or encourage loads over the required minimum, and by furnishing cars of a size is available suited to expected shipper loads.

As an example of the former case, to alleviate a car shortage last year, the ICC issued Service Order No. 1185 (since expired) directing an increase in the minimum loading of mechanical refrigerator cars to increase the utilization of refrigerator cars during an emergency. In the latter case, where railroads in specific situations have published carload rates to encourage heavier loadings, average net weight per car has increased by as much as 10 percent.[2]

Cost savings from increased net-to-tare ratios could result from the use of fewer cars, which will reduce both operating costs and requirements for purchasing more equipment. However, fewer heavier loaded cars might increase wear and tear on tracks and could thus increase maintenance costs. No additional cost will be involved in changing tariffs to provide heavier loading incentives, but shippers will have to compare any cost incentives with the added costs of maintaining larger inventories.

3.2.6 Reduction in Line Speed

Speed-related changes offer railroad management the greatest opportunity to effect fuel conservation within the current institutional structure. Trains are currently run at over-the-road speeds which are higher than the most energy efficient speeds. Presumably, faster speeds are needed to provide shippers with a better service, but often it is to help make up for long delays at origin and destination.

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[1] Peat, Marwick, Mitchell & Co. and Jack Faucett Associates, Industrial Energy Studies of Ground Freight Transportation, Washington, D.C., July 1974, pp. IX-20.

[2] Ibid.

Reducing speed by 2.5 miles per hour on a train of boxcars has been estimated, based on the methodology in this study, to result in a 4 percent energy savings (speeds of about 45 miles per hour are considered as base speeds). A 5-mile-per-hour speed reduction is estimated to reduce energy consumption by an average of 5.6 percent, while a 10-mile-per-hour reduction is estimated to have a 12.9 percent impact on energy used. At slower speeds, the impact of a speed reduction is less significant. To reduce over-the-road speeds, maximum speed limits or horsepower-per-ton ratios can be reduced.

A recent energy conservation study analyzed the effects of reducing horsepower-per-ton ratios and maximum speed limits on minimum run time, required horsepower, and fuel savings.[1] This study was confirmed by field testing. The study concluded that reducing horsepower-per-ton is more effective in conserving energy than reducing maximum speed limits. Reducing maximum allowable speed would be easier to implement but will require greater sacrifices in running time. Horsepower, however, can only be reduced to maximum tonnage ratings for specific units unless helper engines are assigned in ruling grade territory (where the highest horsepower-per-ton is required).

Reduced horsepower-per-ton ratios could be achieved through closer adherence to trailing tonnage ratings of the locomotive used and by a more accurate determination of gross car weight.

[1]According to a recently published study, reported gross car weight in trains ranged from minus 10 percent to plus 5 percent of actual car weights.[2] Because actual weights are often greater than reported weights, extra horsepower is often assigned to a train to protect a schedule or assure adequate power to operate on ruling grades. To compensate for increased road haul time, reductions in line or terminal delays are necessary.

3.2.7 Elimination of Delays and Stops

The elimination of avoidable slow orders, delays, and stops will reduce the need to accelerate and decelerate and thus save energy. The causes of many enroute train delays and stops include track problems which require slow orders, irregular dispatching which creates

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[1] Emerson Consultants, op. cit.

[2] Ibid., p. 44.

congestion, equipment failures, accidents, signal failures, single track operations (train meets), and the need for crew changes approximately every 100 miles. One study developed a list of delays normally experienced by trains and estimated that a 10 percent increase in minimum run time could be overcome by reductions in these delays (see Table 3-3).

To reduce these delays, where appropriate, the following changes could be made: preblock more trains to bypass intermediate yards, modify dispatching, improve maintenance to minimize track and signal problems, improve equipment maintenance, operate longer crew districts to reduce stops for crew changes and modify interchange and 500-mile inspection requirements.

3.2.8 Train Composition

The composition or configuration of the cars in a train affect the aerodynamic resistance and rolling resistance of the train and thus its energy consumption. Factors such as positioning similarly shaped cars together and closing empty boxcar doors can reduce the aerodynamic resistance of a train. Rail carriers can improve train composition by improving the load factor on piggyback cars. For example, a 30-car TOFC with four empty spaces consumes 5.8 percent more energy than a fully loaded train at level, steady state speeds around 50 mph. A comparable COFC train with four empty spaces consumes 3.6 percent more energy than a fully loaded COFC train.

Because the benefits of altering train configuration to reduce wind resistance have not been fully quantified, railroads generally do not configure trains to save fuel. The costs of extra switching required to achieve the improved configurations must be weighed against the cost savings from reduced fuel consumption and other considerations. To develop more energy efficient train configurations, rail carriers could make configuration a factor in making up train consists. Current operating practices do not encourage the adoption of such procedures, however, and little change is foreseen in the next ten years.

Although lower top speeds will minimize to some extent the aerodynamic effects, the presence of side winds, even at 35-mph train speeds, can increase train resistance 15 percent or more.

3.2.9 Improved Yard Operations

Improved yard operations (and reduced delays) have been noted earlier as a means to reduce overall travel time. Improvements in yard

TABLE 3-3

TRAIN DELAYS INDEPENDENT OF SPEED AND POWER

TRAIN INTERFERENCE UNRELATED TO HORSEPOWER

A. Maintenance of Way

1. Faulty signal indication
2. False hotbox detector indication
3. Slow orders
4. Maintenance of Way personnel occupying track section
5. Broken rail
6. Faulty switch

B. Freight Equipment

1. Shifted load
2. Break-in-two
3. Faulty train air
4. Bulkhead flats, high-wide loads, etc. requiring reduced speeds
5. Dragging equipment
6. Heated journal
7. Unscheduled set-out of bad-order car

C. Over-the-road Operating

1. Following train ahead
2. Train ahead going into siding
3. Opposing train going into siding
4. Derailment ahead
5. Hold for another train
6. Waiting in siding
7. "Saw-by" another train
8. Held out of yard due to lack of receiving tracks or yard congestion
9. Missing train orders
10. Accidents

TABLE 3-3

TRAIN DELAYS INDEPENDENT OF SPEED AND POWER (Continued)

D. Terminals

1. Lack of ready power or cabooses
2. Late train make-up
3. Late in processing bills
4. Last minute diversions
5. Late call for crews
6. Late receipts from connections
7. Congestion

E. Other Causes

1. Speed restrictions due to city ordinances
2. Cut train at grade crossings
3. Poor visibility
4. Vandalism

Source: Emerson Consultants, Assessment of Means of Increasing the Efficiency of Fuel Usage in Rail Transportation of Freight, Cambridge, Massachusetts, Transportation Systems Center, 1975, pp. 18-19. (Includes modification by PMM&Co.).

operations, which currently account for 10.6 percent of total fuel consumption, could reduce energy needs. Among the ways in which railroads could reduce yard fuel consumption are:

> bypassing yards wherever possible, perhaps through the improvement of blocking strategies and the use of shorter trains to facilitate such operations (though higher fuel requirements for shorter trains could reduce or negate such savings);
>
> increasing labor flexibility to permit industries and locations to be switched by line crews instead of terminal switch crews (and vice versa), if energy savings would result;
>
> reducing special handlings by eliminating operating problems;
>
> improving supervision and planning to reduce inefficient practices; and
>
> modernizing yards and expanding as appropriate to reduce handlings.

Rail carriers might have an incentive to make yard operations more efficient if they knew more about the costs involved in yard operations. According to a recent report, "the economic cost...of train delays and of reclassifying cars in intermediate yards are unknown."[1] In addition to improving energy conservation, eliminating yard inefficiencies could result in improved equipment utilization and more reliable service.

3.2.10 Reduced Locomotive Idling

The amount of time a locomotive is left idling when not in use is often mentioned in connection with yard operations energy efficiencies. The Association of American Railroads has estimated that mainline

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[1] National Commission on Productivity and the Council of Economic Advisers, Improving Railroad Productivity, (Washington, D.C., November 1973), pp. 307.

locomotives typically spend 40 percent of their available time idling.[1] Assuming an idling consumption rate is 10 gallons per hour and 95 percent availability, approximately 2.4 percent of the fuel annually consumed by railroads is consumed idling.

A diesel engine is generally not shut-down when not in use to minimize thermal and water condensation damage, avoid the need for antifreeze, and other miscellaneous reasons. Nonproductive use of fuel consumed in engine idling can be reduced in two ways:

> shutting down the locomotive in those situations where no damage is expected to occur to the engine from start-up or when special precautions can be made. Such situations include relatively warm weather (above 40 degrees) and the use of heaters to keep engines warm when not in use; and
>
> improving locomotive utilization to reduce idling time.

3.2.11 Reduction in Cabooses

The presence of cabooses on freight trains adds extra weight and, consequently, causes additional fuel consumption. For example, it has been estimated that on a 23-car train a 20-ton caboose represents approximately 2 percent of the train resistance and thus 2 percent of the fuel consumption.

A recent report has questioned the value of the caboose relative to its historical role to protect a train and provide a "home" for the train crew:

> The detection function (of the rear end crew) can be much more accurately performed by trackside detection systems or conceivably, by on-train detection systems. In fact, the caboose has dubious value as a look-out point. Even in the absence of a cloud of dust, excellent vision is required to see the trucks or cars over a mile distant...New signaling and train control systems can obviate the use of manpower to protect the rear of trains...More frequent schedules will

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[1] "No Easy Answers in the Search for Fuel Economy," Railway Gazette International, February 1975, p. 54-7.

> tend to shorten the length of trains, a result which will also reduce the value of housing crew members at the rear of a train. Finally... the adoption of a car management system and elimination of waybills can greatly reduce on-train paperwork.[1]

3.2.12 Tight Control of Fuel Use and Accounting

Railroads today seldom meter fuel to locomotives and have no idea of fuel consumption per trip or per locomotive unit per trip. The system is at best described as "casual" and is replete with opportunities for fuel theft or loss. The financial and physical controls are in need of improvement as a first step to measuring the effect of other improvements. One former oil executive estimated that "paper theft" (i.e., oil never actually delivered but billed to the railroad or other users) can constitute sizable fuel "losses."

Until railroads have a reasonably accurate idea of the quantity of fuel they use, they cannot accurately estimate savings from fuel conservation.

3.2.13 Summary

Throughout the discussion of operating changes to conserve energy, several themes reoccur. Railroads should have tighter controls on purchasing, use, and measurement of fuel used. Functioning independently, railroads can streamline route and yard operations, change speeds, reduce delays, reduce locomotive idling, improve maintenance of equipment and way practices and develop and increase the utilization of computer systems for equipment use and control. Working with other carriers, railroads can modify car service rules, create tariff incentives for greater operating efficiency, and increase pooling of cars and power. The government can encourage greater operations efficiency from an energy standpoint by encouraging the development of tariff incentives, car service rule changes, and a streamlined rail system and can place restrictions or incentives on routes and loads. Although these measures do improve train energy efficiency and consequently reduce fuel costs, the energy implications of adopting these measures are not the only considerations which should be made in evaluating their adoption. In a broader energy perspective, some of these measures

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[1] National Council on Productivity, op. cit., pp. 301.

might lead to rail service which is less tailored to shipper needs and could thus hurt rail competitive position in relation to trucks. In addition, other considerations might outweigh the advantages of fuel savings, for example, changes to reduce fuel use could increase carrier costs in other areas and cause traffic diversion to more energy intensive alternatives.

3.2.14 Technological Changes

In the rail industry, technological changes to improve energy consumption have been limited by many factors, including:

management apathy and the desire to "protect" past investments by not changing the status quo;

funds availability, which has limited the amount of effort railroads can afford to spend on research and development in technology improvements;

interchange requirements and off-line maintenance of nonstandard equipment;

regulations and labor contracts which limit the opportunity for railroads to achieve improved operating strategies through technological change; and

useful life of rail equipment, which is relatively long and, consequently, since only a small proportion of equipment is replaced every year, the payoff from adopting energy-conserving technology on new equipment is realized slowly.

The technological improvements which could improve energy efficiency fall into the following categories:

locomotive streamlining;

other changes in locomotive technology;

reduction in car tare weight;

car streamlining;

other changes in car technology; and

electrification.

Each is discussed below.

3.2.15 Streamlining Locomotives

As operating speeds increase, aerodynamic characteristics have a greater impact on train performance. A recent report on rail technology observed that the current design of U.S. diesel electric freight locomotives are aerodynamically poor for medium- and high-speed operations.[1] Power consumption of locomotives to overcome aerodynamic resistance has been of little interest to locomotive builders in recent years in the U.S., even for passenger units operating at high speeds.

Even at low operating speeds, the power required to move air around the locomotive is not small. At 40 miles per hour, the power required to overcome the aerodynamic drag of a single C-C (3 axle truck) 3,000 horsepower, diesel-electric locomotive is approximately 6 percent of the power output or 180 horsepower. At 70 miles per hour, this rises to 19.7 percent.[2] With winds normally encountered in operation, even slow trains can require substantial increases in power to overcome aerodynamic drag. Streamlining, without any locomotive weight reduction, can reduce the total wind resistance of two 3,000-horsepower units by approximately 41 percent at a constant speed of 50 miles per hour compared to the standard freight unit configuration.

Table 3-4 shows energy savings from the use of streamlined locomotives on solid trains of different car types. The application of good streamlining is especially significant on short fast trains, such as TOFC or COFC trains, operating at about 60 miles per hour average speeds. High speed TOFC/COFC trains exhibit the greatest potential for energy savings from locomotive streamlining--upwards of 12.5 percent--while coal "drags" trains moving at slower speeds (35 miles per hour, for example) indicate possible savings of 3 to 5 percent.

It is estimated that the additional cost involved in the purchase of a streamlined locomotive is approximately $25,000 on a $500,000 locomotive.

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[1] Reebie Associates and Alan R. Cripe, National Intermodal Network Feasibility Study, (Greenwich, Connecticut: Reebie Associates, September 1975), pp. 9.

[2] Ibid., Appendix 6.

TABLE 3-4

ENERGY SAVINGS FROM SUBSTITUTING A STREAMLINED LOCOMOTIVE ON SOLID TRAIN TYPES INDICATED (1)

TYPE OF TRAIN	PER NET TON-MILE LOADED	PER GROSS TON-MILE EMPTY	ASSUMPTIONS
Boxcar	3.5% Savings	5.6% Savings	All Boxcar Train 58 cars, 2 locomotives average size train 40 miles per hour average speed 10 miles per hour headwind
Hopper Car, Covered Hopper Car	3.3% Savings	4.5% Savings	All Hopper Car Train 70 cars, 2 locomotives 40 miles per hour average speed 10 miles per hour headwind
Trailer on Flat Car (TOFC)	10.7% Average		All TOFC Train 30 cars, 2 locomotives 60 miles per hour average speed[2]
Container on Flat Car (COFC)	12.5% Average		All COFC Train 30 cars, 2 locomotives 60 miles per hour average speed[2]

(1) It is assumed that streamlined locomotives will be used in push-pull fashion with one on the rear-end of the train substituting for the caboose and to reduce train base drag.

(2) This is representative of ''Super-C'' (Santa Fe Ry) type operating speeds and was selected to be competitive with trucks moving 55 miles per hour.

3.2.16 Other Changes in Locomotive Technology

Most diesel locomotives now in use were designed when fuel was plentiful at a relatively low price. Many technological changes for the locomotive besides streamlining have been proposed to save energy. Emerson suggested the following:[1]

> Four-cycle diesel engine. Several railroads have tested the difference in fuel consumption between comparable four-cycle and two-cycle engines and have shown that use of the four-cycle engine can result in a 5 percent fuel savings over the two-cycle engine.
>
> Improved fuel-injector spray tips. Improved spray tips increase combustion efficiency and have been shown to increase fuel efficiency by one-quarter to one-half of 1 percent. Fuel injectors are being replaced on most locomotives.
>
> Engine combustion air filtration. Improved air-intake filtration can improve fuel consumption. However, increased engine protection can increase the amount of pressure drop across the filter and consequently increase fuel consumption. It is estimated that use of (low-pressure drop) filters could decrease fuel consumption by three-quarters of 1 percent.
>
> Automatic locomotive control. It is technically feasible to provide locomotives with logic control to take units in a locomotive-consist off- or on-line which will keep operating units at most efficient throttle position as much as possible. The cost of such an installation is unknown and may not yet outweigh potential fuel savings, which have been estimated to be as high as 5 percent.
>
> Turbochargers. Turbocharged locomotives consume less fuel than normally aspirated engines, especially at higher elevations, where it has been shown that turbocharged locomotives cost less to maintain. Furthermore, the turbocharger-parts catcher, which protects the engine from foreign matter, has been shown from preliminary tests to cause an increase of 2 to 4 percent in fuel consumption.

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[1] Emerson, op. cit., pp. 49-55.

> Controls on engine parasitic loads. The external parasitic load constitutes approximately 10 percent of the crankshaft horsepower of current diesel locomotives. The loads are comprised of the air compressors, radiator cooling system, auxiliary generators, and various tooling blowers. It is estimated that from 1 to 3 percent of fuel consumption can be saved by reducing parasitic loads by using clutching mechanisms (air compressor) and more efficient parasitic devices.

Discussion with industry experts suggest that Emerson's estimate may be a bit optimistic or, the savings are within test "noise" (variance) limits, and thus may not be significant. The four-cycle diesel, while perhaps theoretically more efficient, is often "souped-up" to compete with two-cycle engines of similar weight and size, and thus lose some of their inherently slightly better thermal efficiency.

Finally, the reduction of locomotive weight can reduce rail energy consumption. It is estimated that, at moderate speeds, (over 20-25 mph speeds), savings of 1 percent in fuel consumption can result when a four-axle unit is substituted for a six-axle unit. Modern wheel slip systems, use of hydrodynamic drive systems (tested, but not fully debugged), and better truck design can permit locomotive weight reductions of up to 25 percent without sacrificing effective drawbar pull, as has been the reported experience of some European designs.

Current high-power U.S. diesel-electric locomotives generally have about 15 horsepower per ton of weight, some modern European electrics have up to 65 horsepower per ton. Typical European diesel-hydraulic locomotives have 33 horsepower per ton and the diesel hydraulic/gas turbine units about 43 horsepower per ton. Operating characteristics between the United States and Europe are not alike, however. Most U.S. locomotives are designed for heavy "drag" operations, in contrast to European practices of shorter, higher powered trains.

Although U.S. operating practices are decidedly different from European practices, lighter weight locomotives can be used in some U.S. operations, especially where speed is more important than tractive effort (e.g., light, fast trains).

For high-speed service (60 miles per hour) locomotive weight-related energy savings could reach 7 percent. For heavier trains which still utilize full horsepower output of lighter weight locomotives, weight-related energy savings could still be at least 2-3 percent.

Table 3-5 summarizes the energy savings potential systemwide from implementing these measures along with estimates of the incremental cost of their purchase, where possible.

3.2.17 Car Changes

Technological changes related to cars include reducing car tare weight, streamlining cars, as well as others. Each change or set of changes is discussed below.

Reduced Car Tare Weight. Reducing car tare weight decreases grade resistance, inertial resistance, and total rolling resistance and thus energy consumption. Twelve years ago, a radical design articulated-hopper car developed for the Southern Railway provided a 29.5 percent weight reduction over conventional cars in use today. However, because the car was made of aluminum and had automatic hopper doors, the cost was excessive. Today, a similar car is estimated to be 25 percent more expensive than a regular car on a capacity basis. When compared to a standard 70-car all-hopper car train with two locomotives at 40 miles per hour average speed, a train of the articulated aluminum cars is estimated to result in a 9.5 percent energy savings on loaded movements and a 19.8 percent savings on empty movements. A 5 percent weight reduction for a 40-mile-per-hour hopper car movement is estimated to result in a 4.6 percent energy savings on loaded moves and to add a 5 percent one-time cost to purchase of the equipment.

Reducing tare weight of cars in unit trains and where high empty mileages are run is particularly important. For example, for coal unit trains, only 50 percent of the car miles are loaded miles. Every freight car in general service is designed to take severe punishment in yard handling and to withstand high structural stresses in over-the-road operation (generally in the middle of the train) without being damaged or causing an accident. Weight can be reduced by substituting lighter (and generally more expensive) materials, reducing nonhazardous safety margins, adopting improved coupling systems to reduce "slack," and using draft gear designed to reduce internal car structural forces. In some situations, cars can be designed for specific services, when it is known that they will not be subjected to extreme stresses which cars are currently designed to absorb.

The high tare weight of trains in general, and particularly for TOFC, suggests that little new technology is required to achieve results. The principal problem is to convince railroads that weight costs money and fuel.

TABLE 3-5

ESTIMATES FUEL CONSUMPTION SAVINGS FROM LOCOMOTIVE CHANGES

MEASURE	MAXIMUM ESTIMATES OF SYSTEM ENERGY CONSUMPTION SAVINGS SYSTEMWIDE (Percent)	ESTIMATE OF ADDITIONAL COST PER UNIT (Dollars)
Two-cycle versus four-cycle turbocharged engine	1.0[1]	-
Fuel injector spray tips design improvement	0.1	1,600
Engine filters design improvement	0.3	2,000
Automatic on-off unit control (power management)	3.0	5,000
Turbo charger on two-cycle engines	1.0[2]	20,000**
Turbo parts catcher (elimination of)	3.0	Unknown
Parasitic loads	2.0	Unknown
Reduction of locomotive weight:		
Four versus 6-axle diesel engine	0.3	30,000 (Saving)
New locomotive designs	5.0	Unknown
	Net Maximum 14.7[3]	

[1] Estimated that 20 percent of all engines are four-cycle turbocharged.

[2] On a cost per horsepower basis, addition of a turbocharger adds no additional cost.

[3] Compounded savings.

Car Streamlining. Streamlining cars offers another technological opportunity for reducing energy consumption. Streamlining the lighter hopper car discussed above is estimated to save 3.3 percent of total energy consumed when moving loaded and 10.3 percent when moving empty.

Streamlining to reduce energy is most effective at high operating speeds. On an all-COFC train of 30 cars and 2 locomotives moving at an average speed of 60 miles per hour, an average savings of 13.5 percent in energy can be realized by car streamlining.

A private investigation was conducted in 1974 to determine fuel savings which would result from the use of streamlined auto transport cars (see Table -6). Two sets of simulations were run with one using conventional, nonstreamlined cars, and the other using streamlined articulated auto transport cars. Both trains had identical locomotives and total weights. The use of the streamlined cars resulted in reduced fuel consumption in spite of higher speeds for the streamlined car move. From Chicago to Kansas City, the streamlined car train was 10 percent faster and used 10.6 percent less fuel than the standard car train.

Some further improvement would have been made if the locomotive had been streamlined. Power assigned to the run was relatively low--only .94 horsepower per ton--which reduced the train speed to 12.5 miles per hour on the 1.04 percent ruling grade (i.e., the grade which establishes minimum power requirements). However, even on such a heavy train, the benefits of car streamlining are clear.

Streamlining is estimated to result in a maximum 5 percent increase in the costs of purchasing a boxcar. The costs of streamlining depend in part on the material used for weight reduction which could accompany the streamlining process. Retrofit streamlining is not practical, except for perhaps closing "open" cars such as bilevel and tri-level automobile cars, where savings in vandalism and theft provide the economic incentive.

Other Car Changes. Some additional savings in energy which cannot be fully quantified at this time include the use of technological improvements to reduce car rolling resistance due to truck "hunting" (oscillations) and skewing. Constant contact side bearings and other devices are promising in this regard. Radial guidance on curves, or truck "steering," is another truck/car design factor which could have beneficial results.

TABLE 3-6

EXAMPLE OF BENEFITS OF STREAMLINING RAIL CARS AS SHOWN IN SIMULATION RUNS

SIMULATION EQUIPMENT

Movement of 960 automobiles weighing 2.5 tons each, between Chicago and Kansas City, a distance of 450 miles, over profile of AT&SF Railway, observing all permanent speed restrictions, and stops for three crew change. Simulated power included 2 EMD SD40-2 series locomotives, each rated at 3,000 horsepower. Cars simulated were standard open tri-level cars at 45 tons each, and streamlined cars designed by ANBEL Corporation, Houston, Texas, each weighing 30 tons. Both trains had a total tare weight of 3,600 tons, including 80 tri-level cars, or 120 streamlined cars. Simulation performed by EMD Division, General Motors, using their train performance and fuel calculator.

OPERATION	FUEL CONSUMED (Gallons)	RUNNING TIME (Hours)	AVERAGE SPEED (MPH)
Westbound			
Standard Cars	3,923	12	37
Streamlined Cars	3,508	11	41
Difference	415 Savings	1 Saving	4 Increase
Percent Change	11 Percent	8 Percent	11 Percent
Eastbound			
Standard Cars	3,907	12	37
Streamlined Cars	3,497	11	40
Difference	410 Savings	1 Saving	3 Increase
Percent Change	11 Percent	8 Percent	8 Percent

Source: Communication between Alan Cripe and Electro-Motive, Division of General Motors Corporation, September 30, 1974.

Car designs using very long cars are suspect, not only for derailment problems on sharp curves but increased flange resistance (and train resistance) due to high lateral loads during both traction and braking. Further research is required by the industry to identify the solutions and financial benefits.

3.2.18 Electrification

Electrification has often been proposed as an opportunity to conserve energy in rail transportation. Electrification offers the railroads the operating advantages of high, lightweight motive power as well as locomotive maintenance savings.

Electrification, however, does not offer any clearcut advantages in reducing overall energy efficiency. According to a recent study, the overall efficiency of modern electric rail traction is little different from existing diesel traction on a Btu per ton-mile basis, using coal or oil-fired power plants.[1]

Because most electric power plants are coal- or nuclear-fueled, electrification does offer the opportunity for railroads to substitute other types of fuel for petroleum. A recent study estimates that electrifying 6,200 miles of mainline track with the highest density traffic at a cost of almost $900 million (excluding power plants) could shift approximately 200 billion net ton-miles (approximately 30 percent of the total rail traffic) from oil dependency.[2] However, since diesel fuel oil used by the railroads is less than 4 percent of the petroleum used in transportation purposes and less than 2 percent of the nation's total use of petroleum, a shift of up to 30 percent of the railroad's current fuel use away from petroleum will be comparatively minor.[3]

One energy-related reason that railroads have been considering converting to electricity relates to the relative costs of electric and diesel

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[1] Reebie, op. cit., p. 50.

[2] Peat, Marwick, Mitchell & Co. and Jack Faucett Associates, Industrial Energy Studies of Ground Freight Transportation, prepared for the Industrial Energy Analysis Group, U.S. Department of Commerce, July 1974, pp. ix-15.

[3] Railway Progress Institute, A Review of Factors Influencing Railroad Electrification, The Government-Industry Task Force on Railroad Electrification, 1974.

power. However, as noted in a recent article by L. Stanley Crane (then executive vice president for operations at Southern Railway), increases in electric energy costs are catching up with diesel fuel cost increases, which reduces the attractiveness of investing in electric power facilities.[1]

Because electrification does not result in clear-cut energy savings and the rising costs of electric power cloud imminent conversion, it is not included in the analysis of energy savings in this report. Since regenerative braking would only be implemented on electrically powered vehicles, and since only a small number of electric locomotives are currently in use in freight transportation, regenerative braking is also excluded. Capturing the large amount of regenerative braking power on diesel freight locomotives with on-board energy devices is far beyond practical, foreseeable technological developments.

3.2.19 Summary

With rising energy costs, the potential for energy savings through technological changes is a new-found opportunity for railroads to cut operating costs. However, the amount of energy saved from adopting the technological changes outlined in this section depends on the extent of adoption of equipment with these changes. Rail equipment has a relatively long life. Based on current replacement rates, the average life of a locomotive is 24 years and the average life of a rail car, 26 years.[2] Thus, if equipment replacement continues at the current rate and, even if all new equipment is designed to conserve energy, the extent of energy savings from technological changes over the next ten years is relatively small. This subject will be discussed further in the next section.

3.3 INLAND WATERWAYS

3.3.1 Overview of Recent Trends

For this study, the most important trends in waterway operations are the increasing size of towboats and the increasing difficulty in programming new waterway improvements.

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[1] Washington Star, December 8, 1975, pp. D-6.

[2] Association of American Railroads, Yearbook of Railroad Facts, 1975 Edition, 1975.

Inland waterway traffic increased significantly during the 1950s, due in part to the sophistication of the diesel towboat and larger tows. During the 1960s, developments such as the Kort nozzle further advanced the efficiency of river barging. However, the boats built during this time will need to be replaced during the latter part of this decade. Technologically, the new towboats will be similar to the later models in service during the 1972 base year, except for their larger size. The demand for higher speeds, larger tows, and greater maneuverability will result in a need for higher towboat horsepower.

When programming new or replacement locks and dams on the inland waterways, the Corps of Engineers uses traffic projections that assume a constant modal share of water traffic. Experience with simulation modeling tends to confirm the belief that potential increases in lock delays will hinder the growth of water transportation with no change to the existing lock systems.

Programmed improvements on the Ohio River, scheduled to be completed by 1985, will change the 1972 main-stem system of 32 locks and dams to a system of 20 mostly high-lift locks and dams. However, plans have been held up in litigation as attitudes toward the environmental effects of public investment have changed since the commence of the Ohio River project.

3.3.2 Future Changes in Operations

Waterway improvements (including many on the lower Mississippi), designed to improve navigation channels, may result in even higher operating speeds or larger tows. A desire for larger tows, more maneuverability, and higher speeds will likely increase the demand for horsepower faster than increases in payload.

The Howe formula,[1] modified to reflect large tows, is an empirical engineering relationship designed to estimate steady state, still water speed for a given towboat power. Although the horsepower value used in the formula is the installed or available horsepower of the towboat, it can be used to estimate speed at less than full power output.

The relationship between input horsepower and output speed, given the size of the tow, is shown in Figure 3-5. Speed increases at a

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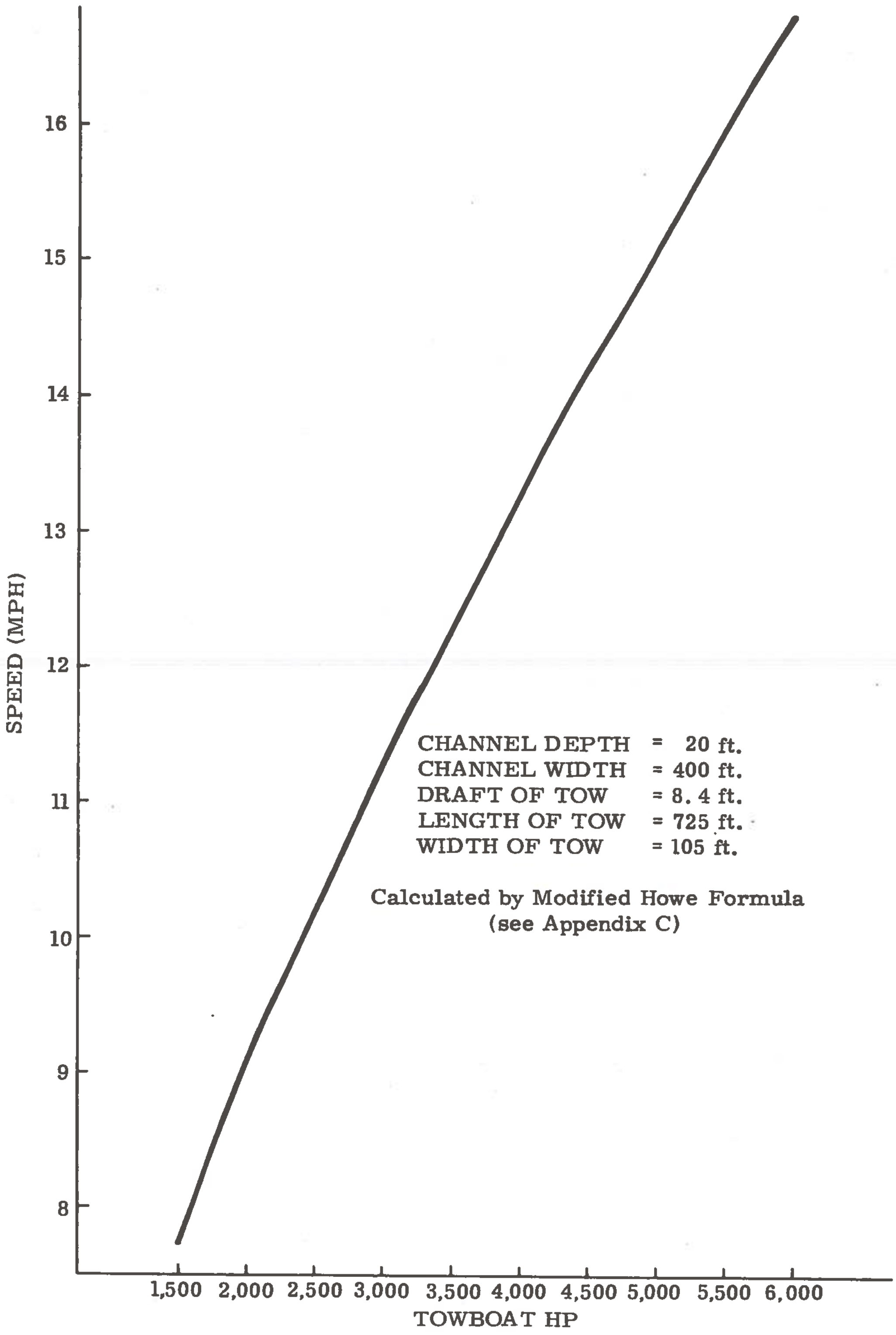
[1] "Process and Production Functions for Inland Waterway Transportation," Paper No. 65, Institute for Quantitative Research in Economics and Management. C. W. Howe, Purdue University, 1964.



CHANNEL DEPTH = 20 ft.
CHANNEL WIDTH = 400 ft.
DRAFT OF TOW = 8. 4 ft.
LENGTH OF TOW = 725 ft.
WIDTH OF TOW = 105 ft.

Calculated by Modified Howe Formula
(see Appendix C)

Source: Calculated by using the Modified Howe Formula.

FIGURE 3-5: EXAMPLE OF STILL WATER SPEED VERSUS TOWBOAT HORSEPOWER decreasing rate with increases in horsepower. This relationship is inverted when Btus per ton-mile are calculated. That is, at increasing speeds, Btus (directly related to horsepower input) increase at an increasing rate (see Figure 3-6).

The relationship between towboat horsepower and tow size and configuration at a constant speed may also be examined. Figure 3-7 shows an irregular increase in required horsepower with increase in the number of barges. Since the modified Howe formula calculates speed or horsepower based on overall barge flotilla or tow dimensions, the optimum relationship is a rectangle. That is, the horsepower requirement would be about the same for 14 barges in an irregular pattern as for 15 barges in a rectangular pattern since the overall size of three barges wide by four barges plus two barges up front is the same as that of three by five barges at least in terms of input to the model. Fifteen barges, however, mean more payload and less Btus per ton-mile. The Btus per ton-mile which correspond to the tows in Figure 3-7 are given in Figure 3-8.

The overall width of the tow, which determines the frontal area of the flotilla, has a greater impact on required horsepower (i. e., offers a greater resistance to movement) than the overall length of the tow. Consequently, when the six barge flotilla is rearranged from three across and two deep (105 feet x 530 feet) to two across and three deep (70 feet x 725 feet), the required horsepower Btus per ton-mile decrease by nearly one-third, somewhat less than the one-third reduction in frontal area, (See Figure 3-7 and 3-8). Handling and channel characteristics dictate the configurations used in each waterway.

It is expected that the average horsepower of new boats will increase faster than average tow size,[1] which would indicate that some increase in running speeds can be expected. This is reflected in the future year assumptions.[2] Therefore, accounting for increased payloads, the rate of overall improvement is mixed.

To test the effects of reducing lock delays, the proposed new locks and dam at Alton, Illinois, and the industrial lock on the Gulf Intracoastal in Louisiana were studied. Both of these locks are currently bottlenecks in the waterway. Delays can sometimes reach 24 hours. The TRANSEN Model cannot examine these points specifically but can

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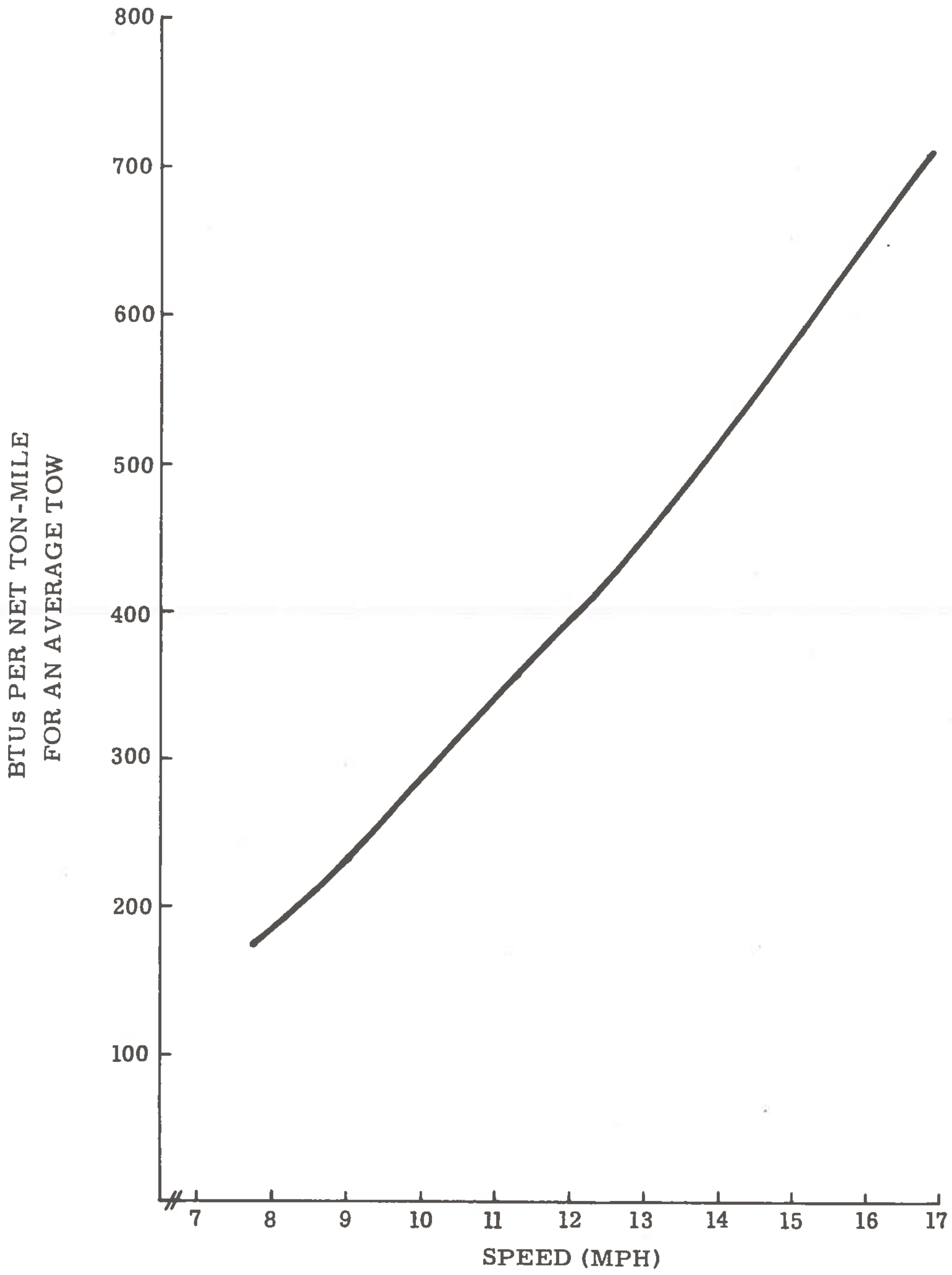
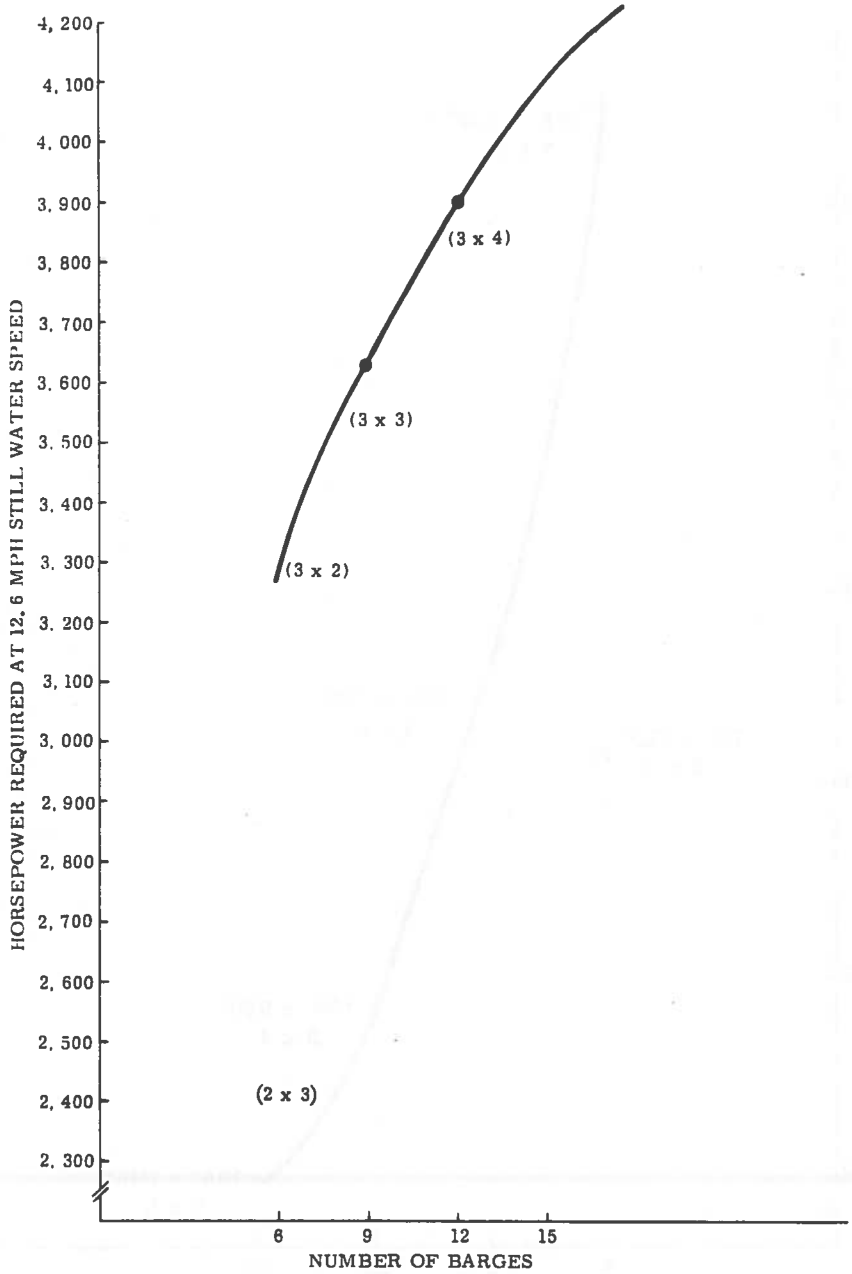
[1] Based on discussion with industry representatives and U. S. Army Corps of Engineer analysts.

[2] See Section IV for analysis of assumptions on speeds.



Source: Calculated from Modified Howe Formula (tow descriptions as in Figure III-5.

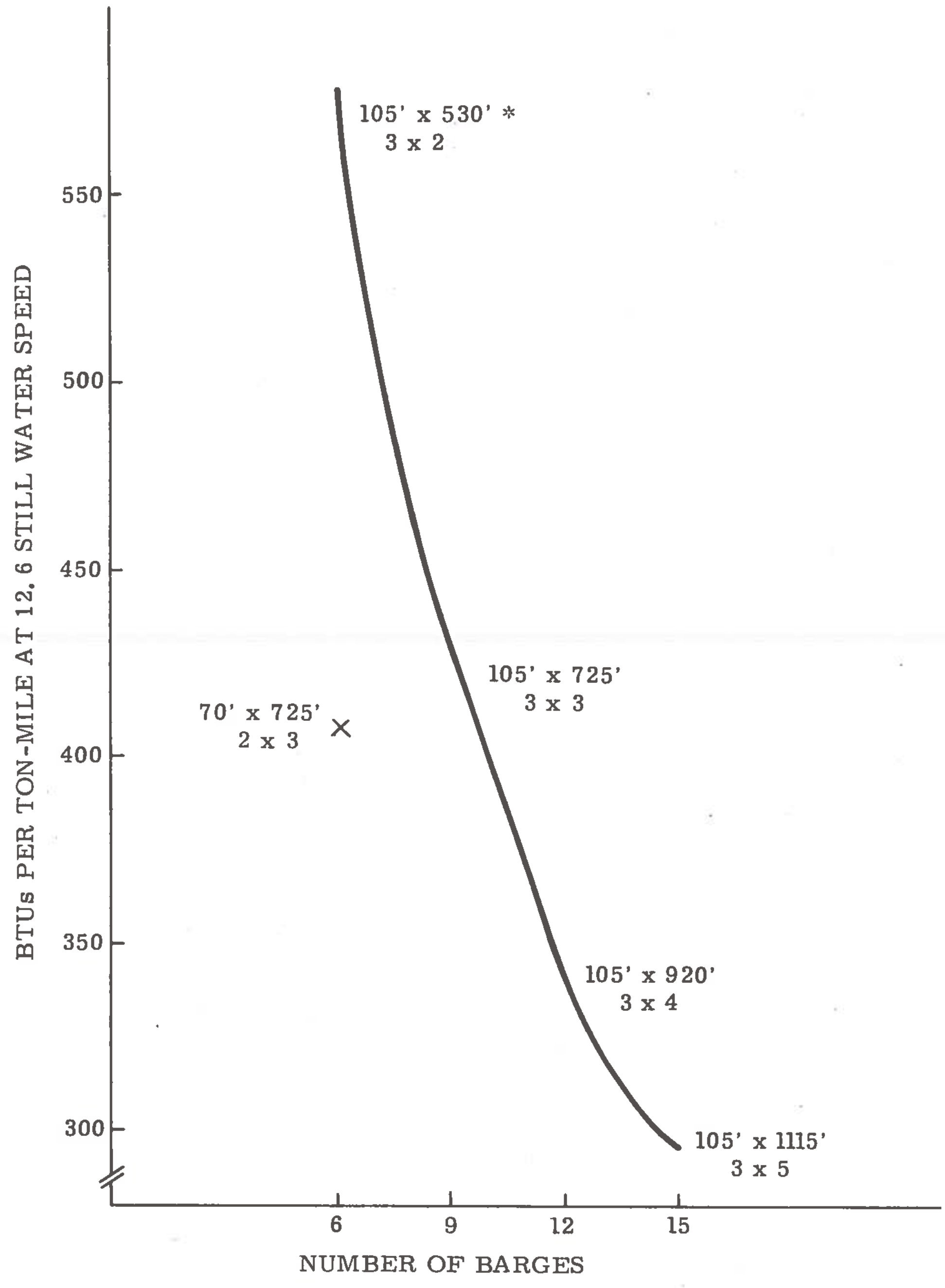
FIGURE 3-6: BTUs PER TON-MILE IN STILL WATER AT VARYING SPEEDS FOR AN "AVERAGE" TOW



Note: (X x Y) = No. of barges wide by no. of barges long.

Source: Calculated from Modified Howe Formula with assumptions outlined in Figure III-5.

FIGURE 3-7: CHANGE IN HORSEPOWER REQUIREMENT WITH CHANGING TOW SIZE



Source: Calculated from Modified Howe Formula (values correspond to calculations made in Figure III-7.

* Dimensions of tow including the towboat.

FIGURE 3-8: CHANGE IN BTUs/TON-MILE WITH CHANGING TON SIZE UNADJUSTED FOR WATER CURRENT VELOCITY examine their effect on average lock delays. The Upper Mississippi lock delays were decreased from the industry change 5 hours to 1.5 hours by 1980 with a resultant drop of 26.18 Btus per ton-mile on that waterway. The Gulf Intracoastal lock delays were reduced from 1.6 to 1.05 hours. Btus per ton-mile improved by 1.35 on this waterway. (See Section IV for detailed analysis of model results.)

3.4 COASTAL AND GREAT LAKES SHIPPING

The study scope did not include an analysis of the trends or potentials in coastal shipping. Consequently only the observed trends of increases in average speed and vessel size and decreases in port time were included in the analysis of operational and technological changes.

Low EI figures in coastal shipping are generally not adjusted for sometimes substantial circuity. However, not all commodities are transported over routes more circuitous than competing modes. For example, most of iron ore carried on the Great Lakes goes to its destination by a route not significantly longer or shorter than the rail route between the same two points. Also, deep sea barging is often confined to a single coast, so that the haul between coastal points may be nearly as direct as land routes.

3.5 PIPELINES

Improvements to pipeline energy efficiency can come from three sources:

larger diameter pipes;

a shift toward turbine drive of pumps; and

optimized operation - smoothing out the rate of deliveries to reduce average velocity.

The second improvement in energy efficiency reflects the general greater energy conversion efficiency of gas or liquid fuel turbines over electric power, but because these turbines run on scarce petroleum or natural gas, and electric power comes from more plentiful domestic energy sources, the improvement may not support basic national energy policy. The third option was not studied due to lack of observed data on pipeline operations.

Additional construction of oil pipelines is necessary to accommodate increased demand for petroleum and shifts in sources of supply of crude oil and to replace outdated or worn out pipelines. The latter reason for new construction is of lesser importance, since pipelines have a very long economic life. Shifts in sources of crude supply is the most important cause for new pipeline construction now and in the near future. New pipeline construction will be dominated by the Alaskan pipeline, pipelines from deep-water ports to refineries, pipelines to bring Alaskan oil inland from west coast ports, and pipelines to bring crude from new offshore fields.

New product pipelines will depend on the rate of growth in petroleum demand and the degree of utilization of current lines. Since a product line serving the midwest cannot be transferred to the southeast to respond to shifts in population and industrialization, average utilization of products lines and overall demand may even drop while the need for new products lines grows. For instance, the colonial pipeline, which supplies products refined in the Gulf states to the Middle Atlantic states, is currently running at near full capacity, with fluid velocities at or near 7 miles per hour compared to the average product velocity in 36 inch pipelines assumed, for this study, at 6 mph.[1] Consequently, growth in demand in this region will be met by imports or transfers via tanker, new refinery construction in the area, or new pipeline construction. Pipeline construction will occur only when the growth in demand is large enough to warrant it and refinery economics favor distant locations. For this study, future pipeline mileages by size were projected based on historical growth rates and recent construction data.[2]

Pipeline energy use is very sensitive to operating velocities and to pipe diameter. Product characteristics, such as specific gravity and viscosity, play a lesser but important role.

3.5.1 Sensitivity of Energy Intensiveness to Pipe Size and Product

Table 3-7 lists the Btus per ton-mile found for crude oil and several products for 22 common pipeline sizes given the velocity assumptions discussed on Page 2-34 and shown in Figures 2-2, and 2-3. For a given velocity, the energy intensiveness of a line will vary inversely

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[1] See Appendix E for discussion of velocity assumptions.

[2] See Appendix E for discussion of pipeline mileage projections.

TABLE 3-7

BTUs PER TON-MILE BY PIPELINE SIZE AND PRODUCT

SIZE	CRUDE	PRODUCT						
		MOGAS	AVGAS	K-JET	N-JET	KERO	DIST	NGL
2	250	517	517	458	459	650	722	618
3	248	501	501	444	444	630	700	599
4	244	481	481	426	427	605	672	575
6	239	451	451	399	400	566	630	539
8	233	423	423	375	376	532	592	506
10	227	404	404	358	359	508	565	483
12	223	384	384	340	341	482	536	459
14	220	374	374	331	332	470	523	447
16	218	358	358	317	318	450	500	428
18	212	342	342	303	303	430	478	409
20	207	328	328	291	291	413	459	393
22	206	319	319	283	283	401	446	382
24	203	308	308	273	274	388	431	369
26	200	296	296	262	262	372	413	354
28	197	285	285	252	253	358	398	341
30	193	275	275	244	244	346	384	329
32	190	266	266	236	236	334	372	318
34	187	257	257	228	228	323	359	307
36	184	245	245	217	217	309	343	294
40	180	237	237	210	210	298	331	284
42	176	231	231	205	205	290	323	276
48	170	215	211	191	191	270	301	257

Source: Calculated from data developed in this study and based on velocity assumptions outlined in Figures 3-2 and 3-3.

with the diameter raised to the power of 1.17.[1] These energy intensiveness values were averaged to arrive at the 1972 pipeline energy consumption given in Section 2.

The products differ in energy intensiveness arithmetically with higher specific gravity (more weight per volume) and exponentially with the inverse of friction factor, which is an empirically derived number that reflects the viscosity and chemical makeup of the product.[2]

3.5.2 Sensitivity of Energy Intensiveness to Fluid Velocity

The above discussion, as well as the average energy intensiveness calculations of the TRANSEN model, assumes a different velocity for each pipeline diameter. Such an assumption cannot be based on empirical evidence because no statistics of operating velocities exist. Velocity assumptions were made because of best available estimates in lieu of pressure drop assumptions or station spacing assumptions, and, further, it is easier to see the effect of this assumption on the results of the energy intensiveness calculations. For a given pipeline diameter energy requirements vary directly with velocity raised to the power of 1.852.

In actual practice, operating velocities of pipelines are greater or less than assumed velocities. This is because lines are shut down for occasional maintenance or reduction in demand, and on other occasions supply needs require higher pumping pressures and greater velocities. The resulting average Btu requirement calculated using an average velocity may be lower than actual Btu requirements by an undetermined amount because of the non-linearity of BTU requirements versus velocity, and the assumption used in this study (some studies have estimated energy intensities for pipelines as much as twice the values calculated in this study). Also, the data used for calculating implied velocities may be subject to some error, and the methodology used is probably the best under the data constraints to which the study team was subjected.

Relatively few operational and technological changes are available (compared to other modes), and center chiefly on reduced velocities (and longer pumping at that velocity) on the operational side, and use

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[1] Derived from equations E-1 and E-2 in Appendix E.

[2] See equation 2 in Appendix E.

of larger lines and more efficient pumps (and prime energy source) on the technological side.

3.6 AIR CARGO

Within the transportation sector, the magnitude of energy savings from air cargo conservation measures is limited by the relatively small amount of fuel consumed by air cargo movements compared to the other freight modes.[1] In addition, the special requirements of air cargo shipments limit the opportunity to shift air cargo shipments to less energy intensive modes.

Most air cargo moving in passenger aircraft is considered as a means to utilize the available capacity not utilized in passenger service. In these situations, air cargo is valued primarily for its marginal revenue contribution. For passenger planes, operating and technological decisions are oriented towards passengers.

3.6.1 Recent Trends in Aircraft Energy Consumption

In response to the oil embargo and rationing of the fuel supply, airlines have made some adjustments in their operating procedures. Among changes which have affected the air cargo movement are:

elimination of some flights--both passenger and all cargo (with the consequent reduction in available capacity);

increases in load factor;

reduction of cruising speeds;

increased use of training simulators (no effect on operations);

more efficient ground operating procedures to save fuel; and

curtailment of some wide-body flights and substitution of narrow-body flights.

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[1] In 1972, air cargo energy consumption is estimated at .4 percent of total freight energy consumption based on the marginal approach and 1.9 percent based on the average approach.

3.6.2 Energy Conservation Measures

In the future, air cargo operations appear most likely to be characterized by the consolidation of shipments in containerized movements to reduce the handling costs involved in ground processing. In the longer term, when current aircraft are no longer economical, technological improvement may be implemented to facilitate the transport of air cargo. Aircraft technology may be developed which is more efficient and more suited to container transport and intermodal transfer. Larger aircraft, the use of improved aerodynamic configurations, such as the high-lift "super critical" wing, and improved engine designs (which may be retrofitted), may reduce energy intensity of this mode.

Fuel consumption is becoming a more important consideration to air carriers as the price of fuel increases. Jet fuel costs, which have in the past accounted for about 12 percent of cash operating costs, have now increased to as high as 20 percent.[1] As a result air carriers are considering several steps to improve their energy efficiency. Four measures which can be changed to reduce the energy consumption by air cargo movements are discussed below:

load factor;

speed;

altitude; and

aircraft mix.

3.6.3 Load Factor

Increased load factors for all cargo aircraft could decrease the number of flights made. Increased load factors appear most likely to be encouraged by the growth of containerized air cargo movements, a trend which is encouraged by attempts to reduce ground handling costs. Currently, a large portion of revenues are consumed in on-the-ground costs. To increase volume through more attractive rates, ground costs in cargo handling, loading, unloading, storage, and security must be substantially reduced.[2] Containerization would be one way to reduce the costs described above.

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[1] 1974 National Transportation Report, U.S. Department of Transportation, Washington, D.C., December 1974, pp. VI-15-16.

[2] L. T. Goodmanson and G.N. Bower, "Cargo Aircraft--A Look Toward the Future", Exxon Air World, Volume 27, No. 3, 1975, p. 63.

Among the several factors which currently limit greater air cargo load factors are:

> the lack of incentive for shippers to move large quantities by air in sizes which lend themselves to increased capacity utilization of aircraft and to containerization . For most commodities, air rates are still too high to attract shipments which are large enough to warrant containerization.[1]
>
> the lack of intermodal coordination, prevented by regulation, which could result in more efficient terminal operations and greater information for shippers and carriers. The Civil Aeronautics Board (CAB) defines air carriers and generally separates them from air freight forwarders to prevent control by a single organization of the entire physical distribution system. Recently, however, the CAB relaxed the regulations to allow three long-haul trucking companies to become air freight forwarders. This modal combination was experimental, to infuse some capital into and increase the distribution outlets for the weak airfreight forwarder industry.[2]
>
> the design of all cargo aircraft. Current aircraft are limited by the size of the cargo loading doors and the bearing strength of the floors. Also, the floors are higher above the ground than the floor of a truck, which limits intermodal transfer. Similarly, the circular shape of the passenger aircraft fuselage limits intermodal transfer.[3]

Increased load factors for air cargo transport through the encouragement of containerization could occur by modifying tariffs to provide incentives for larger shipments, space available movement, increased opportunity for intermodal cooperation, and ultimately, the redesign of aircraft to handle containerized shipments, if sufficient traffic exists to warrant the redesign. Other possibilities may include permitting airlines to pool freight and to work together to revise operating practices which lead to higher capacity utilization.

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[1] R. C. Fraser, A. D. Donheiser, T. C. Miller, "Civil Aviation Development: A Policy and Operations Analysis", Praeger Series, New York 1972.

[2] Ibid., p. 161.

[3] Ibid.

3.6.4 Speed and Altitude

Increasing flight altitude and reducing cruise speed have been recommended as means to improve the energy efficiency of aircraft movements.[1] Currently, the speed of passenger aircraft is influenced by considerations of total operating costs and passenger demand for travel time. As speed decreases, fuel use decreases but other operating costs increase.[2] Thus, nonfuel costs and competitive pressures tend to limit speed reduction solely to conserve fuel.

At a given speed, fuel consumption generally decreases with higher altitude. The optimal altitude for fuel conservation depends on aircraft design, weight, and speed. However, aircraft fly lower than at optimal altitude due to FAA altitude assignment restrictions, determined in part by altimeter technology, which restrict same-direction flights below 29,000 feet to 2,000-foot separations and flights above 29,000 feet to 4,000-foot separations. Thus, flight altitude is determined by sky congestion and FAA regulations. Since flight trip time and departure time (for which sky congestion varies) are in large part passenger-related considerations, operating changes affecting flight speed and altitude are primarily passenger-related considerations as well.

One study measured the impacts on aircraft fuel use on changes in flight speed and altitude. This study estimated that a reduction in aircraft speed of .02 Mach-number (the ratio of airspeed to the speed of sound at a given altitude) would reduce fuel consumption by 1.3 percent and would decrease travel time by 2 minutes for a 1,000-mile trip.[3] A further speed reduction to the long-range cruise speed, the speed at which the aircraft range is 99 percent of its maximum, was estimated to reduce carrier fuel requirements by 3 percent.[4] Decreasing speed to long-range speed on a 1,000-mile flight would increase flight time by 9 minutes on a DC-9 and by 2 minutes on a B-747. The same study estimates that a relaxation of FAA restrictions to permit 2,000-foot cruise altitude increases would result in a decrease of 1.3 percent of fuel used, but would require installation of more expensive altimeters.

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[1] David A. Pilati, Energy Conservation and the Environment, Progress Report-December 31, 1973. Oak Ridge National Laboratory, 1974.

[2] John Pollard et. al., A Summary of Opportunities to Conserve Transportation Energy, pp. 2-28-9.

[3] Pilati, op. cit., pp. 24-6.

[4] Ibid.

3.6.5 Aircraft Mix

Recent trends have shown increased movement by air cargo on passenger as opposed to all-cargo aircraft. Growth in lower-hold cargo movements has been responsible for the overall growth in air cargo since 1970.[1] This growth is occurring partly because of increased use of wide-bodied aircraft for which carriers have been trying to fill up the lower-hold capacity, especially because of the reduced costs made possible by larger aircraft size. This trend is likely to continue in the future. Increased use of lower-hold capacity might be amplified if the CAB allowed passenger carriers more freedom and flexibility in marketing and pricing practices.

3.6.6 Technology

In general, the development of aircraft technology has occurred to meet the needs of passenger travel. Cargo aircraft have been designed as adaptations of passenger vehicles, since the air cargo market has been limited until very recently. Improved vehicle design for cargo purposes would have limited returns, since such a large portion of total air cargo costs is in ground handling.[2]

Any major changes in aircraft technology are beyond the ten-year scope of this study, with short-term technological changes expected to be "improvements to and derivatives of current cargo aircraft."[3] A recent study noted that "the current generation of freighters, being relatively new, are likely to be in use for at least five more years since air freight carriers, having just re-equipped with stretched DC-8s are unwilling to commit themselves to another fleet re-equipment cycle and manufacturers of aircraft recognize the limited profit potential of air cargo operation."[4]

Aircraft technological changes in the next ten years will probably be oriented toward adapting aircraft movements to containerization, as noted earlier, including adaptations of doors and floors. However,

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[1] Pollard, op. cit., pp. 4-15.

[2] R. C. Fraser et. al., op. cit.

[3] Goodmanson, op. cit., pp. 63.

[4] R. C. Fraser, et. al., op. cit., 158.

any major air frieghter is not expected to materialize within the next 15 years.[1]

3.7 RAIL/TRUCK MODAL SHIFTS

Modal shift from highway to rail, especially TOFC/COFC is not technically either an operational change or a change in technology, but is perhaps in a class by itself. It depends largely on who originates the change. If a shipper decides to ship via rail instead of truck - either in carload or using TOFC/COFC - it may result in energy savings which is a result of neither operational nor technological change. If a motor carrier uses TOFC as a substitute to over-the-road movement, it may constitute an operational change.

Increased use of TOFC by motor carriers is inhibited by ICC rate regulation, and in some cases operating rights restrictions, mutual suspicion between the modes, frequently marginal economies, but perhaps most importantly, service quality. Regulatory operating restrictions include prohibitions against railroads from providing Plan II piggyback pickup and delivery service outside of local commercial zones.

The market and opportunity for mutual cooperation between both modes in selected markets does not exist, as industry experiments, market studies (conducted by such companies as the former Penn Central, Illinois Central, and B&O railroads, Spector Freight System), and PMM&Co.'s own experience suggest. These include the northeast corridor (through many operating and clearance problems need be solved) and the corridors between Chicago-Detroit; Chicago to St. Louis and points south, Detroit to St. Louis and points west and south.

Some freight shipments, by virtue of shipment size, length of haul, and nature of origin and destination served, could reasonably move on either truck or rail carriers. Many of these shipments, primarily those in manufactured goods which are higher in value and more subject to loss and damage, have been attracted to truck rather than rail because of trucks' faster speeds, improved service, including better security and reliability, and competitive prices. If railroads were to improve the quality of their service, they could attract or reattrack truck freight.

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[1] Aviation Week and Space Technology, October 28, 1974, pp. 107-8.

While early studies suggest a 2 to 1 energy advantage of TOFC over truck, more recent studies (Railroad and FRA sponsored) show that to provide competitive service and speed, the fuel advantage of rail over truck is significantly less, and in mountainous or rail circuitous territory TOFC may even be less efficient than via highway, especially when fuel consumption for pickup and delivery is included. Another example of a situation where the energy efficiency advantage of rail movements is not clearcut is the movement of traffic on branch lines. Two studies described by the United States Railway Association in their Final System Plan conclude that, for short trips with light loads, more energy may be required to move a shipment by rail than by truck.[1] However, in most situations, transfer of traffic from truck to rail would result in improved energy efficiency of the entire transportation system.

Many of the measures described to improve the energy efficiency of the rail mode also could improve the quality of service offered by the railroads. Such measures include reduced delays, development of run-through trains, and improvements in yard operations. However, other changes proposed to improve energy efficiency, including heavier loads in under-loaded cars and slower running speeds, might endanger potential traffic shifts from trucks to rail.

Intermodal TOFC and COFC (i. e., piggyback) movements offer railroads a major opportunity to attract some of the rail/truck competive traffic. TOFC/COFC movements provide an opportunity to offer better service, improved equipment utilization, reduced damage and shipment handling, and greater flexibility through easier intermodal transfer for delivery to destinations off rail lines. Dedicated intermodal trains offer an opportunity for quicker service and for service not held up by intermediate switching. TOFC movements consume more energy than regular train movements because of faster speeds, higher tare weights, and the potential for increased circuity (since the existence of fewer unloading facilities limits choice of unloading destinations). However, TOFC movements generally, but not always, require somewhat less energy than comparable truck movements and thus offer an opportunity for reduced energy consumption through truck/rail transfer in specific situations.

Currently, TOFC movements are more common than COFC movements. COFC movements are employed predominantly for international shipping and related inland movements. TOFC movements are more

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[1] United States Railway Association, Final System Plan, Supplemental Report, September 1975, pp. 96-8.

flexible because they do not need special terminals and thus the logistical problem of providing container chassis at various intermodal terminals is eliminated. However, COFC trains have lower aerodynamic and rolling resistance than TOFC trains, because of their lighter weight, lower profile, and lack of highway running gear; thus, COFC movements consume less energy. Table 3-8 shows the comparative energy consumption values (in terms of percentage savings at varying stages of streamlining) for COFC and TOFC movements.

Congested piggyback facilities are another factor limiting piggyback growth. Major expansion of TOFC/COFC service will require new investment in cars and loading terminals. One study estimated a need for one new piggyback car ($32,000) for each new 10 trailer loadings per year, a new locomotive ($500,000) for each new 500 trailer loadings per year, and a new terminal ($5 million) for each new 12,500 trailer loadings per year.[1]

Growth in intermodal movements may be encouraged by:

operating cost reductions in the terminal areas (i.e., improved operating concepts);

increased attention by rail carriers to develop and market intermodal service to meet shipper needs;

government aid in financial expansion of TOFC/COFC facilities; and

regulatory efforts to improve intermodal coordination.

A proposal is currently in Congress to expand ICC jurisdiction by amending Section 216 to permit, after hearings, through-rates and joint-rates between trucks and rail carriers. The purpose of this proposal, among other things, is to encourage the growth of piggyback service by permitting the shipper to contact only the originating carrier for rates and routes.[2]

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[1] David Rubin et. al., <u>Transportation Energy Conservation Options,</u> October 1973, pp. 12-3-12-4.

[2] Ex Parte 301

TABLE 3-8

ENERGY SAVINGS FROM STREAMLINING EQUIPMENT ON TOFC/COFC MOVEMENTS

TYPE OF TRAIN	EXTENT OF STREAMLINING	ENERGY SAVINGS RELATIVE TO COMPARABLE NONSTREAMLINED MOVEMENT (Percent)
All-TOFC Train	Streamlined Locomotive	10.7
All-COFC Train	Streamlined Locomotive	12.5
All-COFC Train	Steamlined Cars	13.5
All-COFC Train	Streamlined Locomotive and Streamlined Cars	24.4

Assumptions: Train moves with 30 cars, 2 locomotives at 60 miles per hour average speed (truck competitive).

Source: PMM&Co. estimates.

In 1972, 1.3 million loaded car movements handled approximately 2.3 million trailers and trailer-sized containers.[1] Approximately 4 percent of the total net rail tons are represented by piggyback movements. The number of trailers and containers handled rose at an average compound annual rate of 11 percent from 1964 to 1969, while total rail revenue carloadings fell by .5 percent per year. Container terminations dropped in 1970 and 1971 but increased from 1971 to 1972 by 14.5 percent and by 12.7 percent from 1972 to 1973.[2]

Estimates of the potential market for piggyback service vary considerably, based on estimates of which commodities and trip types are considered amenable to transfer to intermodal service. The National Council on Productivity estimates that for traffic of manufactured products (STCC classes 19-40)--the traffic for which containerization is most suited--rail containers only handle 5 percent of the traffic by weight.[3] A study of the potential for intermodal traffic in the 400-1,200 mile range estimated that in 1971 only 4 percent of the freight shipped that was amenable to intermodal shipments was actually moving in piggyback service.[4] In another study, the American Trucking Association examined those shipments of commodity groups most amenable to truck/rail competition (STCC groups 20-39) and broke the shipments into 42 categories based on different weight and mileage combinations.[5] Each category for which rail and truck each carried 10 percent of the traffic was deemed "competitive." As a result, 26.5 percent of the tonnage shipped in these groups in 1972 was considered truck/rail competitive. Based on comparisons with the output from the TRANSEN calculations, it was estimated that 44 percent of this competitive traffic was already moving by rail. The remainder was considered to be potential traffic for truck to rail shift for this study. Appendix A, under scenario inputs, discusses the estimation process in more detail.

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[1] Association of American Railroads, Yearbook of Railroad Facts, 1973 Edition, Washington, D.C.

[2] National Council on Productivity, op. cit., p. 143.

[3] Ibid.

[4] U.S. Environmental Protection Agency, quoting Reebie (50).

[5] American Trucking Association, Intercity Freight Fuel Use Efficiencies, (Washington, D.C., American Trucking Association, December 15, 1975).

Because of the assumptions made in this study regarding modal shift, which may be considered by some to be tenuous at best, energy savings due to this shift are treated separately, and not included in rail energy calculations developed in the following sections of this report.

4. ENERGY CONSERVATION SCENARIOS

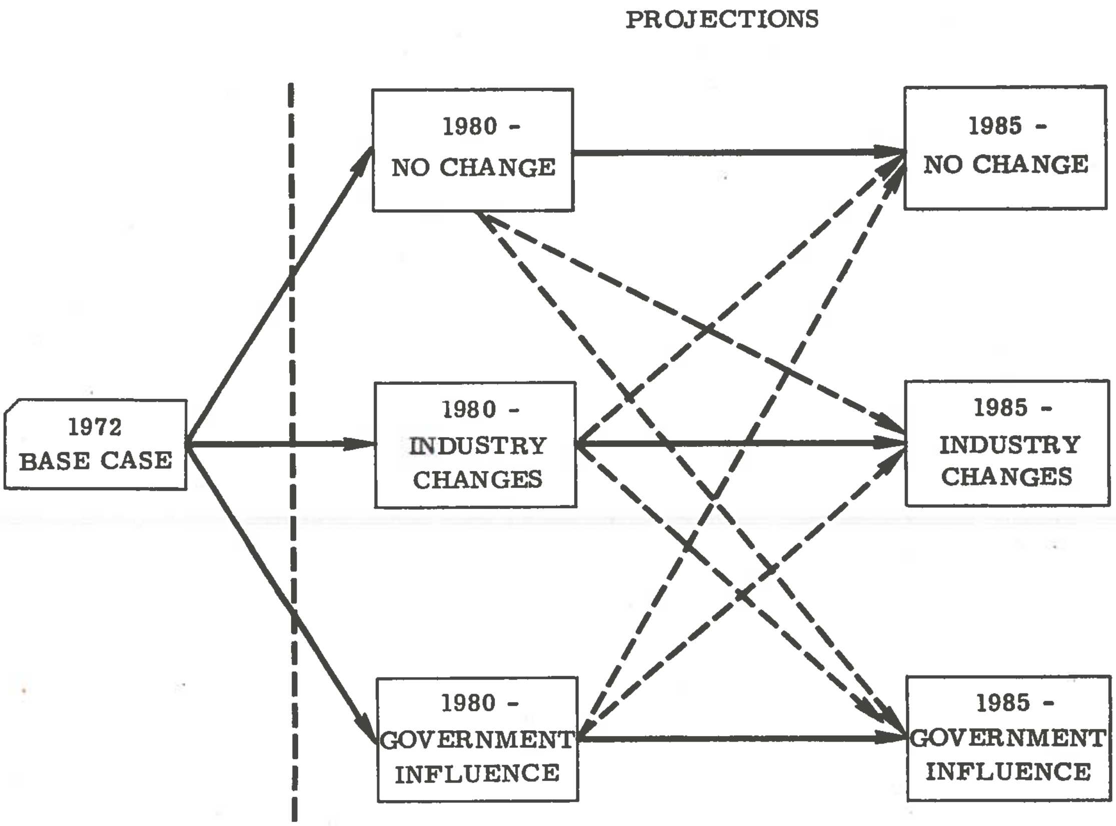
This section describes a series of scenarios which project freight transportation and energy consumption by transportation mode five and ten years in the future under varying conditions of energy conservation. This section is intended to combine the energy conservation measures discussed in Section 3 into overall consumption projections to show the relative impacts of each and, given varying estimates of the extent of their implementation, to indicate the impact of energy consumption of their combined impacts.

This section does not necessarily predict what will happen in the next ten years; the projections are indications of what could reasonably happen and serve as benchmark indicators of the combined potential impacts of energy conservation measures. A well-researched basis for forecasting commodity projections, rates of technology development and implementation, and economic impacts was not possible within the scope of this study.

Three sets of scenarios were developed for each mode where appropriate: (1) base year, (2) industry change, and (3) government influence. Each of the three is comprised of projections for 1980 and 1985 based on different assumptions. The assumptions are:

> Base-Case Scenario - Increases in traffic will be consistent with expected growth of the economy with no changes in energy efficiency or shifts between modes.
>
> Industry-Change Scenario - Transportation carriers will implement changes to conserve energy within the context of the traffic growth developed for the first set of scenarios.
>
> Government-Influence Scenario - Government influence will be used to achieve greater energy conservation measures within the transportation sector.

For each set of projections, energy consumption estimates were developed for 1980 and 1985, as shown in Figure 4-1. The solid lines represent the null, middle, and extreme range of scenario possibilities. The broken lines indicate alternative scenarios which were not studied.



Solid lines: Scenario paths studied

Dotted lines: Scenario paths not studied

FIGURE 4-1: SCENARIO ALTERNATIVES, 1980 AND 1985

This section begins with a discussion of the basis for developing the forecasted levels of traffic for each mode for 1980 and 1985. Next, the results of the scenario projections are discussed for each mode in terms of base-case estimates and changes from the base case due to implementation of energy conservation measures. The appendixes include a discussion of how the estimates of energy conservation measures translate into inputs for the TRANSEN model. The scope of the study did not permit an elaborate analysis of more scenarios and a greater exploration of differences in energy consumption for the different commodity groups.

4.1 TRAFFIC PROJECTIONS

Projections of demand for overall freight transportation were developed based on the historical trend that transportation demand grows at a rate consistent with that of the economy. The process of developing transportation projections involved:

- computing growth rates for different production sectors of the economy which correspond to the commodity groups in this study;
- applying these growth rates to overall freight transportation demand; and
- asssigning the transportation projections to the individual modes.

The process is described below in more detail.

The Bureau of Labor Statistics (BLS) has published 1970, 1980, and 1985 input-output tables which distribute overall economic demand according to production sectors of the economy.[1] The tables measure producers' value in 1963 dollars. From the BLS output, production sectors were combined to match the commodity groupings in this study, and annual growth rates were computed for the 1970-1980 and 1980-1985 periods. These results were compared with another Department of Commerce study on economic projections and were found

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[1] Bureau of Labor Statistics, The Structure of the U.S. Economy in 1980 and 1985. Washington, D.C., U.S. Department of Labor, 1975.

to be more conservative.[1] Table 4-1 shows the estimated annual growth rates for the 19 commodity groups for the two time intervals in this study based on BLS calculations.

These growth rates were applied to the total freight transportation ton-mile estimates developed in the TRANSEN model for each commodity group. The assumption was used that growth in demand for freight transportation for a commodity group will be comparable to growth in production of that commodity over the same time period. The estimates of total freight transportation demand thus obtained were allocated among the transportation modes according to each mode's share of the transportation ton-mile market in 1972 to provide base-case projections.[2] This procedure does not imply that the study team believes that modal shifts in traffic will not occur between 1972 and 1985; it indicates that, in the absence of any indication of future modal shares, the study team has adopted 1972 modal shares as base-case indicators of future energy consumption.

Base-year (i.e., 1972) tonnage estimates for truck and rail was also compared to independent estimates developed simultaneously with this study (by Jack Faucett Associates, Inc., in March 1976, for the Office of Transportation Planning and Analyses, Office of the Secretary, Department of Transportation). Although both studies use the same sources for truck data, base-year commodity estimates are substantially different. This difference reflects two different approaches to using the same partial information to estimate total

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[1] Department of Commerce, U.S. Industrial 1975 Outlook, Washington, D.C., U.S. Department of Commerce, 1975. This study developed projections for the 1974-1980 period for a range of industry groups.

[2] The projections were summed for each mode and were compared with overall modal forecasts developed by George H. K. Wang and Roy Epstein for five modes in Econometric Models of Aggregate Freight Transportation Demand, Working Paper No. WP-210-U1-81-A (Cambridge, Massachusetts: Transportation Systems Center, May 28, 1975). Their analysis forecasted ton-miles for rail, barge, air, and truck based on historical trends from 1947 to 1972 and assumptions in the future. They used Gross National Product, industry production indices, and freight rates as independent variables. Their results were comparable with the TRANSEN results for rail and pipeline, 15 and 21 percent higher for truck (for 1980 and 1985 respectively), 70 and 76 percent higher for barge (when barge included just inland movements), and three and six times higher for air cargo movements.

TABLE 4-1

ESTIMATED ANNUAL GROWTH RATES FOR COMMODITY GROUPS[1]

Commodity Group	Annual Growth Rates 1972-1980 (%)	 1980-1985 (%)
Agricultural products	4.03	2.21
Metallic ores	10.06	4.90
Coal, coke produced from coal	4.08	2.17
Crude oil, petroleum	4.62	3.60
Nonmetallic minerals	7.15	4.51
Food, kindred products, tobacco	2.78	2.33
Textiles, apparel, leather	3.91	2.41
Lumber, wood products, furniture	2.01	2.47
Pulp, paper, allied products	7.57	4.24
Chemicals, allied products	7.06	4.45
Rubber, plastic products	5.86	3.89
Clay, concrete, glass, stone	3.88	2.83
Primary metal products	6.65	3.92
Fabricated metal products	5.13	3.20
Nonelectrical machinery	6.58	4.20
Electrical machinery	5.75	4.08
Transportation equipment	6.76	2.63
Instruments, photo goods	5.71	4.22
Waste, scrap materials	5.08	2.86

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[1] Source: The Structure of the U.S. Economy in 1980 and 1985, Bureau of Labor Statistics, U.S. Department of Labor, 1975, from Table B-4, Industrial Composition of Total Final Demand (producer's value in millions of 1963 dollars). Projection estimates were developed largely from 1970 GNP data (which the BLS indicates included aggregation problems). Projections did not include consideration of happenings in the 1970-1978 period, which could--had adequate data been available--influenced annual growth rates. See pages 139-149 of the reference for a further explanation of forecast procedures.

population. In total, however, both studies are in close agreement, and differ by less than 3 percent for tons and 4 percent for ton-miles. Part of the difference is undoubtedly due to differences in commodity description and statistical variances within each commodity group. Individual commodity differences were not investigated. (Section I lists the STCC codes included in commodity descriptions in this study.)

By 1985, Faucett estimates total truck tons and ton-miles at 2.4 billion and 613 billion, respectively, compared to PMM&Co. base-case estimates of 2.7 billion and 637 billion--a surprisingly close estimate given the different approach and assumptions used. However, the significant variance by commodity continue to exist.

For rail, estimates are much closer, as would be expected given the more complete reporting of rail traffic to the ICC. Total tons and ton-miles for 1972 differ between the studies by only 1 percent for both statistics. By 1985, Faucett rail ton-miles are estimated at 1,450 billion compared to PMM&Co.'s 1985 base-case estimate of 1,111 billion--23 percent difference (based on different growth forecasts).

Total ton and ton-mile estimates for 1972 for inland and coastal water traffic are 891 million tons and 598 ton-miles by PMM&Co. compared to 987 million tons and 604 billion ton-miles by Faucett. For 1985, PMM&Co. base-case projections are 1,630 million tons and 1,098 billion ton-miles, compared to Faucett's 1,429 million tons and 991 billion ton-miles. Again, the variances among individual commodities are greater than the total, for reasons discussed previously.

Total pipeline tons are virtually identical for 1972. However, ton-miles in the Faucett study (476 billion) are estimated to be 30 percent greater. By 1985, Faucett projects tonnage of 1.2 million versus the PMM&Co. estimate of 1.5 million--a reasonably comparable estimate. Faucett ton-miles are projected at 843 billion compared to PMM&Co.'s 620 billion ton-mile projection.

For air cargo, Faucett's estimates indicate an average haul per ton nearly twice that of PMM&Co. (1105 miles versus 620 miles). Although significant differences exist among commodities, the Faucett study includes "government enterprises" which is assumed to include MATS (Military Air Transport Service) and other noncommercial flights (not included in the PMM&Co. study). By 1985, Faucett ton and ton-mile estimates are 5.6 million and 6.3 billion versus

PMM&Co.'s estimate of 4.6 million and 2.7 billion, respectively. PMM&Co. assumed the average length of haul to decrease, whereas, Faucett assumed no change.

In developing air cargo estimates, PMM&Co. used earlier 1970 Faucett projections. These estimates were then projected to 1972 using historical compound growth rates. The revised Faucett data for 1972 were not available in time for consideration in this study. Though percentage differences are large between this study and Faucett's newer figures, the volume of freight is small relative to other modes and does not have much impact on total freight energy consumption.

4.2 SCENARIO RESULTS

The following discussion describes the results of the scenario projections for each of the different sets of assumptions: base-case, industry change, and government influence. Each mode is discussed separately. Backup detail for computation of scenario inputs appears in the appendices, where necessary.

4.2.1 Truck

The truck scenario projections involved four general types of input changes from the base-case analysis. First, changes were made in traffic levels to account for both growth in the market and shifts in modal shares. Second, changes were made in truck-fleet capacity because of lighter weight vehicles and the introduction of twin trailers, and the third change accounted for shift from gasoline to diesel. Fourth, changes were made in the rate of fuel consumption, achieved through a series of improvements to the engine and the vehicle. The primary difference between the industry-change and government-influence scenarios was that government influence was projected to involve accelerated efforts to reduce vehicle weight, accelerated retrofit activity for certain engine and body improvements, and a greater shift of traffic from truck to rail.

4.2.2 Base-Case Scenarios

The base-case projections represent no change from 1972 conditions except for the volume of goods carried. The sole purpose of this scenario is to provide a basis for comparison of industry-change and government-influence scenarios in 1980 and 1985 with corresponding 1972 levels of technology and operating practices. The average length of haul is also assumed to be the same as in 1972. Tables 4-2 through

TABLE 4-2

TRUCK TRAFFIC MEASURES (BASE-CASE SCENARIO: 1980)

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	363212	280	101832
METALIC ORES	16460	138	2279
COAL & COKE	9093	86	785
PETROLEUM	220784	209	46316
NONMET MINERAL	47644	226	10811
FOOD PRODUCTS	205929	271	55859
TEXTILES	92970	237	22038
LUMBER & FURN	73185	212	15569
PULP & PAPER	80176	189	15194
CHEMICALS	182000	253	46058
RUBBER&PLASTIC	85110	228	19477
STONE & GLASS	174533	183	32032
PRIMARY METAL	106699	272	29043
FABRIC. METAL	115065	302	34760
NON-ELEC MACH.	81163	321	26109
ELECTRIC MACH.	80937	225	18212
TRANSPORT EQUI	211064	202	42786
INSTRUMENTS	118604	183	21770
SCRAP	17301	124	2161
TOTAL/AVERAGE	2281925	236	543098

4-5 show TRANSEN model outputs for 1980 and 1985 base-case projections, respectively. Because operational and technological factors remained the same as for 1972, Btu consumption by commodity increased by the same amount as traffic did for each commodity. Total Btus grew at a rate somewhat less than that for total tons due to the variation of growth and energy intensity among commodities. Total tonnage is projected to increase by 47.9 percent from 1972 to 1980 and by 17.2 percent from 1980 to 1985, as compared to a 20.3 percent increase in tonnage between 1962 and 1970. Given the distribution of growth among commodities, this implies an increase in Btu use of 46.1 percent from 1972 to 1980 and 16.8 percent from 1980 to 1985.

4.2.3 Industry-Change Scenarios

The industry-change projections include some shift of traffic from truck to rail based on the assumption that TOFC/COFC (piggyback) traffic will absorb some of the truck traffic. The basis for determining the amount of traffic to be shifted is an analysis of truck/rail competitive traffic performed by the American Trucking Association.[1] The study estimated the amount of truck/rail competitive traffic by commodity group for the 13 relevant commodity groups in this study; lumber, furniture, and bulk commodities were not included. For the development of these scenarios, we assumed a 20 percent shift of the competitive traffic from truck to rail for 1980 and a 40 percent shift for 1985. Appendix A describes the calculations of the shift in more detail.

Since the truck/rail competitive traffic is generally in the long-haul market, a shift of this traffic to rail implies a decrease in the truck average length of haul for all commodities. Thus, a new projected average length of haul was calculated based on the assumption that the shifted traffic will have an average haul 50 percent greater than the prevailing average haul. The base-case average haul is 238 miles. In the 1980 and 1985 projections, this value changes to 232 and 225 miles, respectively. Appendix A provides the details of this calculation.

Based on discussions with the American Trucking Association, no change in truck tare weight was projected, since additional weights of safety and environmental pollution control devices will likely be offset by weight savings in other areas.

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[1] See Appendix A.

TABLE 4-3

TRUCK BTU CONSUMPTION (BASE-CASE SCENARIO: 1980)

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	53496	185209	238706	657	2344.
METALIC ORES	562	3942	4505	273	1976
COAL & COKE	211	1471	1683	165	2143
PETROLEUM	6468	78446	84915	384	1833
NONMET MINERAL	3189	18575	21764	456	2013
FOOD PRODUCTS	31805	104008	135814	659	2431
TEXTILES	7413	50549	57962	623	2630
LUMBER & FURN	11871	29698	41570	568	2670
PULP & PAPER	8009	26508	34517	430	2271
CHEMICALS	9417	86984	96401	529	2093
RUBBER&PLASTIC	5611	44007	49619	583	2547
STONE & GLASS	16255	68810	85065	487	2055
PRIMARY METAL	5336	52769	58106	544	2000
FABRIC. METAL	9240	68862	78103	678	2246
NON-ELEC MACH.	9620	45254	54874	676	2101
ELECTRIC MACH.	5145	34734	39880	492	2189
TRANSPORT EQUI	22278	79165	101444	480	2370
INSTRUMENTS	16142	39486	55628	469	2555
SCRAP	2600	2876	5477	316	2534
TOTAL/AVERAGE	224677	1021362	1246038	546	2294

TABLE 4-4

TRUCK TRAFFIC MEASURES (BASE-CASE SCENARIO: 1985)

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	405342	280	113779
METALIC ORES	20905	139	2910
COAL & COKE	10116	87	882
PETROLEUM	263399	210	55305
NONMET MINERAL	59413	227	13497
FOOD PRODUCTS	231052	271	62775
TEXTILES	104681	237	24835
LUMBER & FURN	82697	213	17629
PULP & PAPER	98697	189	18726
CHEMICALS	226227	253	57341
RUBBER&PLASTIC	102982	229	23606
STONE & GLASS	200714	183	36892
PRIMARY METAL	129222	272	35241
FABRIC. METAL	134742	302	40747
NON-ELEC MACH.	99668	322	32095
ELECTRIC MACH.	98825	225	22253
TRANSPORT EQUI	240403	203	48797
INSTRUMENTS	145879	183	26813
SCRAP	19919	125	2488
TOTAL/AVERAGE	2674877	238	636620

TABLE 4-5

TRUCK BTU CONSUMPTION (BASE-CASE SCENARIO: 1985)

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	59678	206768	266447	657	2341
METALIC ORES	716	5039	5756	275	1977
COAL & COKE	237	1657	1895	187	2147
PETROLEUM	7707	93592	101300	384	1831
NONMET MINERAL	3989	23159	27148	456	2011
FOOD PRODUCTS	35742	116749	152491	660	2429
TEXTILES	8332	56919	65252	623	2627
LUMBER & FURN	13387	33619	47006	568	2666
PULP & PAPER	9854	32654	42508	430	2270
CHEMICALS	11737	108184	119921	530	2091
RUBBER&PLASTIC	6788	53284	60073	583	2544
STONE & GLASS	18674	79194	97869	487	2652
PRIMARY METAL	6470	63965	70435	545	1998
FABRIC. METAL	10818	80639	91458	678	2244
NON-ELEC MACH.	11806	55566	67372	676	2099
ELECTRIC MACH.	6274	42410	48684	492	2187
TRANSPORT EQUI	25380	90194	115575	480	2368
INSTRUMENTS	19862	48580	68443	469	2552
SCRAP	2999	3324	6324	317	2540
TOTAL/AVERAGE	260459	1195503	1455962	544	2287

The shift to diesel trucks is assumed to be virtually 100 percent complete by 1980 for vehicles above 50,000 lbs. GVW. For the industry-change scenarios, 70 percent of the base-case gasoline truck capacity for vehicles in the 32,000 to 50,000 lbs. GVW category is assumed to shift to diesel by 1980. The corresponding figure for 1985 is assumed to be 80 percent. For trucks between 19,000 and 32,000 lbs. GVW, the assumptions are 35 and 50 percent for 1980 and 1985, respectively. No change was assumed for vehicles under 19,000 lbs. GVW. (There is considerable difference of opinion within the trucking industry regarding the economics of diesel engines in small trucks, and whether the trend will be for more or less diesels in such vehicles).

The industry-change scenarios are based on modest change in state regulations, including those pertaining to operation of trailer "doubles." The 1972 base-case assumptions included all current "doubles" operation in the single-trailer category since no data were available on operations of these vehicle types. A 3 percent shift of capacity from box and irregular (but not tank) tractor-trailer combinations of vehicles larger than 70,000 lbs. GVW to "doubles" was assumed from the 1972 base-case by 1980 and another 3 percent by 1985.

Fuel efficiency improvements are based on proportionate savings identified for the largest trucks and then applied to other truck types according to the applicability of the improvement to the truck type in question. New trucks with improved fuel economy are assumed to be installed at a rate sufficient to cover 10 percent of the fleet-vehicle miles traveled per year. It is assumed that retrofit components will be installed on 25 percent of the remaining pre-1975 trucks per year. The retrofit item--thermostatically controlled cooling fans--are assumed to provide a 6 percent improvement on large trucks from the 1972 base-year fuel consumption rates. Trucks operating in 1975 which have derated engines or smaller engines, in addition to thermostatic fans, are assumed to be 8 percent more efficient than 1972 base-energy intensity levels.

The basic schedule of technology improvements adopted for this study (based on published literature, studies, interviews, and, in some cases, study team estimates) is as follows:

Technological Improvement	Reduction in Truck Energy Intensity
Thermostatically Clutch Modulated Fan (Retrofit)	6%

Fan with Better Tailoring of Engine Performance Requirements to Needs	8%
Fan and Tailored Engine with Air Foil and Radial Tires	15%
Fan, Tailored Engine, Air Foil and Radial Tires with Streamlined Trailer	20%
Fan, Tailored Engine and Radial Tires with Aerodynamic Design	30%[1]

Appendix A describes the assumptions made relative to the rate of implementation of these technological improvements for the 72,000 lb., GVW tractor-trailer combination vehicle and the corresponding fleet impact on reductions in energy intensity. These estimates formed the basis for scaling down percentage improvements of other vehicle types, where such vehicles could not fully benefit from the technological improvements applicable to large tractor trailers. For example, energy savings from streamlining for flatbed tractor-trailer combinations are not equal or comparable to opportunities with box-type, tractor-trailer combinations. Among certain truck types, no improvements were anticipated by 1980 and only minimal improvements by 1985. Table 4-6 summarizes the estimated fleet-percent, energy-intensity savings (mpg improvements) by truck types for 1980 and 1985.

Appendix A develops modal shifts and operational improvements which are assumed for 1980 and 1985 for the industry-change scenario. Inputting these factors into the TRANSEN model results in the projected tons and ton-miles included in Table 4-7 and the corresponding energy statistics included in Table 4-8.

Comparison of the industry-change results with the 1980 base-case shows a 14 percent decrease in total truck Btu consumption, made up of both modal shift and reductions in energy intensity. This reduction includes a 52 percent decrease in gasoline consumption and a 6 percent decrease in the use of diesel fuel. Total ton-miles decreased

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[1] Some industry and government research personnel feel that 30 percent is an optimal figure, and that when side winds are considered, the true realizable gain will be substantially less--perhaps only 25 percent.

TABLE 4-6

PROJECTED PERCENT CHANGE IN MILES PER GALLON OVER 1972 BASE CASE BY TRUCK TYPE

INDUSTRY CHANGE SCENARIOS

	Truck Type			Percent Change	
	GVW (000 lbs.)	Body	Fuel	1980	1985
1	10-19	Box	Gasoline	0	7
2	10-19	Box	Diesel	0	7
3	19-32	Box	Gasoline	5	12
4	19-32	Box	Diesel	5	12
5	32-50	Box	Gasoline	5	12
6	32-50	Box	Diesel	6	13
7	50-70	Box	Gasoline	10	17
8	50-70	Box	Diesel	10	17
9	>70	Box	Diesel	10	17
10	>70	Box Twin Tr.	Diesel	9	16
11	10-19	Irregular	Gasoline	0	2
12	10-19	Irregular	Diesel	0	2
13	19-32	Irregular	Gasoline	0	5
14	19-32	Irregular	Diesel	0	5
15	32-50	Irregular	Gasoline	6	9
16	32-50	Irregular	Diesel	7	10
17	50-70	Irregular	Gasoline	7	10
18	50-70	Irregular	Diesel	7	10
19	>70	Irregular	Diesel	7	10
20	>70	Irr. Twin Tr.	Diesel	6	9
21	32-50	Tank	Gasoline	5	8
22	32-50	Tank	Diesel	5	8
23	50-70	Tank	Gasoline	7	10
24	50-70	Tank	Diesel	7	10
25	>70	Tank	Diesel	7	10

TABLE 4-7

TRUCK TRAFFIC MEASURES
(INDUSTRY CHANGE SCENARIO: 1980)

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	363212	278	101115
METALIC ORES	16460	137	2263
COAL & COKE	9093	86	789
PETROLEUM	220784	208	45991
NONMET MINERAL	47644	225	10725
FOOD PRODUCTS	194809	261	50992
TEXTILES	89624	230	20657
LUMBER & FURN	73185	211	15468
PULP & PAPER	73762	180	13311
CHEMICALS	171080	243	41652
RUBBER&PLASTIC	77110	215	16619
STONE & GLASS	171391	180	30948
PRIMARY METAL	104061	267	27801
FABRIC. METAL	106780	310	33097
NON-ELEC MACH.	74183	304	22561
ELECTRIC MACH.	72681	210	15291
TRANSPORT EQUI	185736	187	34839
INSTRUMENTS	110065	175	19277
SCRAP	17301	122	2115
TOTAL	2178957		505517

TABLE 4-8

TRUCK BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1980)

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	26727	192746	219473	604	2170
METALIC ORES	306	3870	4177	253	1845
COAL & COKE	113	1469	1582	174	2004
PETROLEUM	1589	77135	78724	356	1711
NONMET MINERAL	1428	18716	20144	422	1878
FOOD PRODUCTS	18748	95394	114143	585	2238
TEXTILES	4734	45221	49955	557	2418
LUMBER & FURN	6775	31573	38349	524	2479
PULP & PAPER	3956	24023	27980	379	2102
CHEMICALS	3597	77004	80601	471	1935
RUBBER&PLASTIC	2226	36566	38793	503	2334
STONE & GLASS	7823	68554	76377	445	2467
PRIMARY METAL	2229	49789	52018	499	1871
FABRIC. METAL	3979	63840	67819	635	2049
NON-ELEC MACH.	3646	39887	43533	586	1929
ELECTRIC MACH.	2784	28167	30951	425	2024
TRANSPORT EQUI	8371	67644	76016	409	2181
INSTRUMENTS	8627	36962	45589	414	2364
SCRAP	1273	3682	4955	286	2342
TOTAL/AVERAGE	108940	962246	1071186	491	2119

from 543.1 billion to 505.5 billion from the 1980 base-case to the industry-change scenario (but nonetheless, an increase over the 363 billion ton-miles in the base 1972 base-case). Although this amounts to a 7 percent shift in traffic, its effect on vehicle-miles (and therefore, on fuel consumption) is diffused in an uneven manner by the traffic changes among commodities. The 14 percent decrease in average Btus per ton-mile value is 6.4 percent due to traffic shifts and 7.6 percent due to technology improvement factors. Tables 4-9 and 4-10 summarize similar modal output results for 1980 and 1985.

The industry-change assumptions show trucking with 544.2 billion ton-miles, a 15 percent decrease from the 1985 base-case. Total improvements by 1985 are projected to result in a 25 percent decrease in Btus consumed by trucks over what would have happened had nothing but total traffic volume increased (no modal shifts) since 1972. The total 25 percent reduction is composed of a 13 percent modal traffic shift and 12 percent due to operations and technology improvement factors.

4.2.4 Government-Influence Scenarios

Governments can promote improved truck energy conservation in several ways. The Federal Government may:

modify rate regulations to promote energy efficiency, such as permitting lower rates to attract backhaul traffic for vehicles which would otherwise move empty and providing incentives for fuller loading of trailers;

further modify regulatory requirements to reduce circuity, gateway restrictions, pooling, etc.;

increase weight and size limits on federal highways;

implement a differential tax structure which favors more fuel-efficient vehicles (such as larger tax differential between diesel and gasoline fuel);

promote research which hastens and reduces the user cost of new energy saving technology;

provide incentives to promote joint rail/truck intermodal operations where energy savings can be achieved;

TABLE 4-9

TRUCK TRAFFIC MEASURES
(INDUSTRY CHANGE SCENARIO: 1985)

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	405342	278	112759
METALIC ORES	20905	137	2874
COAL & COKE	10116	86	879
PETROLEUM	263399	208	54807
NONMET MINERAL	59413	225	13375
FOOD PRODUCTS	206099	252	52095
TEXTILES	97144	225	21942
LUMBER & FURN	82697	211	17455
PULP & PAPER	82905	170	14113
CHEMICALS	199080	234	46578
RUBBER&PLASTIC	84033	201	16934
STONE & GLASS	194291	179	34805
PRIMARY METAL	123019	263	32380
FABRIC. METAL	115339	295	34025
NON-ELEC MACH.	82525	285	23585
ELECTRIC MACH.	78665	194	15282
TRANSPORT EQUI	182706	169	30945
INSTRUMENTS	110868	152	16871
SCRAP	19919	122	2442
TOTAL/AVERAGE	2418460	225	544153

TABLE 4-10

TRUCK BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1985)

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	23676	210350	234026	577	2075
METALIC ORES	306	4832	5139	245	1787
COAL & COKE	109	1609	1719	170	1956
PETROLEUM	1444	89578	91022	345	1660
NONMET MINERAL	1526	22838	24365	410	1821
FOOD PRODUCTS	15891	93716	109607	531	2104
TEXTILES	4362	45546	49908	513	2274
LUMBER & FURN	6177	34777	40954	495	2346
PULP & PAPER	3187	24760	27947	337	1980
CHEMICALS	3201	83004	86206	433	1850
RUBBER&PLASTIC	1846	35461	37307	444	2203
STONE & GLASS	7218	75235	82453	424	2369
PRIMARY METAL	2263	56487	58750	477	1814
FABRIC. METAL	3200	62905	66106	573	1942
NON-ELEC MACH.	2923	40502	43426	526	1841
ELECTRIC MACH.	2351	26903	29254	371	1914
TRANSPORT EQUI	5830	58436	64267	351	2076
INSTRUMENTS	6451	31431	37882	341	2245
SCRAP	1186	4285	5472	274	2241
TOTAL/AVERAGE	93155	1002661	1095817	453	2013

discourage unnecessary competition which results in wasteful energy practices; and

review regulations pertaining to exempt commodities, contract carriers, and private fleet operation which are energy inefficient.

State governments may:

encourage the use of larger trucks and larger shipment sizes through the tax system;

increase size and weight limits and permit "doubles" on highways suitable to larger vehicles; and

increase differential between gasoline tax and diesel fuel tax to promote greater use of diesel trucks, especially in smaller and local delivery vehicles.

This list is not exhaustive but rather highlights the most important areas. Also, some of the changes suggested could have undesirable side effects which could offset or negate the value of energy conservation. This study cannot examine the ramifications of the above but does attempt to illustrate the potential impact of changes promoted by government; to do this, educated assumptions must also be made. The assumptions made in the government-influence scenario are:

expanded operation of highway doubles, shifting 30 percent of 1980 and 50 percent of 1985 traffic from 70,000 lb. GVW and greater vehicles to highway doubles; and

implementation of government-sponsored aerodynamic technology by 1981, in time to affect 1985 truck energy intensity levels.

Through a combination of government incentives to foster vehicle and technology improvements, the number of trucks which are 20 percent more energy efficient than their 1972 counterparts is assumed to increase by 10 percent over the number of vehicles in the industry-change scenario previously discussed. Further, the rate of implementation of trucks which are 20 percent more fuel efficient is assumed to be one out of every two vehicles installed in 1978 and 100 percent of all vehicles installed in 1979 and thereafter. As a last technology assumption, sufficient retrofits of radial tires, air foils, thermostatic fans, etc., are assumed to trucks sold in the 1975-1978 era to make them 15 percent more fuel efficient than their 1972 counterparts. With the assumed schedule of replacements and retrofits discussed in Appendix A, the total fleet fuel performance (miles per gallon) is calculated to increase over the 1972 case by 15 percent by 1980 and 23 percent by 1985.

On the operating side, these scenarios assume greater shifts of traffic from truck to rail. In 1980, 30 percent of the rail competitive traffic is assumed to be shifted from truck to rail, and in 1985, a 60 percent shift is assumed. As a result of these shifts, the overall average truck length of haul is changed from 238 to 229 miles in 1980 and to 218 miles in 1985 (see Appendix A).

Because of greater accommodation in noise and safety regulations to weight considerations, a 0.5 percent decrease in tare weight is also assumed for the government scenario.

As in the industry-change scenario, the improvements are scaled down for vehicles which cannot benefit from all of the improvements associated with the 70,000 lb. GVW, or larger, tractor-trailer combination used to estimate energy efficiency improvements. The estimated miles per gallon fuel improvements are listed in Table 4-11.

Table 4-12 depicts the traffic remaining after shifts from the 1980 base case shown above in Table IV-2. The aggregate decrease in traffic due to loss of some modal share of the market in 1980 is 10 percent. Btu consumption by commodity is listed in Table 4-13 for 1980. The difference from the 1980 base case is 20 percent. A comparison of Btu's per ton-mile with the 1980 base case shown in Table 4-3 shows that 11 percent of the improvement is attributed to factors other than traffic modal shift.

By 1985, government-influence scenario changes in modal share are projected to result in a 22 percent decrease in truck ton-miles from that which would have occurred if modal shares had remained constant (1985 base case). Total fuel is indicated to decline by 35 percent from this 1985 base case, which amounts to a 4 percent drop in total fuel consumption from the 1980 government case outlined in Table 4-13. Estimates for the 1985 government-influence scenario are given in Tables 4-14 and 4-15.

Btus per ton-mile in Table 4-13 are 17 percent lower than Btus per ton-mile shown in Table 4-5, indicating a 17 percent improvement in energy efficiency (miles per gallon) due to technology and operation changes. Thus, it is assumed that if total truck Btus are reduced by 35 percent, then 18 percent (35 percent minus 17 percent)

TABLE 4-11

PROJECTED PERCENT CHANGE IN MILES PER GALLON OVER 1972 BASE CASE BY TRUCK TYPE

GOVERNMENT INFLUENCE SCENARIOS

	Truck Type			Percent Change	
	GVW (000 lbs.)	Body	Fuel	1980	1985
1	10-19	Box	Gasoline	5	13
2	10-19	Box	Diesel	5	13
3	19-32	Box	Gasoline	10	18
4	19-32	Box	Diesel	10	18
5	32-50	Box	Gasoline	10	18
6	32-50	Box	Diesel	11	19
7	50-70	Box	Gasoline	15	23
8	50-70	Box	Diesel	15	23
9	>70	Box	Diesel	15	23
10	>70	Box Twin Tr.	Diesel	14	22
11	10-19	Irregular	Gasoline	0	4
12	10-19	Irregular	Diesel	0	4
13	19-32	Irregular	Gasoline	2	7
14	19-32	Irregular	Diesel	2	7
15	32-50	Irregular	Gasoline	9	10
16	32-50	Irregular	Diesel	10	11
17	50-70	Irregular	Gasoline	10	11
18	50-70	Irregular	Diesel	10	11
19	>70	Irregular	Diesel	10	11
20	>70	Irr. Twin Tr.	Diesel	9	10
21	32-50	Tank	Gasoline	7	9
22	32-50	Tank	Diesel	7	9
23	50-70	Tank	Gasoline	10	11
24	50-70	Tank	Diesel	10	11
25	>70	Tank	Diesel	10	11

TABLE 4-12

TRUCK TRAFFIC MEASURES
(GOVERNMENT INFLUENCE SCENARIO: 1980)

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	363212	278	101052
METALIC ORES	16460	137	2261
COAL & COKE	9093	87	792
PETROLEUM	220784	208	45971
NONMET MINERAL	47644	225	10720
FOOD PRODUCTS	189249	257	48701
TEXTILES	87950	228	20094
LUMBER & FURN	73185	211	15442
PULP & PAPER	70555	175	12381
CHEMICALS	165620	239	39575
RUBBER&PLASTIC	73110	208	15259
STONE & GLASS	169821	179	30524
PRIMARY METAL	102781	265	27270
FABRIC. METAL	102638	302	31093
NON-ELEC MACH.	70693	296	20923
ELECTRIC MACH.	68554	203	13936
TRANSPORT EQUI	173072	179	30987
INSTRUMENTS	105795	171	18087
SCRAP	17301	123	2127
TOTAL/AVERAGE	2127514	229	487200

TABLE 4-13

TRUCK BTU CONSUMPTION
(GOVERNMENT INFLUENCE SCENARIO: 1980)

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	32384	179009	211393	582	2091
METALIC ORES	346	3705	4052	246	1791
COAL & COKE	112	1427	1539	169	1944
PETROLEUM	2380	74131	76512	346	1664
NONMET MINERAL	1796	17840	19636	412	1831
FOOD PRODUCTS	19600	84221	103822	548	2131
TEXTILES	4862	41250	46112	524	2294
LUMBER & FURN	7746	29091	36837	503	2385
PULP & PAPER	4117	20878	24996	354	2018
CHEMICALS	4381	69261	73643	444	1860
RUBBER&PLASTIC	2505	31364	33870	463	2219
STONE & GLASS	9366	63146	72512	427	2375
PRIMARY METAL	2658	46611	49269	479	1806
FABRIC. METAL	4545	56320	60865	593	1957
NON-ELEC MACH.	4395	34516	38912	550	1859
ELECTRIC MACH.	2848	24154	27002	393	1937
TRANSPORT EQUI	9265	55881	65147	376	2102
INSTRUMENTS	9070	32046	41117	388	2273
SCRAP	1581	3311	4893	282	2299
TOTAL/AVERAGE	123967	868169	992136	466	2036

TABLE 4-14

TRUCK TRAFFIC MEASURES
(GOVERNMENT INFLUENCE SCENARIO: 1985)

COMMODITY	TONS 10**3	AVG. HAUL	TON-MILES 10**6
AGRICULTURE	405342	278	112794
METALIC ORES	20905	137	2873
COAL & COKE	10116	87	883
PETROLEUM	263399	208	54895
NONMET MINERAL	59413	225	13392
FOOD PRODUCTS	193622	243	47126
TEXTILES	93735	220	20644
LUMBER & FURN	82697	211	17456
PULP & PAPER	75010	158	11908
CHEMICALS	185506	223	41525
RUBBER&PLASTIC	73942	182	13509
STONE & GLASS	191080	177	33924
PRIMARY METAL	119918	259	31151
FABRIC. METAL	105683	277	29357
NON-ELEC MACH.	73954	263	19516
ELECTRIC MACH.	68585	174	11947
TRANSPORT EQUI	153858	140	21650
INSTRUMENTS	93363	130	12215
SCRAP	19919	123	2458
TOTAL/AVERAGE	2290042	218	499228

TABLE 4-15

TRUCK BTU CONSUMPTION
(GOVERNMENT INFLUENCE SCENARIO: 1985)

COMMODITY	TOTAL GASOLINE BTUS 10**9	TOTAL DIESEL BTUS 10**9	TOTAL BTUS 10**9	BTUS PER TON 10**3	BTUS PER TON-MILE
AGRICULTURE	27510	192474	219984	542	1950
METALIC ORES	344	4722	5066	242	1763
COAL & COKE	108	1592	1701	168	1926
PETROLEUM	1747	88082	89829	341	1636
NONMET MINERAL	1752	22360	24112	405	1800
FOOD PRODUCTS	15366	77690	93057	480	1974
TEXTILES	4208	39671	43880	468	2125
LUMBER & FURN	6873	31828	38701	468	2217
PULP & PAPER	3036	19629	22665	302	1903
CHEMICALS	3308	70284	73592	396	1772
RUBBER&PLASTIC	1650	26140	27791	375	2057
STONE & GLASS	8031	67105	75136	393	2214
PRIMARY METAL	2389	49651	52040	434	1670
FABRIC. METAL	3203	50188	53392	505	1818
NON-ELEC MACH.	3004	30815	33819	457	1732
ELECTRIC MACH.	1999	19525	21524	313	1801
TRANSPORT EQUI	4946	38157	43104	280	1991
INSTRUMENTS	4956	20908	25864	277	2117
SCRAP	1428	3970	5398	271	2196
TOTAL/AVERAGE	95866	854797	950664	415	1904

must be due to modal shifts of traffic away from truck. Without this modal shift, truck fuel would not have decreased from 1980 to 1985, since traffic increases would have outpaced gains for operating and technological improvements.

4.2.5 Rail

For the rail scenarios, the projections were developed from estimated changes in (1) levels of traffic and (2) degree of implementation of the operating and energy consumption measures described in Section 3.

Base-Case Scenarios

Tables 4-16 through 4-20 and 4-21 through 4-25 show the results of the rail base-case projections for 1980 and 1985, respectively. These tables are based on projections of rail traffic without any change in rail energy intensity or modal shifts and serve as a base from which to compare the impacts of implementing operating and technological changes to conserve energy.

For the base-case 1980 scenario, rail traffic shows an increase of 47 percent over 1972 with Btus increasing by 45.9 percent for loaded moves and 47 percent for empty moves, or 46.3 percent overall. For the base-case 1985 scenario, ton-miles were projected to increase by 71.9 percent over 1972 with energy consumed increasing by 70.1 percent on loaded moves, 71.4 percent on empty moves, and 70.6 percent overall.

Industry-Change Scenarios

The industry-change scenarios reflect those efforts which rail carriers could make to conserve energy in transporting the traffic projected for the base-case scenario. Table 4-26 summarizes the operating changes from Section 3 which the carriers could implement and estimates a reasonable impact on rail operations and rail energy consumption of implementing each change. These estimates indicate that the largest potential impact on energy consumption would result from reducing empty backhauls, speed, and stops and delays, followed in importance by improvements in train composition.

Table 4-27 shows the impact of implementing the technological changes discussed in Section 3. The projected systemwide impact of implementing these changes is tempered by the long life of rail equipment and, consequently, the small proportion of equipment which is

TABLE 4-16

RAIL NET TON-MILES BY CAR TYPE
(BASE CASE SCENARIO: 1980)

10**6

COMMODITY	CAR TYPE BOXCAR	 COVER HOPPER	 FLAT CAR*	 GON-DOLA	 OPEN HOPPER	 TANK CAR	 MISC@	 TOTAL
AGRICULTURE	31136	60020	2864	1396	715	0	19743	115875
METALIC ORES	1584	13297	0	4312	20773	0	4106	44073
COAL & COKE	0	0	0	10411	184369	0	0	194780
PETROLEUM	1619#	0	374	0	0	21088	440	23521
NONMET MINERAL	7917	19115	0	9813	24267	5226#	859	67196
FOOD PRODUCTS	31554	24085	5505	0	0	11751	45295	118790
TEXTILES	1905	0	634	0	0	0	0	2539
LUMBER & FURN	61665	11019	19591	6389	381#	0	8984	108029
PULP & PAPER	73605	0	1569	0	0	509	3121	78805
CHEMICALS	24586	50722	2501	0	0	51579	5369	140758
RUBBER&PLASTIC	5464	0	621	0	0	0	292	6377
STONE & GLASS	18755	24082	3205	979	3209	0	2415	52645
PRIMARY METAL	20561	1139#	10937	25490	1329#	0	3002	62459
FABRIC. METAL	3132	0	1725	5074	0	0	571	10502
NON-ELEC MACH.	1601	0	5187	412	0	0	0	7200
ELECTRIC MACH.	5465	0	2013	262	0	0	312	8052
TRANSPORT EQUI	24485	654#	24997	812	0	251#	0	51200
INSTRUMENTS	1404	0	267	0	0	0	0	1671
SCRAP	6157	351	0	7749	1340	611	217	16425
TOTAL	322595.	211085.	81989.	73101.	236383.	91016.	94727.	1110895.

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-17

RAIL BTUS FOR LOADED CAR MOVEMENTS BY COMMODITY BY CAR TYPE (BASE CASE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	12830	17349	2554	498	334	0	17363	50928
METALIC ORES	516	3680	0	1034	4599	0	1591	11421
COAL & COKE	0	0	0	2497	47622	0	0	50120
PETROLEUM	876#	0	334	0	0	7133	225	8568
NONMET MINERAL	3019	5290	0	3380	5373	1253#	333	18647
FOOD PRODUCTS	16301	9412	5078	0	0	3845	22842	57478
TEXTILES	1816	0	566	0	0	0	0	2381
LUMBER & FURN	36028	4066	14458	2672	169#	0	4199	61591
PULP & PAPER	35761	0	1351	0	0	169	1574	38855
CHEMICALS	11794	16744	2230	0	0	16305	2510	49583
RUBBER&PLASTIC	5881	0	557	0	0	0	219	6657
STONE & GLASS	8074	6665	2365	355	888	0	1129	19476
PRIMARY METAL	7334	245#	3968	8936	302#	0	1182	21967
FABRIC. METAL	3159	0	1539	2309	0	0	372	7379
NON-ELEC MACH.	1329	0	4657	215	0	0	0	6202
ELECTRIC MACH.	7058	0	1857	110	0	0	278	9303
TRANSPORT EQUI	19576	386#	26011	400	0	176#	0	46549
INSTRUMENTS	1761	0	253	0	0	0	0	2014
SCRAP	3181	130	0	2859	313	189	107	6779
TOTAL	176292	63967	67778	25265	59601	29071	53923	475898

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-18

RAIL BTUS FOR EMPTY CAR MOVEMENTS BY COMMODITY BY CAR TYPE (BASE CASE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	5489	9015	2112	268	120	0	12890	29894
METALIC ORES	277	2300	0	618	2097	0	708	6000
COAL & COKE	0	0	0	1390	19688	0	0	21079
PETROLEUM	498#	0	277	0	0	5293	189	6257
NONMET MINERAL	1646	3221	0	1697	2589	871#	236	10259
FOOD PRODUCTS	7628	5423	5362	0	0	2837	14122	35372
TEXTILES	922	0	564	0	0	0	0	1486
LUMBER & FURN	16734	2553	9668	1625	75#	0	2908	33564
PULP & PAPER	16841	0	1215	0	0	130	1346	19533
CHEMICALS	4806	9824*	1931	0	0	11098	1842	29501
RUBBER&PLASTIC	2957	0	540	0	0	0	181	3677
STONE & GLASS	4520	4292	1680	191	366	0	832	11881
PRIMARY METAL	3480	251#	4275	5247	154#	0	925	14331
FABRIC. METAL	1509	0	1556	1507	0	0	319	4891
NON-ELEC MACH.	796	0	4515	155	0	0	0	5467
ELECTRIC MACH.	3713	0	1895	56	0	0	241	5906
TRANSPORT EQUI	14412	304#	25028	263	0	177#	0	40184
INSTRUMENTS	793	0	283	0	0	0	0	1076
SCRAP	1518	80	0	1652	192	125	74	3640
TOTAL	88539	37263	60901	14668	25281	20530	36813	283996

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-19

TOTAL RAIL BTU CONSUMPTION BY COMMODITY BY CAR TYPE (BASE CASE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	18319	26364	4666	766	454	0	30253	80821
METALIC ORES	793	5981	0	1652	6696	0	2299	17421
COAL & COKE	0	0	0	3887	67311	0	0	71198
PETROLEUM	1374#	0	611	0	0	12426	414	14824
NONMET MINERAL	4664	8511	0	5076	7962	2124#	568	28906
FOOD PRODUCTS	23929	14836	10440	0	0	6682	36964	92850
TEXTILES	2738	0	1130	0	0	0	0	3867
LUMBER & FURN	52762	6619	24127	4297	244#	0	7107	95155
PULP & PAPER	52602	0	2566	0	0	299	2920	58388
CHEMICALS	16600	26568	4161	0	0	27403	4352	79084
RUBBER&PLASTIC	8838	0	1097	0	0	0	400	10334
STONE & GLASS	12594	10957	4045	546	1254	0	1961	31357
PRIMARY METAL	10814	496#	8243	14182	457#	0	2107	36298
FABRIC. METAL	4668	0	3094	3817	0	0	692	12270
NON-ELEC MACH.	2126	0	9172	370	0	0	0	11668
ELECTRIC MACH.	10772	0	3752	166	0	0	519	15209
TRANSPORT EQUI	33988	690#	51039	663	0	353#	0	86733
INSTRUMENTS	2554	0	537	0	0	0	0	3090
SCRAP	4698	209	0	4511	505	314	181	10419
TOTAL	264832	101230	128680	39934	84882	49601	90736	759893

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-20

RAIL ENERGY INTENSITY MEASURES
(BASE CASE SCENARIO: 1980)

1980

COMMODITY	RAIL BTU CONSUMPTION, PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET TON 10**3
AGRICULTURE	697	450
METALIC ORES	395	74
COAL & COKE	366	134
PETROLEUM	630	397
NONMET MINERAL	430	101
FOOD PRODUCTS	782	699
TEXTILES	1523	1666
LUMBER & FURN	881	724
PULP & PAPER	741	735
CHEMICALS	562	482
RUBBER&PLASTIC	1621	1623
STONE & GLASS	590	315
PRIMARY METAL	581	356
FABRIC. METAL	1168	877
NON-ELEC MACH.	1621	1669
ELECTRIC MACH.	1889	2137
TRANSPORT EQUI	1694	1638
INSTRUMENTS	1849	2980
SCRAP	634	176
AVERAGE	684 0	357

TABLE 4-21

RAIL NET TON-MILES BY CAR TYPE (BASE CASE SCENARIO: 1985)

10**0

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	34748	60982	3196	1558	798	0	22033	129316
METALIC ORES	2012	16888	0	5477	26381	0	5659	56417
COAL & COKE	0	0	0	11588	205203	0	0	216791
PETROLEUM	1932#	0	447	0	0	25158	525	28061
NONMET MINERAL	9872	23836	0	12237	30261	6516#	1071	83793
FOOD PRODUCTS	35404	27697	6176	0	0	13185	50820	133282
TEXTILES	2145	0	714	0	0	0	0	2859
LUMBER & FURN	69681	12452	22138	7220	431#	0	10152	122072
PULP & PAPER	90608	0	1931	0	0	627	3842	97009
CHEMICALS	30561	70505	3109	0	0	64113	6674	174961
RUBBER&PLASTIC	6612	0	751	0	0	0	354	7718
STONE & GLASS	21569	27695	3685	1126	3691	0	2778	60543
PRIMARY METAL	24920	1380#	13255	30894	1611#	0	3639	75700
FABRIC. METAL	3667	0	2020	5942	0	0	669	12298
NON-ELEC MACH.	1966	0	6369	506	0	0	0	8841
ELECTRIC MACH.	6672	0	2457	320	0	0	381	9831
TRANSPORT EQUI	27889	745#	28471	925	0	286#	0	58317
INSTRUMENTS	1726	0	329	0	0	0	0	2055
SCRAP	7087	404	0	8920	1543	703	250	18908
TOTAL	379068	248584	95050	86712	269918	110588	108847	1298767

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-22

RAIL BTUS FOR LOADED CAR MOVEMENTS BY CAR TYPE
(BASE CASE SCENARIO: 1985)

10**9

COMMODITY	CAR TYPE BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	14318	19361	2850	556	373	0	19377	56835
METALIC ORES	656	4674	0	1314	5841	0.	[illegible]	[illegible]
COAL & COKE	0	0	0	2779	53004	0	0	55783
PETROLEUM	1045#	0	398	0	0	8510	268	10221
NONMET MINERAL	3764	6597	0	4214	6700	1563#	415	23253
FOOD PRODUCTS	18290	10561	5698	0	0	4314	25629	64491
TEXTILES	2045	0	637	0	0	0	0	2682
LUMBER & FURN	40711	4595	16338	3019	191#	0	4745	69598
PULP & PAPER	44022	0	1663	0	0	208	1938	47831
CHEMICALS	14660	20813	2772	0	0	20267	3119	61631
RUBBER&PLASTIC	7116	0	674	0	0	0	265	8055
STONE & GLASS	9285	7665	2720	408	1021	0	1298	22398
PRIMARY METAL	8889	297#	4810	10830	367#	0	1432	26625
FABRIC. METAL	3699	0	1802	2704	0	0	436	8640
NON-ELEC MACH.	1632	0	5719	264	0	0	0	7616
ELECTRIC MACH.	8617	0	2267	134	0	0	340#	11357
TRANSPORT EQUI	22297	440#	29627	455	0	201	0	53020
INSTRUMENTS	2165	0	311	0	0	0	0	2477
SCRAP	3661	149	0	3291	360	218	123	7803
TOTAL	206871	75151	78285	29970	67856	35280	61168	554581

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-23

RAIL BTUS FOR EMPTY CAR MOVEMENTS BY CAR TYPE
(BASE CASE SCENARIO: 1985)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	6126	10060	2357	299	133	0	14385	33361
METALIC ORES	351	2922	0	785	2663	0	900	7620
COAL & COKE	0	0	0	1547	21913	0	0	23461
PETROLEUM	594#	0	331	0	0	6314	225	7464
NONMET MINERAL	2052	4017	0	2116	3228	1086#	294	12793
FOOD PRODUCTS	8559	6085	6016	0	0	3183	15845	39687
TEXTILES	1038	0	636	0	0	0	0	1674
LUMBER & FURN	18910	2885	10925	1836	85#	0	3286	37927
PULP & PAPER	20732	0	1496	0	0	160	1656	24045
CHEMICALS	5974	12211	2400	0	0	13795	2290	36669
RUBBER&PLASTIC	3578	0	653	0	0	0	219	4449
STONE & GLASS	5198	4936	1950	220	421	0	957	13681
PRIMARY METAL	4217	304#	5181	6359	187#	0	1121	17369
FABRIC. METAL	1767	0	1822	1765	0	0	374	5728
NON-ELEC MACH.	978	0	5544	191	0	0	0	6713
ELECTRIC MACH.	4533	0	2314	68	0	0	294#	7210
TRANSPORT EQUI	16416	346#	28507	300	0	201	0	45770
INSTRUMENTS	975	0	348	0	0	0	0	1323
SCRAP	1747	92	0	1901	220	144	86	4190
TOTAL	103744	43857	70479	17386	28852	24883	41932	331133

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-24

TOTAL RAIL BTU CONSUMPTION BY CAR TYPE
(BASE CASE SCENARIO: 1985)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	20444	29422	5207	855	506	0	33763	90196
METALIC ORES	1007	7595	0	2099	8503	0	2683	21887
COAL & COKE	0	0	0	4327	74917	0	0	79244
PETROLEUM	1640#	0	729	0	0	14824	493	17686
NONMET MINERAL	5816	10613	0	6330	9928	2649#	709	36045
FOOD PRODUCTS	26848	16645	11713	0	0	7497	41473	104178
TEXTILES	3083	0	1272	0	0	0	0	4355
LUMBER & FURN	59621	7479	27263	4855	276#	0	8031	107525
PULP & PAPER	64754	0	3159	0	0	368	3594	71875
CHEMICALS	20634	33024	5172	0	0	34062	5409	98301
RUBBER&PLASTIC	10694	0	1327	0	0	0	484	12505
STONE & GLASS	14483	12601	4670	628	1443	0	2255	36079
PRIMARY METAL	13107	601#	9990	17189	553#	0	2554	43994
FABRIC. METAL	5466	0	3623	4469	0	0	810	14368
NON-ELEC MACH.	2610	0	11263	455	0	0	0	14328
ELECTRIC MACH.	13150	0	4581	202	0	0	634	18567
TRANSPORT EQUI	38713	786#	58134	755	0	402#	0	98789
INSTRUMENTS	3140	0	660	0	0	0	0	3799
SCRAP	5408	241	0	5192	581	362	209	11993
TOTAL	310616	119008	148764	47356	96708	60163	103101	885714

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-25

RAIL ENERGY INTENSITY MEASURES
(BASE CASE SCENARIO: 1985)

COMMODITY	RAIL BTU CONSUMPTION PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET TON 10**3
AGRICULTURE	697.	450.
METALIC ORES	395.	73.
COAL & COKE	366.	134.
PETROLEUM	630.	397.
NONMET MINERAL	430.	101.
FOOD PRODUCTS	782.	699.
TEXTILES	1523.	1666.
LUMBER & FURN	881.	724.
PULP & PAPER	741.	735.
CHEMICALS	562.	482.
RUBBER&PLASTIC	1621.	1623.
STONE & GLASS	596.	315.
PRIMARY METAL	581.	356.
FABRIC. METAL	1168.	877.
NON-ELEC MACH.	1621.	1869.
ELECTRIC MACH.	1889.	2137.
TRANSPORT EQUI	1694.	1638.
INSTRUMENTS	1849.	2980.
SCRAP	634.	176.
AVERAGE	682.4	354.

TABLE 4-26
IMPACT ON RAIL MODE OF OPERATING CHANGES TO CONSERVE ENERGY

INDUSTRY CHANGE SCENARIOS

OPERATING CHANGE	MODEL INPUT VARIABLES AFFECTED	HOW INDUSTRY COULD AFFECT CHANGE[1]	ASSUMED IMPACT ON BASE CASE INPUT VARIABLES[4]	
			1976-1980	1976-1985
Reduce Circuity	Circuity	Modify car service rules, routings and tariffs	5%	10%
Reduce Empty Backhauls	Empty/Loaded Car Mile Ratio	- Modify car service rules - Improve equipment control and distribution practices - Use less specialized equipment - Join together to pool equipment - Provide tariff incentives - Improve car maintenance; upgrade commodity loading classifications	5%	10%
Increase Load Per Car	Load Per Car	- Provide tariff incentives - Furnish appropriate size cars	1%	2%
Reduce Speed	Energy/Ton-Mile, Loaded and Empty	- Reduce speed limits - Decrease horsepower per ton power ratio	4%[2]	5.6%[3]
Reduce Stops And Delays	Energy/Ton-Mile, Loaded and Empty	- Preblock trains to bypass intermediate yards - Reduce train delays - Improve maintenance of way - Improve equipment maintenance - Invest in improved signalling - Operate longer crew districts - Modify interchange and 500-mile inspection requirements	2%	4%
Improve Train Composition	Energy/Ton-Mile, Loaded and Empty	- Improve homogeneity of train configuration - Improve load factor on piggyback cars	1%	2%
Improve Yard Operations	Energy/Ton-Mile, Loaded and Empty	- Bypass yards, where possible - Improve overall yard operational efficiency - Allow more flexibility in industry switching between road and yard crews - Reduce special handling - Modernize yards	0.5%	1%
Reduce Locomotive Idling	Energy/Ton-Mile, Loaded and Empty	- Shut engine down when not needed - Use block heaters where needed - Increase locomotive utilization	0.5%	1%
Eliminate Cabooses	Energy/Ton-Mile, Loaded and Empty	Eliminate Cabooses	0%	0.5%

[1] Summary of issues presented in Chapter 3.

[2] Assuming a 2.5 mile per hour reduction in speed.

[3] Assuming a 5.0 mile per hour reduction in speed.

[4] Input variable is named in second column. Application of impact percent is an algebraic (product), not an arithmetic reduction. For instance, if base case circuity is 17%, a 5% change would reduce the 17% to 17 - 17x.05 = 16.15%.

TABLE 4-27
IMPACT ON RAIL MODE OF TECHNOLOGY CHANGES TO CONSERVE ENERGY

INDUSTRY CHANGE SCENARIO

TECHNOLOGICAL CHANGE	ESTIMATED EFFECT ON ENERGY CONSUMPTION IF ADOPTED UNIVERSALLY[9]	ESTIMATED EQUIPMENT TURNOVER RATE		ESTIMATED IMPACT ON ENERGY CONSUMPTION UNDER INDUSTRY CHANGE SCENARIOS (Percent Savings)	
		Over 5 year period	Over 10 year period	1976-1980	1976-1985
Locomotive Streamlining	Hopper Car Moves:				
	Loaded - 3.3% reduction			.18	.71
	Empty - 4.5% reduction			.24	.97
	Flat Car Moves:	21.4%[4]	42.8%[4]		
	Loaded - 7.4% reduction			.40	1.59
	Empty - 8.4% reduction			.45	1.80
	Boxcar and All Other Moves:				
	Loaded - 3.5% reduction			.19	.75
	Empty - 5.6% reduction			.30	1.20
Other Locomotive Changes	17.2% reduction	21.4%[4]	42.8%[4]	1.92	3.68
Car Streamlining	Loaded Moves: 3.3% reduction[2]			.13[6]	.51[6]
	Empty Moves: 10.3% reduction	19.4%[5]	38.8%[5]	.40[6]	1.60[6]
Reduced Car-Tare Weight	Loaded Moves: 4.6% reduction[4]			.22	.89
	Empty Moves: 9.6% reduction	19.4%[5]	38.8%[5]	.47	1.86

ASSUMPTIONS

[1] Estimates of savings are assigned separately to open and covered hopper cars, flat cars (of which 53 percent of car miles are assumed in TOFC/COFC service), and boxcars. Savings for all car types not mentioned are assumed the same as for boxcars.

[2] It is assumed that streamlining on the specially designed hopper car can be generalized to other car types.

[3] A 5 percent tare weight reduction is assumed.

[4] The rate of replacement of locomotives in service over the next ten years is assumed to be the same as that which occurred in 1974 for Class I railroads. According to the Association of American Railroads (Yearbook of Railroad Facts, 1975 Edition), the ratio of new locomotives to locomotives in service in 1974 was 4.27% representing a 23.9-year replacement cycle.

[5] The rate of replacement of cars in service over the next 10 years is assumed to be the same as that which occurred in 1974. According to the Association of American Railroads (ibid), the ratio of new freight cars to the total in 1974 was 3.88%, representing a 25.8-year replacement cycle.

[6] 80 percent of all cars are assumed to be amenable to streamlining.

[7] The estimated equipment turnover rate for the five year period is assumed to apply and the change is assumed to be adopted on one-quarter of all new equipment.

[8] The estimated equipment turnover rate for the ten year period is assumed to apply and the change is assumed to be adopted on one-half of all new equipment.

[9] Percent reduction in BTUs per ton (net or gross). Savings are compounded.

projected to be replaced yearly (which can therefore be subject to technological changes). The impacts are also based on the assumption that not all new equipment purchases by rail carriers will be made to conserve energy. The impact of the long rail-equipment cycle is to reduce the potential impact of technological changes on energy consumption relative to operating changes.

The inputs to the rail scenario runs do not include shift of traffic from truck to rail for increased piggyback movements. The amount of the shift is calculated separately and is based on estimates of truck/rail competitive traffic as outlined in Section 3. No change in commodity distribution by car type was assumed in this rail portion of the analysis.

Those changes which would directly impact the values of energy intensity input into the TRANSEN calculations were combined as follows:

> those changes which affect rail energy consumption while trains are in transit (i.e., speed and train configuration) were considered multiplicative; and
>
> those changes which affect rail energy consumption when trains are not in transit (i.e., yard operations and locomotive idling) were considered additive.

Tables 4-28 through 4-32 and 4-33 through 4-37 show the results of the projections for the industry change scenarios for 1980 and 1985, respectively. For 1980, ton-miles are projected to decrease by 0.9 percent from the 1980 base-case due to the combined effects of operational and technological changes, including a 5 percent decrease in circuity. As a result, loaded Btus are projected to decrease by 9.9 percent on loaded moves, by 15.7 percent for empty moves, and 12.0 percent in Btus overall compared with the 1980 base case. The resulting impact on energy intensity is a projected 11.3 percent decrease in the Btu per ton-mile ratio of 684 to 607 and a 12.0 percent decrease in the Btu per ton ratio.

For the 1985 industry change projections, ton-miles are projected to decrease by 1.4 percent over the 1985 base-case, which is a further result of operational and technological change, including a 10 percent decrease in circuity. With the reduced traffic, the calculations show a projected decrease of 19.5 percent in Btus over the 1985 base-case for loaded moves, a 26.1 percent decrease for empty moves, and a 21.9 percent overall. As a result, the Btu per ton-mile ratio is

TABLE 4-28

RAIL NET TON-MILES BY CAR TYPE (INDUSTRY CHANGE SCENARIO: 1980)

10**6

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	30868	59512	2838	1384	709	0	19567	114877
METALIC ORES	1571	13185	0	4275	20589	0	4069	43689
COAL & COKE	0	0	0	10321	182737	0	0	193059
PETROLEUM	1605#	0	371	0	0	20909	436	23321
NONMET MINERAL	7848	18953	0	9728	24052	5181#	851	66614
FOOD PRODUCTS	31285	24478	5456	0	0	11653	44894	117765
TEXTILES	1881	0	640	0	0	0	0	2521
LUMBER & FURN	61133	10926	19414	6334	378#	0	8904	107089
PULP & PAPER	72976	0	1555	0	0	505	3094	78130
CHEMICALS	24376	56245	2479	0	0	51145	5322	139567
RUBBER&PLASTIC	5399	0	644	0	0	0	290	6334
STONE & GLASS	18594	23879	3176	970	3181#	0	2394	52194
PRIMARY METAL	20385	1129#	10838	25271	1317	0	2976	61917
FABRIC. METAL	3077	0	1732	5033	0	0	566	10409
NON-ELEC MACH.	1571	0	5169	409	0	0	0	7149
ELECTRIC MACH.	5401	0	2020	261	0	0	310	7991
TRANSPORT EQUI	24286	649#	24783	806	0	249#	0	50773
INSTRUMENTS	1363	0	298	0	0	0	0	1661
SCRAP	6104	348	0	7682	1328	606	215	16283
TOTAL	319722	209304	81414	72476	234291	90249	93887	1101340

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-29

RAIL BTUS FOR LOADED CAR MOVEMENTS BY CAR TYPE
(INDUSTRY CHANGE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	11580	15665	2293	450	301	0	15644	45932
METALIC ORES	466	3325	0	931	4153	0	1432	10306
COAL & COKE	0	0	0	2247	42930	0	0	45178
PETROLEUM	790#	0	300	0	0	6429	202	7721
NONMET MINERAL	2722	4779	0	3051	4852	1128#	299	16832
FOOD PRODUCTS	14699	8490	4563	0	0	3469	20597	51819
TEXTILES	1629	0	517	0	0	0	0	2146
LUMBER & FURN	32484	3669	12991	2407	152#	0	3778	55481
PULP & PAPER	32224	0	1212	0	0	152	1419	35008
CHEMICALS	10644	15082	2003	0	0	14721	2258	44707
RUBBER&PLASTIC	5280	0	524	0	0	0	198	6001
STONE & GLASS	7273	6021	2125	320	802	0	1016	17557
PRIMARY METAL	6619	221#	3559	8051	272#	0	1065	19788
FABRIC. METAL	2820	0	1399	2080	0	0	336	6635
NON-ELEC MACH.	1187	0	4203	194	0	0	0	5583
ELECTRIC MACH.	6337	0	1690	99	0	0	251	8377
TRANSPORT EQUI	17654	348#	23350	361	0	159#	0	41872
INSTRUMENTS	1554	0	256	0	0	0	0	1810
SCRAP	2868	117	0	2580	283	171	96	6114
TOTAL	158829	57716	60986	22770	53745	26229	48591	428865

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-30

RAIL BTUS FOR EMPTY CAR MOVEMENTS BY CAR TYPE
(INDUSTRY CHANGE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	4639	7588	1780	226	100	0	10855	25188
METALIC ORES	234	1936	0	521	1753	0	676	5120
COAL & COKE	0	0	0	1171	16463	0	0	17634
PETROLEUM	421#	0	233	0	0	4461	159	5275
NONMET MINERAL	1391	2711	0	1429	2165	734#	198	8629
FOOD PRODUCTS	6448	4565	4518	0	0	2392	11898	29821
TEXTILES	776	0	484	0	0	0	0	1261
LUMBER & FURN	14144	2149	8147	1369	63#	0	2450	28321
PULP & PAPER	14235	0	1024	0	0	110	1134	16503
CHEMICALS	4062	8270	1627	0	0	9356	1552	24867
RUBBER&PLASTIC	2491	0	476	0	0	0	152	3120
STONE & GLASS	3820	3613	1429	161	306	0	701	10030
PRIMARY METAL	2941	211#	3602	4420	129#	0	779	12082
FABRIC. METAL	1264	0	1328	1270	0	0	269	4131
NON-ELEC MACH.	666	0	3826	131	0	0	0	4623
ELECTRIC MACH.	3128	0	1618	47	0	0	203	4997
TRANSPORT EQUI	12189	256#	21098	222	0	149#	0	33914
INSTRUMENTS	656	0	269	0	0	0	0	925
SCRAP	1283	67	0	1391	160	105	63	3070
TOTAL	74790	31367	51458	12357	21140	17307	31089	239507

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-31

TOTAL RAIL BTU CONSUMPTION BY CAR TYPE (INDUSTRY CHANGE SCENARIO: 1980)

10**9

COMMODITY	CAR TYPE							
	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	16219	23253	4073	675	401	0	26499	71120
METALIC ORES	699	5261	0	1451	5906	0	2108	15425
COAL & COKE	0	0	0	3418	59394	0	0	62812
PETROLEUM	1211#	0	533	0	0	10891	361	12996
NONMET MINERAL	4113	7490	0	4481	7017	1862#	498	25461
FOOD PRODUCTS	21147	13056	9081	0	0	5860	32495	81639
TEXTILES	2405	0	1002	0	0	0	0	3407
LUMBER & FURN	46627	5618	21137	3776	215#	0	6228	83801
PULP & PAPER	46460	0	2237	0	0	262	2553	51511
CHEMICALS	14706	23351	3630	0	0	24076	3810	69574
RUBBER&PLASTIC	7771	0	1000	0	0	0	350	9121
STONE & GLASS	11093	9634	3554	481	1108	0	1717	27587
PRIMARY METAL	9560	432#	7161	12470	401#	0	1844	31870
FABRIC. METAL	4084	0	2727	3351	0	0	605	10767
NON-ELEC MACH.	1853	0	8028	325	0	0	0	10206
ELECTRIC MACH.	9466	0	3307	146	0	0	454	13373
TRANSPORT EQUI	29843	604#	44449	582	0	308#	0	75786
INSTRUMENTS	2211	0	524	0	0	0	0	2735
SCRAP	4151	184	0	3971	443	276	159	9184
TOTAL	233618	89083	112444	35127	74885	43535	**79681**	**668373**

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-32

RAIL ENERGY INTENSITY MEASURES
(INDUSTRY CHANGE SCENARIO: 1980)

COMMODITY	RAIL BTU CONSUMPTION PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET-TON 10**3
AGRICULTURE	619.	396.
METALIC ORES	[illegible].	65.
COAL & COKE	353.	118.
PETROLEUM	557.	348.
NONMET MINERAL	382.	89.
FOOD PRODUCTS	693.	614.
TEXTILES	1351.	1465.
LUMBER & FURN	783.	638.
PULP & PAPER	659.	649.
CHEMICALS	498.	424.
RUBBER&PLASTIC	1440.	1431.
STONE & GLASS	529.	277.
PRIMARY METAL	515.	313.
FABRIC. METAL	1034.	769.
NON-ELEC MACH.	1428.	1633.
ELECTRIC MACH.	1674.	1877.
TRANSPORT EQUI	1493.	1430.
INSTRUMENTS	1646.	2615.
SCRAP	564.	155.
AVERAGE	607.	314.

TABLE 4-33

RAIL NET TON-MILES BY CAR TYPE
(INDUSTRY CHANGE SCENARIO: 1985)

10**6

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	34149	65847	3167	1532	791	0	21837	127322
METALIC ORES	1977	16601	0	5382	26148	0	5168	55277
COAL & COKE	0	0	0	11388	203387.	0	0	214775
PETROLEUM	1898#	0	443	0	0	24731	520	27593
NONMET MINERAL	9702	23432	0	12026	29993	6406#	1061	82620
FOOD PRODUCTS	34687	27232	6297	0	0	12964	50375	131554
TEXTILES	2092	0	735	0	0	0	0	2827
LUMBER & FURN	68479	12241	21938	7095	427#	0	10061	120241
PULP & PAPER	88966	0	2015	0	0	616	3809	95406
CHEMICALS	30038	69320	3081	0	0	63034	6615	172088
RUBBER&PLASTIC	6470	0	807	0	0	0	339	7615
STONE & GLASS	21198	27227	3652	1106	3658	0	2753	59595
PRIMARY METAL	24492	1357#	13137	30363	1597#	0	3607	74552
FABRIC. METAL	3557	0	2041	5846	0	0	664	12108
NON-ELEC MACH.	1900	0	6373	498	0	0	0	8771
ELECTRIC MACH.	6515	0	2498	316	0	0	378	9707
TRANSPORT EQUI	27332	733#	28378	910	0	282#	0	57636
INSTRUMENTS	1579	0	460	0	0	0	0	2040
SCRAP	6965	397	0	8766	1529	692	248	18596
TOTAL	371996	244387	95022	85228	267529	108725	107434	1280320

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-34

RAIL BTUS FOR LOADED CAR MOVEMENTS BY CAR TYPE (INDUSTRY CHANGE SCENARIO: 1985)

10**9

COMMODITY	CAR TYPE							
	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	11509	15550	2287	446	301	0	15686	45780
METALIC ORES	528	3757	0	1053	4728	0	1634	11699
COAL & COKE	0	0	0	2227	43029	0	0	45256
PETROLEUM	838#	0	320	0	0	6844	217	8219
NONMET MINERAL	3019	5303	0	3387	5423	1253#	335	18721
FOOD PRODUCTS	14634	8474	4709	0	0	3460	20757	52034
TEXTILES	1629	0	530	0	0	0	0	2159
LUMBER & FURN	32681	3689	13114	2426	154#	0	3836	55901
PULP & PAPER	35345	0	1405	0	0	168	1569	38488
CHEMICALS	11786	16712	2225	0	0	16282	2522	49526
RUBBER&PLASTIC	5690	0	586	0	0	0	208	6484
STONE & GLASS	7457	6162	2183	328	828	0	1050	18008
PRIMARY METAL	7140	239#	3862	8702	297#	0	1158	21396
FABRIC. METAL	2931	0	1474	2172	0	0	353	6930
NON-ELEC MACH.	1288	0	4633	213	0	0	0	6133
ELECTRIC MACH.	6876	0	1868	108	0	0	275	9127
TRANSPORT EQUI	17852	353#	23910	366	0	162#	0	42643
INSTRUMENTS	1618	0	353	0	0	0	0	1971
SCRAP	2938	120	0	2642	291	175	100	6266
TOTAL	165758	60359	63460	24069	55051	28343	49700	446740

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-35

RAIL BTUS FOR EMPTY CAR MOVEMENTS BY CAR TYPE
(INDUSTRY CHANGE SCENARIO: 1985)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	4180	6902	2031	203	116	0	9883	23314
METALIC ORES	240	2004	0	534	2305	0	618	5700
COAL & COKE	0	0	0	1053	18969	0	0	20022
PETROLEUM	405#	0	285	0	0	4323	155	5168
NONMET MINERAL	1400	2755	0	1439	2795	743#	202	9335
FOOD PRODUCTS	5822	4175	5333	0	0	2180	10878	28387
TEXTILES	703	0	568	0	0	0	0	1272
LUMBER & FURN	12902	1979	9414	1249	74#	0	2256	27873
PULP & PAPER	14133	0	1357	0	0	110	1137	16737
CHEMICALS	4076	8378	2068	0	0	9446	1572	25541
RUBBER&PLASTIC	2431	0	610	0	0	0	145	3185
STONE & GLASS	3547	3387	1680	149	365	0	657	9784
PRIMARY METAL	2878	209#	4464	4338	162#	0	770	12821
FABRIC. METAL	1190	0	1600	1202	0	0	257	4249
NON-ELEC MACH.	656	0	4824	130	0	0	0	5610
ELECTRIC MACH.	3073	0	2045	47	0	0	202	5368
TRANSPORT EQUI	11176	238#	24707	204	0	138#	0	36462
INSTRUMENTS	619	0	424	0	0	0	0	1043
SCRAP	1192	63	0	1293	191	99	59	2896
TOTAL	70623	30089	61412	11841	24975	17039	28789	244767

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-36

TOTAL RAIL BTU CONSUMPTION BY CAR TYPE
(INDUSTRY CHANGE SCENARIO: 1985)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	15688	22452	4318	650	417	0	25568	69094
METALIC ORES	767	5761	0	1587	7033	0	2251	17399
COAL & COKE	0	0	0	3280	61998	0	0	65277
PETROLEUM	1244#	0	604	0	0	11167	372	13387
NONMET MINERAL	4419	8059	0	4826	8218	1996#	537	28055
FOOD PRODUCTS	20456	12649	10042	0	0	5640	31635	80421
TEXTILES	2332	0	1099	0	0	0	0	3431
LUMBER & FURN	45583	5668	22529	3675	228#	0	6092	83774
PULP & PAPER	49478	0	2763	0	0	277	2707	55224
CHEMICALS	15862	25090	4293	0	0	25728	4094	75067
RUBBER&PLASTIC	8120	0	1196	0	0	0	353	9669
STONE & GLASS	11004	9549	3864	477	1193	0	1706	27792
PRIMARY METAL	10017	447#	8326	13040	458#	0	1927	34217
FABRIC. METAL	4121	0	3074	3374	0	0	610	11180
NON-ELEC MACH.	1944	0	9457	342	0	0	0	11743
ELECTRIC MACH.	9949	0	3913	155	0	0	478	14495
TRANSPORT EQUI	29027	591#	48617	570	0	299#	0	79105
INSTRUMENTS	2237	0	778	0	0	0	0	3015
SCRAP	4130	183	0	3935	482	274	158	9162
TOTAL	236381	90448	124872	35910	80026	45382	78489	691508

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-37

RAIL ENERGY INTENSITY MEASURES
(INDUSTRY CHANGE SCENARIO: 1985)

COMMODITY	RAIL BTU CONSUMPTION PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET TON 10**3
AGRICULTURE	543.	345
METALIC ORES	315.	58.
COAL & COKE	304.	110.
PETROLEUM	485.	301.
NONMET MINERAL	340.	79.
FOOD PRODUCTS	611.	539.
TEXTILES	1214.	1308.
LUMBER & FURN	697.	564.
PULP & PAPER	579.	565.
CHEMICALS	436.	368.
RUBBER&PLASTIC	1270.	1252.
STONE & GLASS	466.	243.
PRIMARY METAL	459.	277.
FABRIC. METAL	923.	681.
NON-ELEC MACH.	1339.	1529.
ELECTRIC MACH.	1493.	1664.
TRANSPORT EQUI	1372.	1310.
INSTRUMENTS	1478.	2301.
SCRAP	493.	135.
AVERAGE	540.1	276.

projected to decrease by 20.8 percent from 682 to 540 and the Btu per ton ratio is projected to decrease by 22.0 percent. Further, the 1985 industry change scenario projections show an 11.0 percent decrease in Btus per ton-mile over the 1980 industry change projections and a 12.1 percent decrease over 1980 in Btus per ton.

Government-Influence Scenarios

The government influence scenario projections are based on assumptions regarding the level of implementation of the operational and technological changes discussed in Section 3. Table 4-38 shows the potential for government influence on rail operations of changes to conserve energy. As in the industry scenarios, the impact of modal shift from truck to rail is shown separately, apart from this discussion. The table summarizes those types of involvement which have been previously outlined, but for different levels of estimated implementation. The table also shows estimates of reasonable values for the impacts of these changes on rail operations and energy consumption. The government is assumed to increase energy conservation potential in those areas which can be affected by tariff incentives, increased regulations, and involvement in carrier cooperation and labor issues. Once again, the predominant savings are projected to result from reductions in empty backhauls, speed, and stops and delays.

Table 4-39 shows the effects of implementing technological changes, given government financial incentives for using energy-conserving equipment. Again, the long life of rail equipment minimizes the impacts of implementing technological changes relative to operating changes.

These impacts on rail operations and energy consumption are combined as they were for the industry-change scenario projections. Tables 4-40 through 4-44 and 4-45 through 4-49 show the results of the projections for the government-influence scenarios for 1980 and 1985, respectively. For 1980, ton-miles are estimated to decrease by 1.4 percent over the 1980 base-case projections and 0.6 percent over the industry-change scenario projections. Btus are projected at levels 13.7 percent less than the 1980 base case for loaded moves, 24.9 percent less for empty moves, and 17.9 percent less overall. The result is a level of energy intensity which is 16.7 percent less than the 1980 base-case for Btus per ton-mile and 17.9 percent less for Btus per ton.

4.2.6 Modal Shift

Energy consumption associated with modal shift from truck to rail was calculated separately so as to identify the potential magnitude of the shift and to permit the development of alternatives to those estimated in this study.

TABLE 4-38

IMPACT ON RAIL MODE OF OPERATING CHANGES TO CONSERVE ENERGY

GOVERNMENT INFLUENCE SCENARIOS

OPERATING CHANGE	MODEL INPUT VARIABLES AFFECTED	HOW GOVERNMENT COULD INFLUENCE CHANGE[1]	IMPACT ON BASE CASE INPUT VARIABLES[4]	
			1976-1980	1976-1985
Reduce Circuity	Circuity	- Encourage the development of more short route trackage rights agreements. - Encourage the development of tariff incentives - Restrict circuity - Eliminations of unnecessary duplicate circuitous route service	10%	20%
Reduce Empty Backhauls	Empty/Loaded Car	- Modify car service rules - Encourage tariff incentives - Encourage coordinated pickup and delivery - Eliminate duplicate route service - Provide for increased allowance of private car use on loaded return moves - Encourage greater use of assigned cars in controlled backhaul moves	10%	20%
Increase Load Per Car	Load Per Car	- Encourage tariff incentives - Increase minimum carload requirements	3%	6%
Reduce Speed	Energy/Ton-Mile, Loaded and Empty	Mandate speed limits	5.6%[2]	12.9%[3]
Reduce Stops And Delays	Energy/Ton-Mile, Loaded and Empty	- Encourage right-of-way upgrading - Eliminate unnecessary inspections	2.5%	5%
Improve Yard Operations	Energy/Ton-Mile, Loaded and Empty	Encourage financing of yard improvement	0.5%	1.0%
Eliminate Cabooses	Energy/Ton-Mile, Loaded and Empty	Legislate elimination of cabooses	0%	0.5%

[1] Summary of issues presented in Chapter 3.

[2] Assuming a 5 mile per hour reduction in speed.

[3] Assuming a 10 mile per hour reduction in speed.

[4] Input variable is named in second column. Application of impact percent is an algebraic (product), not an arithmetic reduction. For instance, if base case circuity is 17%, a 10% change would reduce the 17% to 17 - 17x.1 = 15.3%.

TABLE 4-39

IMPACT ON RAIL MODE OF TECHNOLOGY CHANGES TO CONSERVE ENERGY

GOVERNMENT INFLUENCE SCENARIO

TECHNOLOGICAL CHANGE	ESTIMATED EFFECT ON ENERGY CONSUMPTION IF ADOPTED UNIVERSALLY[9]	ESTIMATED EQUIPMENT TURNOVER RATE		ESTIMATED IMPACT ON ENERGY CONSUMPTION UNDER INDUSTRY CHANGE SCENARIOS (Percent Savings)	
		Over 5 year period	Over 10 year period	1976-1980	1976-1985
Locomotive Streamlining	Hopper Car Moves:	21.4%	42.8%		
	Loaded - 3.3% reduction			.36	1.06
	Empty - 4.5% reduction			.48	1.45
	Flat Car Moves:				
	Loaded - 7.4% reduction			.79	2.38
	Empty - 8.4% reduction			.90	2.70
	Boxcar and All Other Moves:				
	Loaded - 3.5% reduction			.38	1.13
	Empty - 5.6% reduction			.60	1.80
Other Locomotive Changes	17.2% reduction	21.4%	42.8%	1.84	5.52
Car Streamlining	Loaded Moves: 3.3% reduction	19.4%	38.8%	.26	.77
	Empty Moves: 10.3% reduction			.80	2.39
Reduced Car-Tare Weight	Loaded Moves: 4.6% reduction	19.4%	38.8%	.45	1.34
	Empty Moves: 9.6% reduction			.93	2.79

ASSUMPTIONS

[1] Estimates of savings are assigned separately to open and covered hopper cars, flat cars (of which 53 percent of car miles are assumed in TOFC/COFC service), and boxcars. Savings for all car types not mentioned are assumed the same as for boxcars.

[2] It is assumed that streamlining on the specially designed hopper car can be generalized to other car types.

[3] A 5 percent tare weight reduction is assumed.

[4] The rate of replacement of locomotives in service over the next ten years is assumed to be the same as that which occurred in 1974 for Class I railroads. According to the Association of American Railroads (Yearbook of Railroad Facts, 1975 Edition), the ratio of new locomotives to locomotives in service in 1974 was 4.27% representing a 23.9-year replacement cycle.

[5] The rate of replacement of cars in service over the next 10 years is assumed to be the same as that which occurred in 1974. According to the Association of American Railroads (ibid), the ratio of new freight cars to the total in 1974 was 2.88%, representing a 25.8-year replacement cycle.

[6] 80 percent of all cars are assumed to be amenable to streamlining.

[7] The estimated equipment turnover rate for the five year period is assumed to apply and the change is assumed to be adopted on one-half of all new equipment.

[8] The estimated equipment turnover rate for the ten year period is assumed to apply and the change is assumed to be adopted on three-quarters of all new equipment.

[9] Percent reduction in BTUs per ton (net or gross). Savings are compounded.

TABLE 4-40

RAIL NET TON-MILES BY CAR TYPE
(GOVERNMENT INFLUENCE SCENARIO: 1980)

10**6

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	30599	59003	2838	1372	709	0	19567	114088
METALIC ORES	1557	13072	0	4238	20492	0	4069	43428
COAL & COKE	0	0	0	10232	182737	0	0	192969
PETROLEUM	1591#	0	371	0	0	20730	436	23129
NONMET MINERAL	7780	18791	0	9644	24052	5137#	851	66255
FOOD PRODUCTS	31014	24270	5456	0	0	11554	44896	117190
TEXTILES	1861	0	646	0	0	0	0	2507
LUMBER & FURN	60601	10832	19414	6279	378#	0	8904	106409
PULP & PAPER	72345	0	1555	0	0	501	3094	77495
CHEMICALS	24165	55766	2479	0	0	50710	5322	138441
RUBBER&PLASTIC	5344	0	659	0	0	0	290	6293
STONE & GLASS	18433	23675	3176	962	3181	0	2394	51821
PRIMARY METAL	20208	1120#	10839	25052	1317#	0	2976	61511
FABRIC. METAL	3037	0	1743	4991	0	0	566	10337
NON-ELEC MACH.	1552	0	5179	405	0	0	0	7137
ELECTRIC MACH.	5341	0	2037	258	0	0	310	7946
TRANSPORT EQUI	24036	643#	24849	799	0	247#	0	50575
INSTRUMENTS	1339	0	313	0	0	0	0	1652
SCRAP	6051	345	0	7616	1328	601	215	16155
TOTAL	316853	207518	81554	71848	234194	89480	93890	1095335

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-41

RAIL BTUS FOR LOADED CAR MOVEMENTS BY CAR TYPE (GOVERNMENT INFLUENCE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	11028	14950	2206	429	290	0	15066	43969
METALIC ORES	444	3167	0	891	3982	0	1381	9867
COAL & COKE	0	0	0	2152	41357	0	0	43509
PETROLEUM	754#	0	288	0	0	6145	195	7382
NONMET MINERAL	2603	4553	0	2906	4674	1080#	289	16106
FOOD PRODUCTS	14038	8120	4389	0	0	3311	19825	49683
TEXTILES	1554	0	502	0	0	0	0	2057
LUMBER & FURN	31009	3504	12489	2302	146#	0	3647	53096
PULP & PAPER	30789	0	1167	0	0	146	1366	33468
CHEMICALS	10165	14404	1927	0	0	14034	2180	42710
RUBBER&PLASTIC	5041	0	516	0	0	0	191	5748
STONE & GLASS	6960	5737	2043	305	771	0	980	16797
PRIMARY METAL	6313	211#	3426	7703	262#	0	1025	18941
FABRIC. METAL	2682	0	1355	1989	0	0	323	6349
NON-ELEC MACH.	1128	0	4058	185	0	0	0	5372
ELECTRIC MACH.	6044	0	1639	95	0	0	242	8019
TRANSPORT EQUI	16822	332#	22557	344	0	152#	0	40207
INSTRUMENTS	1472	0	258	0	0	0	0	1731
SCRAP	2739	112	0	2464	271	163	93	5841
TOTAL	151585	55091	58820	21765	51755	25032	46803	410850

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-42

RAIL BTUS FOR EMPTY CAR MOVEMENTS BY CAR TYPE (GOVERNMENT INFLUENCE SCENARIO: 1980)

10**9

COMMODITY	CAR TYPE							
	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	4058	6697	1560	197	0	0	9569	22081
METALIC ORES	204	1709	0	455	1799	0	595	4763
COAL & COKE	0	0	0	1024	16976	0	0	18000
PETROLEUM	368#	0	205	0	0	3906	140	4619
NONMET MINERAL	1217	2393	0	1250	2232	643#	175	7909
FOOD PRODUCTS	5640	4029	3960	0	0	2094	10481	26204
TEXTILES	678	0	429	0	0	0	0	1106
LUMBER & FURN	12370	1896	7141	1197	65#	0	2158	24827
PULP & PAPER	12451	0	898	0	0	96	999	14444
CHEMICALS	3553	7298	1426	0	0	8192	1367	21836
RUBBER&PLASTIC	2175	0	427	0	0	0	134	2737
STONE & GLASS	3341	3189	1252	141	316	0	617	8856
PRIMARY METAL	2572	186#	3157	3865	133#	0	687	10601
FABRIC. METAL	1101	0	1171	1111	0	0	237	3620
NON-ELEC MACH.	581	0	3360	115	0	0	0	4055
ELECTRIC MACH.	2730	0	1430	41	0	0	179	4380
TRANSPORT EQUI	10662	226#	18543	194	0	130#	0	29756
INSTRUMENTS	569	0	247	0	0	0	0	816
SCRAP	1122	59	0	1217	165	92	55	2711
TOTAL	65392	27682	45206	10807	21686	15153	27394	213320

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-43

TOTAL RAIL BTU CONSUMPTION BY CAR TYPE (GOVERNMENT INFLUENCE SCENARIO: 1980)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	15085	21647	3766	626	290	0	24635	66050
METALIC ORES	649	4876	0	1347	5782	0	1976	14630
COAL & COKE	0	0	0	3176	58333	0	0	61509
PETROLEUM	1122#	0	493	0	0	10051	335	12002
NONMET MINERAL	3820	6946	0	4156	6907	1723#	464	24015
FOOD PRODUCTS	19678	12149	8349	0	0	5405	30306	75887
TEXTILES	2232	0	931	0	0	0	0	3163
LUMBER & FURN	43379	5400	19630	3498	211#	0	5805	77924
PULP & PAPER	43240	0	2064	0	0	242	2365	47911
CHEMICALS	13718	21703	3353	0	0	22226	3547	64546
RUBBER&PLASTIC	7216	0	943	0	0	0	325	8485
STONE & GLASS	10301	8925	3295	446	1057	0	1598	25653
PRIMARY METAL	8886	397#	6583	11569	395#	0	1711	29541
FABRIC. METAL	3783	0	2526	3100	0	0	561	9969
NON-ELEC MACH.	1709	0	7418	300	0	0	0	9427
ELECTRIC MACH.	8774	0	3068	136	0	0	421	12399
TRANSPORT EQUI	27484	558#	41100	538	0	282#	0	69962
INSTRUMENTS	2041	0	505	0	0	0	0	2546
SCRAP	3861	171	0	3680	436	256	148	8552
TOTAL	216977	82773	104026	32572	73441	40185	74197	624170

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-44

RAIL ENERGY INTENSITY MEASURES
(GOVERNMENT INFLUENCE SCENARIO: 1980)

COMMODITY	RAIL BTU CONSUMPTION PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET TON TON**3
AGRICULTURE	579.	368.
METALIC ORES	337.	62.
COAL & COKE	319.	116.
PETROLEUM	519.	322.
NONMET MINERAL	362.	84.
FOOD PRODUCTS	648.	571.
TEXTILES	1261.	1359.
LUMBER & FURN	732.	593.
PULP & PAPER	618.	603.
CHEMICALS	466.	393.
RUBBER&PLASTIC	1348.	1330.
STONE & GLASS	495.	258.
PRIMARY METAL	480.	290.
FABRIC. METAL	964.	712.
NON-ELEC MACH.	1321.	1508.
ELECTRIC MACH.	1560.	1739.
TRANSPORT EQUI	1383.	1320.
INSTRUMENTS	1542.	2425.
SCRAP	529.	145.
AVERAGE	**570.**	**293.**

TABLE 4-45

RAIL NET TON-MILES BY CAR TYPE
(GOVERNMENT INFLUENCE SCENARIO: 1985)

10**6

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON- DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	33849	64712	3138	1518	777	0	21640	125634
METALIC ORES	1960	16315	0	5335	25681	0	5122	54412
COAL & COKE	0	0	0	11288	199755	0	0	211043
PETROLEUM	1882#	0	439	0	0	24305	516	27141
NONMET MINERAL	9617	23028	0	11920	29457	6295#	1051	81369
FOOD PRODUCTS	34385	26765	6240	0	0	12741	49925	130056
TEXTILES	2066	0	741	0	0	0	0	2806
LUMBER & FURN	67879	12030	21739	7033	419#	0	9970	119070
PULP & PAPER	88193	0	1997	0	0	606	3775	94570
CHEMICALS	29597	68129	3233	0	0	61952	6556	169467
RUBBER&PLASTIC	6385	0	835	0	0	0	349	7568
STONE & GLASS	21013	26759	3619	1097	3593	0	2728	58809
PRIMARY METAL	24278	1334#	13017	30097	1568#	0	3249	73544
FABRIC. METAL	3494	0	2048	5799	0	0	658	11999
NON-ELEC MACH.	1864	0	6351	494	0	0	0	8709
ELECTRIC MACH.	6428	0	2516	313	0	0	375	9632
TRANSPORT EQUI	27055	721#	28202	903	0	277#	0	57157
INSTRUMENTS	1510	0	521	0	0	0	0	2032
SCRAP	6903	390	0	8689	1502	680	245	18409
TOTAL	368357	240182	94636	84486	262752	106856	106160	1263426

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

\# Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-46

RAIL BTUS FOR LOADED CAR MOVEMENTS BY CAR TYPE
(GOVERNMENT INFLUENCE SCENARIO: 1985)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	10117	13531	2000	392	263	0	13788	40090
METALIC ORES	463	3271	0	925	4106	0	1436	10202
COAL & COKE	0	0	0	1958	37346	0	0	39304
PETROLEUM	738#	0	280	0	0	5949	190	7157
NONMET MINERAL	2650	4617	0	2976	4710	1092#	295	16340
FOOD PRODUCTS	12657	7374	4114	0	0	3025	18238	45608
TEXTILES	1425	0	472	0	0	0	0	1897
LUMBER & FURN	28721	3211	11444	2128	135#	0	3372	49011
PULP & PAPER	31025	0	1228	0	0	145	1379	33777
CHEMICALS	10266	14581	2060	0	0	14173	2218	43298
RUBBER&PLASTIC	4979	0	535	0	0	0	190	5703
STONE & GLASS	6539	5365	1905	289	720	0	923	15741
PRIMARY METAL	6271	208#	3378	7626	258#	0	927	18669
FABRIC. METAL	2553	0	1305	1911	0	0	311	6080
NON-ELEC MACH.	1121	0	4070	187	0	0	0	5378
ELECTRIC MACH.	6009	0	1659	95	0	0	242	8004
TRANSPORT EQUI	15674	308#	20952	322	0	141#	0	37397
INSTRUMENTS	1371	0	353	0	0	0	0	1724
SCRAP	2581	104	0	2319	255	152	88	5499
TOTAL	145359	52571	55754	21129	47794	24677	43597	390879

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-47

RAIL BTUS FOR EMPTY CAR MOVEMENTS BY CAR TYPE (GOVERNMENT INFLUENCE SCENARIO: 1985)

10**9

	CAR TYPE							
COMMODITY	BOXCAR	COVER HOPPER	FLAT CAR*	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	3078	5087	1195	150	68	0	7253	16830
METALIC ORES	176	1477	0	393	1349	0	213	3609
COAL & COKE	0	0	0	774	11103	0	0	11877.
PETROLEUM	299#	0	168	0	0	3149	114	3729
NONMET MINERAL	1031	2031	0	1059	1636	542#	148	6446
FOOD PRODUCTS	4288	3077	3138	0	0	1588	7983	20073
TEXTILES	516	0	340	0	0	0	0	856
LUMBER & FURN	9501	1458	5539	919	43#	0	1655	19116
PULP & PAPER	10408	0	799	0	0	80	835	12121
CHEMICALS	2984	6175	1289	0	0	6882	1153	18483
RUBBER&PLASTIC	1782	0	375	0	0	0	110	2267
STONE & GLASS	2612	2496	989	110	213	0	482	6902
PRIMARY METAL	2119	154#	2627	3182	95#	0	513	8690
FABRIC. METAL	869	0	954	885	0	0	189	2895
NON-ELEC MACH.	478	0	2854	96	0	0	0	3428
ELECTRIC MACH.	2253	0	1223	34	0	0	149	3659
TRANSPORT EQUI	8231	175#	14578	150	0	100#	0	23235
INSTRUMENTS	440	0	285	0	0	0	0	725
SCRAP	878	47	0	951	112	72	43	2102
TOTAL	51943	22177	36351	8702	14619	12413	20840	167044

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-48

TOTAL RAIL BTU CONSUMPTION BY CAR TYPE (GOVERNMENT INFLUENCE SCENARIO: 1985)

10**9

COMMODITY	CAR TYPE							
	BOXCAR	COVER HOPPER	FLAT CAR *	GON-DOLA	OPEN HOPPER	TANK CAR	MISC@	TOTAL
AGRICULTURE	13195	18618	3195	542	330	0	21040	56920
METALIC ORES	639	4748	0	1318	5455	0	1650	13811
COAL & COKE	0	0	0	2732	48449	0	0	51181
PETROLEUM	1037#	0	447	0	0	9098	304	10886
NONMET MINERAL	3681	6648	0	4035	6346	1633#	443	22786
FOOD PRODUCTS	17145	10451	7252	0	0	4613	26221	65682
TEXTILES	1941	0	812	0	0	0	0	2753
LUMBER & FURN	38222	4669	16983	3047	178#	0	5028	68127
PULP & PAPER	41433	0	2027	0	0	225	2213	45898
CHEMICALS	13250	20756	3348	0	0	21055	3371	61781
RUBBER&PLASTIC	6761	0	910	0	0	0	300	7971
STONE & GLASS	9151	7661	2894	399	934	0	1405	22643
PRIMARY METAL	8390	362#	6005	10808	353#	0	1441	27359
FABRIC. METAL	3421	0	2259	2796	0	0	500	8976
NON-ELEC MACH.	1599	0	6924	283	0	0	0	8806
ELECTRIC MACH.	8261	0	2882	129	0	0	391	11663
TRANSPORT EQUI	23905	464#	35529	472	0	241#	0	60632
INSTRUMENTS	1811	0	638	0	0	0	0	2449
SCRAP	3459	151	0	3270	367	224	131	7602
TOTAL	197302	74748	92104	29831	62412	37090	64436	557924

* Includes TOFC/COFC traffic.

@ Includes auto rack, refrigerator, and stock cars.

Based on data reported in one-percent waybill sample, which may have been incorrectly assigned to this car type. Statistics are included since the amounts should be reflected in the total traffic.

TABLE 4-49

RAIL ENERGY INTENSITY MEASURES
(GOVERNMENT INFLUENCE SCENARIO: 1985)

COMMODITY	RAIL BTU CONSUMPTION PER NET TON-MILE	RAIL BTU CONSUMPTION PER NET TON 10**3
AGRICULTURE	453.	284.
METALIC ORES	254.	46.
COAL & COKE	243.	86.
PETROLEUM	401.	245.
NONMET MINERAL	280.	64.
FOOD PRODUCTS	505.	440.
TEXTILES	981.	1049.
LUMBER & FURN	572.	459.
PULP & PAPER	485.	469.
CHEMICALS	365.	303.
RUBBER&PLASTIC	1053.	1031.
STONE & GLASS	385.	198.
PRIMARY METAL	372.	222.
FABRIC. METAL	748.	547.
NON-ELEC MACH.	1011.	1145.
ELECTRIC MACH.	1211.	1338.
TRANSPORT EQUI	1061.	1004.
INSTRUMENTS	1205.	1844.
SCRAP	413.	112.
AVERAGE	441.6	223.

TABLE 4-50

ESTIMATE OF NET TON-MILES AND ENERGY CONSUMPTION MODAL SHIFT FREIGHT (HIGHWAY TO RAIL TOFC/COFC)

BTU's x 10^9

Commodity		Net Ton-Miles x 10^6 1980				1985			
		Industry Change		Government Influence		Industry Change		Government Influence	
		Net Ton-Miles	BTU's	Net Ton-Miles	BTU's	Net Ton-Miles	BTU's	Net Ton-Miles	BTU's
6	Food Products	4,504	7,495	6,755	10,335	10,106	16,109	15,159	17,615
7	Textiles	1,181	1,848	1,772	2,553	2,661	3,978	3,864	4,231
9	Pulp & Paper	1,790	2,575	2,684	3,562	4,401	6,034	6,604	6,703
10	Chemicals	4,117	6,027	6,175	8,354	10,234	14,256	15,352	15,874
11	Rubber & Plastic	2,728	4,237	4,092	5,856	6,462	9,577	9,903	10,794
12	Stone & Glass	864	967	1,296	1,344	1,766	1,868	2,649	2,119
13	Primary Metal	1,041	688	1,562	948	2,525	1,583	3,787	1,746
14	Fabricated Metal	4,018	6,324	6,027	8,733	9,410	14,171	14,115	15,569
15	Non-Electric Machinery	3,343	5,192	5,015	7,181	8,212	12,178	12,317	13,426
16	Electric Machinery	2,741	4,487	4,111	6,191	6,693	10,481	10,040	11,496
17	Transportation Equipment	7,573	13,586	11,360	18,789	17,251	29,551	25,877	32,605
18	Instruments	2,297	4,107	3,446	5,558	9,418	15,926	14,127	17,306
	Total	36,197	57,534	54,295	79,406	89,139	135,713	133,794	149,483
	Average BTU/Net Ton-Mile	1,589		1,462		1,522		1,117	

Appendix A and Table A-27 develop and summarize the methodology for estimating modal shift annual tonnage, by commodity. Ton-miles were calculated by multiplying the tons of each commodity shifted times an estimated average haul, assumed to be 50 percent greater than the truck average haul. BTU estimates were calculated by multiplying ton miles by energy intensity calculated in two ways:

> BTU per ton-mile by commodity for flat car associated traffic (scenario total BTU's for flat car for a particular commodity divided by the corresponding ton-miles), assuming all the traffic moved by TOFC/COFC.
>
> BTU per ton-mile by the commodity average for all car types handling the commodity.

The first method reflects the probable nature of the modal shift, that is, from truck to TOFC/COFC. Net ton-miles and energy consumption associated with the modal shift are summarized in Table IV-50, and are the results assumed in this study.

If the all rail commodity BTU per ton-mile average were used, net ton-miles would stay the same, but total energy consumption would be:

	BTU's x10	
	1980	1985
Industry Change	41,472	93,865
Government Influence	57,929	112,755

Roughly estimated, energy consumption (BTU per ton-mile) of truck traffic shifted to rail TOFC/COFC would be cut by a low of 22 percent in the 1980 industry change scenario up to about 41 percent in the 1985 government influence scenario. Total BTU savings (ΔBTU times ton-miles) would range from 19 $\times 10^{12}$ to 105 $\times 10^{12}$ BTU's annually in the respective scenario.

According to this study, base case TOFC/COFC energy intensity is about 68 percent that of truck, compared to the all rail average of 30 percent. Said another way, TOFC/COFC energy intensity is more than twice that of the same commodities moved in conventional rail cars, but still substantially less than truck (overall, but not always in specific cases). According to our study, TOFC/COFC energy intensity gains or loses no relative advantage in the various scenarios, but follows fairly closely the percentage savings in energy intersity of all other car types.

4.2.7 Inland Waterways

For inland waterways, the industry-change scenarios examine the impacts of increased tow sizes and account for programmed changes in the waterway structures. Because of the long lead times to build new structures, only one government-scenario projection was run for the year 1985. We believe, however, it is optimistic to assume that waterway projects already programmed and designed but currently held up in the courts could be completed even by 1985.

Base-Case Scenarios

The 1980 and 1985 base-case projections reflect only increases in traffic. Since average haul per ton is not projected to change from the base year, both tons and ton-miles are projected to grow at the same rate. Appendix C gives the 1980 and 1985 ton projections.

Tables 4-51 and 4-52 depict the barge energy-consumption estimates by commodities for 1980 and 1985. The small differences in Btus per ton and Btus per ton-mile which appear between these cases and the 1972 case result from program rounding by computer. The energy intensiveness of these projections by waterway are exactly the same as for 1972, as shown in Table 4-53. Btus per ton-mile are based on river miles.

Industry-Change Scenarios

From 1980 to 1985, average tow horsepower on the Ohio and Upper Mississippi Rivers is assumed to increase by 11 percent and tons per tow are assumed to increase by 9 percent, as discussed in Appendix C.

These assumptions, used as input to the TRANSEN model, result in barge Btus per ton-mile by waterway as shown in Table 4-54 and 4-55. No increase in lock delays was assumed on the Ohio River, since adequate locking capacity exists to meet traffic flows up to this time. On the Upper Mississippi, however, lock delays were increased from an average of 4 hours to 5 hours (due primarily to no physical changes to locks and dam 26). The increase in tow speed of 1 mile per hour on the Ohio, in contrast to a .8 mile per hour tow speed increase on the Upper Mississippi is due to an increase of one foot

TABLE 4-51

BARGE BTU CONSUMPTION (BASE-CASE SCENARIO: 1980)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE *	TOTAL BTUS 10**9
AGRICULTURE	123790	172	8896
METALIC ORES	211128	263	2373
COAL & COKE	83702	296	13729
PETROLEUM	96332	336	23249
NONMET MINERAL	64878	339	8084
FOOD PRODUCTS	165596	201	1284
TEXTILES	182067	300	8
LUMBER & FURN	17907	226	364
PULP & PAPER	54566	220	246
CHEMICALS	189379	290	10779
RUBBER&PLASTIC	84501	169	1
STONE & GLASS	83976	239	716
PRIMARY METAL	216050	240	3007
FABRIC. METAL	194016	231	101
NON-ELEC MACH.	119715	284	53
ELECTRIC MACH.	260871	267	17
TRANSPORT EQUI	59538	267	2
INSTRUMENTS	9723	374	12
SCRAP	38173	310	724
AVERAGE	98668	278	73652

* Actual miles, not adjusted for circuity.

TABLE 4-52

BARGE BTU CONSUMPTION (BASE-CASE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE*	TOTAL BTUS 10**9
AGRICULTURE	124101	172	9928
METALIC ORES	211118	263	3014
COAL & COKE	83702	296	15281
PETROLEUM	96332	336	27736
NONMET MINERAL	64878	339	10081
FOOD PRODUCTS	165595	201	1440
TEXTILES	181541	299	9
LUMBER & FURN	17907	226	411
PULP & PAPER	54563	220	303
CHEMICALS	189379	290	13399
RUBBER&PLASTIC	84501	169	1
STONE & GLASS	83978	239	824
PRIMARY METAL	215829	240	3640
FABRIC. METAL	194027	231	118
NON-ELEC MACH.	119658	284	65
ELECTRIC MACH.	260571	266	21
TRANSPORT EQUI	57465	257	2
INSTRUMENTS	9714	373	15
SCRAP	38172	310	833
AVERAGE/TOTAL	99054	280	87129

* Actual miles, not adjusted for circuity.

TABLE 4-53

BARGE BTUS PER TON-MILE BY WATERWAY (BASE-CASE SCENARIO: 1980 AND 1985)

WATERWAY	BTUS/TON-MILE UPSTREAM	BTUS/TON-MILE DOWNSTREAM	STILL WATER TOW SPEED
OHIO	456	173	13
UPPER MISS.	495	182	12
LOWER MISS.	276	103	16
GIWW	475	475	12
AIWW	330	330	12
PACWW	242	242	12

TABLE 4-54

BARGE BTUS PER TON-MILE BY WATERWAY
(INDUSTRY CHANGE SCENARIO: 1980)

WATERWAY	BTUS/TON-MILE		
	UPSTREAM	DOWNSTREAM	STILL WATER TOW SPEED
OHIO	409	161	13
UPPER MISS.	474	190	13
LOWER MISS.	259	101	17
GIWW	475	475	12
AIWW	330	330	12
PACWW	242	242	12

TABLE 4-55

BARGE BTUS PER TON-MILE BY WATERWAY (INDUSTRY CHANGE SCENARIO: 1985)

WATERWAY	BTUS/TON-MILE		
	UPSTREAM	DOWNSTREAM	STILL WATER TOW SPEED
OHIO	387	158	14
UPPER MISS.	463	197	14
LOWER MISS.	280	102	15
GIWW	476	476	12
AIWW	330	330	12
PACWW	242.	242.	12

TABLE 4-56

BARGE BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1980)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE*	TOTAL BTUS 10**9
AGRICULTURE	122623	170	8812
METALIC ORES	196738	245	2211
COAL & COKE	77599	275	12728
PETROLEUM	92148	322	22239
NONMET MINERAL	60877	318	7585
FOOD PRODUCTS	159533	193	1237
TEXTILES	171330	282	7
LUMBER & FURN	17722	224	360
PULP & PAPER	52188	211	235
CHEMICALS	180906	277	10297
RUBBER&PLASTIC	80546	161	1
STONE & GLASS	80334	229	685
PRIMARY METAL	205753	229	2863
FABRIC. METAL	186569	222	97
NON-ELEC MACH.	113144	268	50
ELECTRIC MACH.	249546	255	16
TRANSPORT EQUI	57844	259	2
INSTRUMENTS	9698	373	12
SCRAP	37037	301	703
AVERAGE/TOTAL	93975	265	70149

* Actual miles, not adjusted for circuity.

in the average Ohio River channel depth between 1980 and 1985. This increase in depth is due to the deeper pools created by the new lock at Galipolis to come on line after 1980.

On the Lower Mississippi, Btu consumption per ton-mile shows an increase from 1980 to 1985, due largely to changes in average tow configuration from a long narrow tow of 18 barges (three by six) to a wider, shorter tow of 20 barges (four by five).[1] Such a change in configuration and tow size (necessary for safety and operating reasons - a three by seven type configuration is not safe to handle) had a significant change on operating speeds and therefore on total horsepower hours and fuel consumption. The speed calculated was 15.3 miles per hour in stillwater. Had the tow been three by seven barges with one barge out (three by six plus two), the speed would have been 17.4 miles per hour with the same horsepower input. Consequently the Btus per ton-mile would have been less. The increase in lock delays is very small and, since these affect only the few tributary rivers and not the main stem, they are not very important.

Due entirely to a slight increase in lock delays on the Gulf Intracoastal Waterway (GIWW), Btus consumed per ton-mile are projected to increase. A 7 percent increase in lock delays resulted in a .05 percent increase in Btu consumption per ton-mile.

From 1972 to 1980, few changes are projected on the coastal waterways. Energy intensiveness is constant on the Atlantic. The Gulf Intracoastal and the Pacific Coast waterways may experience a small increase in lock delays, resulting in a small rise in energy consumption per ton-mile.

As explained in Section 2, the effect of different waterways on the different commodities determines the variation in energy intensiveness among commodities. It appears from examination of the overall average Btus per ton-mile that the increase in energy intensity from 1980 to 1985 may be credited to two sources: increase in lock delays on the Upper Mississippi and less efficient tow dimensions on the Lower Mississippi (to maintain good maneuverability). Tables 4-56 and 4-57 outline the commodity specific and overall average energy intensiveness of inland waterways.

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[1] Tow dimensions given number of barges were obtained from discussions with Corps of Engineers district offices.

Government-Influence Scenario

Because of the long lead times necessary to complete new river projects such as the proposed new locks and dam at Alton, Illinois, and the proposed new industrial lock on the Gulf Intracoastal Waterway, the only government scenario is for 1985. Two changes resulting from new locks are assumed to cut lock delays on the Upper Mississippi from 5 to 1.5 hours and on the GIWW from 1.6 to 1.05 hours, and comprise the only scenario differences from the 1985 industry-change case. Comparing Table 4-58 with Table 4-55, the change has resulted in 26.2 fewer Btus per ton-mile on the Upper Mississippi, both upstream and downstream, and 1.4 fewer Btus per ton-mile on the GIWW. When this effect is distributed throughout the traffic, it amounts to 3 Btus per ton-mile, as may be seen by comparing Table 4-57 to 4-59.

4.2.8 Coastal Movements

For coastal movements, two sets of projections were made: one for the base-case and one for industry-change projections.

Base-Case Scenarios

The base-case projections differ from the 1972 case only by the traffic projections. Appendix C shows the traffic projections for 1980 and 1985 respectively. Tables 4-60 and 4-61 show the energy intensiveness of coastal shipping and barging in 1980. Energy intensiveness figures for 1985 are given in Tables 4-62 and 4-63.

Industry Change Scenarios

For these scenarios, three changes are assumed to occur:

- increases in ship size;
- increases in ship speeds; and
- reductions in port time.

Both decreases in port time and increases in ship size contribute to greater energy efficiency. However, increases in speed lower energy efficiency. The net effect in shipping is mixed. Those commodities shipped in tankers and break-bulk ships realize an overall improvement, while those commodities shipped in dry-bulk ships are

TABLE 4-57

BARGE BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	124797	173	9984
METALIC ORES	201153	251	2872
COAL & COKE	76154	270	13903
PETROLEUM	94094	329	27092
NONMET MINERAL	60552	317	9409
FOOD PRODUCTS	163156	198	1419
TEXTILES	179436	296	9
LUMBER & FURN	17863	226	410
PULP & PAPER	52716	213	293
CHEMICALS	186646	285	13206
RUBBER&PLASTIC	85005	170	1
STONE & GLASS	81020	231	795
PRIMARY METAL	208563	232	3518
FABRIC. METAL	190040	226	116
NON-ELEC MACH.	114403	271	62
ELECTRIC MACH.	257303	263	21
TRANSPORT EQUI	57296	256	2
INSTRUMENTS	9731	374	15
SCRAP	36961	300	807
AVERAGE/TOTAL	95427	269	83938

TABLE 4-58

BARGE BTUS PER TON-MILE BY WATERWAY (GOVERNMENT INFLUENCE SCENARIO: 1985)

WATERWAY	BTUS/TON-MILE		
	UPSTREAM	DOWNSTREAM	STILL WATER TOW SPEED
OHIO	387	158	14
UPPER MISS.	436	170	14
LOWER MISS.	280	102	15
GIWW	474	474	12
AIWW	330	330	12
PACWW	242	242	12

TABLE 4-59

BARGE BTU CONSUMPTION
(GOVERNMENT INFLUENCE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	121048	168	9684
METALIC ORES	200833	250	2867
COAL & COKE	75564	268	13795
PETROLEUM	93380	326	26886
NONMET MINERAL	59938	313	9313
FOOD PRODUCTS	159728	193	1389
TEXTILES	178431	293	9
LUMBER & FURN	17834	225	409
PULP & PAPER	52518	212	291
CHEMICALS	185280	283	13109
RUBBER&PLASTIC	85005	170	1
STONE & GLASS	79456	227	780
PRIMARY METAL	206467	229	3482
FABRIC. METAL	188216	224	115
NON-ELEC MACH.	113786	270	61
ELECTRIC MACH.	257317	263	21
TRANSPORT EQUI	58974	255	2
INSTRUMENTS	9702	373	15
SCRAP	35690	290	779
AVERAGE/TOTAL	94379	266	83017

TABLE 4-60

COASTAL SHIP BTU CONSUMPTION
(BASE CASE SCENARIO: 1980)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	218262	198	764
METALIC ORES	151427	203	22667
COAL & COKE	66230	231	1405
PETROLEUM	240060	170	60415
NONMET MINERAL	94216	215	3284
FOOD PRODUCTS	638723	313	3979
TEXTILES	662003	312	168
LUMBER & FURN	308435	194	878
PULP & PAPER	285467	330	479
CHEMICALS	666634	312	11535
RUBBER&PLASTIC	529802	315	82
STONE & GLASS	78352	222	601
PRIMARY METAL	564814	314	1851
FABRIC. METAL	552403	315	477
NON-ELEC MACH.	580172	314	259
ELECTRIC MACH.	628150	313	138
TRANSPORT EQUI	370286	322	383
INSTRUMENTS	476498	317	299
SCRAP	128392	207	38
AVERAGE/TOTAL	253538	226	109710

TABLE 4-61

COASTAL BARGE BTU CONSUMPTION (BASE CASE SCENARIO: 1980)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	348770	316.	748
METALIC ORES	0	0.	0
COAL & COKE	104344	363.	1811
PETROLEUM	309676	219	10627
NONMET MINERAL	149336	342	7808
FOOD PRODUCTS	630807	309	206
TEXTILES	654056	309	1
LUMBER & FURN	493743	311	602
PULP & PAPER	278020	321	14
CHEMICALS	658681	308	1408
RUBBER&PLASTIC	522030	311	1
STONE & GLASS	123833	352	1007
PRIMARY METAL	556996	310	373
FABRIC. METAL	544602	310	165
NON-ELEC MACH.	572334	310	72
ELECTRIC MACH.	620248	309	11
TRANSPORT EQUI	362727	316	61
INSTRUMENTS	0	0	0
SCRAP	204284	329	66
AVERAGE/TOTAL	208936	274	24990

TABLE 4-62

COASTAL SHIP BTU CONSUMPTION
(BASE CASE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	218269	198	852
METALIC ORES	151431	203	28787
COAL & COKE	66228	231	1564
PETROLEUM	240061	170	72076
NONMET MINERAL	94216	215	4095
FOOD PRODUCTS	638745	313	4465
TEXTILES	663318	312	189
LUMBER & FURN	308459	194	993
PULP & PAPER	285473	330	590
CHEMICALS	666618	312	14338
RUBBER&PLASTIC	532403	315	89
STONE & GLASS	78343	222	284
PRIMARY METAL	564798	314	2243
FABRIC. METAL	552465	315	558
NON-ELEC MACH.	580682	314	318
ELECTRIC MACH.	627921	313	168
TRANSPORT EQUI	370138	322	437
INSTRUMENTS	476303	317	368
SCRAP	120842	207	44
AVERAGE/TOTAL	254081	226	132467

TABLE 4-63

COASTAL BARGE BTU CONSUMPTION
(BASE CASE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	348780	316	835
METALIC ORES	0	0	0
COAL & COKE	104341	363	2016
PETROLEUM	309676	219	12678
NONMET MINERAL	149337	342	9737
FOOD PRODUCTS	630828	309	232
TEXTILES	655370	309	1
LUMBER & FURN	493781	311	681
PULP & PAPER	278026	321	17
CHEMICALS	658665	308	1751
RUBBER&PLASTIC	524628	311	2
STONE & GLASS	123818	352	1157
PRIMARY METAL	556980	310	453
FABRIC. METAL	544664	310	193
NON-ELEC MACH.	572843	310	88
ELECTRIC MACH.	620020	309	14
TRANSPORT EQUI	362578	316	69
INSTRUMENTS	0	0	0
SCRAP	192145	329	77
AVERAGE/TOTAL STOP 0 /B /MAI	208920	274	30008

TABLE 4-64

SHIP SIZE AND SPEED ASSUMPTIONS

	BASE CASE		INDUSTRY CHANGE			
			SIZE (DWT)		SPEED (MPH)	
SHIP TYPE	SIZE (DWT)	SPEED (MPH)	1980	1985	1980	1985
Dry Bulk	17,500	17.4	18,000 (19,000)*	18,500 (20,000)*	18.0	18.2
Tanker	25,000	17.4	30,000	35,000	18.0	18.2
Break Bulk	12,500	19.72	14,000	15,000	20.7	20.9

*Metallic Ores are assumed to grow faster in size.

TABLE 4-65

COASTAL SHIP BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1980)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	228046	207	798
METALIC ORES	157344	211	23553
COAL & COKE	65492	228	1389
PETROLEUM	230198	163	57933
NONMET MINERAL	96823	221	3375
FOOD PRODUCTS	632176	310	3939
TEXTILES	655367	309	166
LUMBER & FURN	323436	204	921
PULP & PAPER	280260	324	470
CHEMICALS	659981	309	11429
RUBBER&PLASTIC	523668	312	81
STONE & GLASS	80042	227	253
PRIMARY METAL	558548	311	1830
FABRIC. METAL	546184	311	535
NON-ELEC MACH.	573847	311	256
ELECTRIC MACH.	621643	310	136
TRANSPORT EQUI	364758	318	378
INSTRUMENTS	471235	314	295
SCRAP	132977	214	40
AVERAGE/TOTAL	251755	224	107,768

TABLE 4-66

COASTAL BARGE BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1980)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	345734	314	741
METALIC ORES	0	0	0
COAL & COKE	101308	353	1759
PETROLEUM	307146	217	10540
NONMET MINERAL	146300	335	7650
FOOD PRODUCTS	627771	307	205
TEXTILES	651020	307	1
LUMBER & FURN	490707	310	599
PULP & PAPER	274984	317	14
CHEMICALS	655645	307	1402
RUBBER&PLASTIC	518994	309	1
STONE & GLASS	120797	343	982
PRIMARY METAL	553960	308	371
FABRIC. METAL	541566	309	164
NON-ELEC MACH.	569298	308	71
ELECTRIC MACH.	617212	308	11
TRANSPORT EQUI	359691	313	60
INSTRUMENTS	0	0	0
SCRAP	201248	324	65
AVERAGE/TOTAL	206046	270	24644

TABLE 4-67

COASTAL SHIP BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	228209	207	[illegible]
METALIC ORES	157111	211	29667
COAL & COKE	55405	223	1544
PETROLEUM	217283	153	65237
NONMET MINERAL	96249	220	4183
FOOD PRODUCTS	607498	297	4247
TEXTILES	631073	297	188
LUMBER & FURN	324147	204	1043
PULP & PAPER	268576	310	595
CHEMICALS	634239	297	13642
RUBBER&PLASTIC	505476	299	94
STONE & GLASS	79365	225	288
PRIMARY METAL	536555	299	2131
FABRIC. METAL	524723	299	530
NON-ELEC MACH.	551794	298	302
ELECTRIC MACH.	597114	298	160
TRANSPORT EQUI	349802	305	413
INSTRUMENTS	451655	301	340
SCRAP	132790	214	[illegible]
AVERAGE/TOTAL	248585	222	125713

TABLE 4-68

COASTAL BARGE BTU CONSUMPTION
(INDUSTRY CHANGE SCENARIO: 1985)

COMMODITY	BTUS PER TON	BTUS PER TON-MILE	TOTAL BTUS 10**9
AGRICULTURE	344226	312	824
METALIC ORES	0	0	0
COAL & COKE	99787	348	1928
PETROLEUM	305881	216	12,523
NONMET MINERAL	144783	331	9440
FOOD PRODUCTS	626274	307	230
TEXTILES	650816	306	1
LUMBER & FURN	489226	309	675
PULP & PAPER	273472	316	17
CHEMICALS	654111	306	1738
RUBBER&PLASTIC	520074	308	2
STONE & GLASS	119264	339	1115
PRIMARY METAL	552426	308	449
FABRIC. METAL	540110	308	191
NON-ELEC MACH.	568289	307	87
ELECTRIC MACH.	615466	307	14
TRANSPORT EQUI	358024	312	68
INSTRUMENTS	0	0	0
SCRAP	187591	324	75
AVERAGE/TOTAL	204583	268	29385

more affected by the change in speed than the other changes. Table 4-64 outlines the scenario assumptions by ship type. Ship types are matched with commodities in Appendix D. The slight improvements in coastal barge energy intensiveness is due entirely to the drop in port time. Tables 4-65 and 4-66 give the industry change figures for 1980 and Tables 4-67 and 4-68 give the corresponding figures for 1985.

4.2.9 Pipeline

For the pipeline portion of the analysis, two sets of future year scenarios were developed: one for the base case and one for industry-change assumptions. For the industry-change scenarios, the distribution of barrel-miles by pipeline size was assumed to shift toward larger pipelines. Specifically, 50 percent of the additional barrel-miles from 1972 was allocated to pipelines of 26 inches and greater, with the remaining 50 percent allocated to the smaller pipelines. The Alaska Pipeline was accounted for in crude line changes, resulting in a somewhat larger shift than product lines. As a result of this assumption, capacity was shifted toward larger pipelines, with a average reduction in energy intensiveness. Table 4-69 gives the changes in the distribution of capacity.

The results of the scenario projections are shown in Tables 4-70 and 4-71 for traffic and energy consumption data, respectively.

4.2.10 Air Cargo

Two sets of scenarios were run for air-cargo movements: one for the base case and one for industry change. Government influence over air cargo movements up to 1985 was considered minimal, except for possible regulatory impacts on air cargo pricing and intermodal coordination. Therefore, no government scenario was run.

Tables 4-72 and 4-73 show the base-case projections for 1980 and 1985. Ton-miles are projected to increase by 53.8 percent by 1980 from the 1972 level and by 79.8 percent by 1985. The scenario estimates also include continuation of the current trend toward greater movement of air cargo in passenger/cargo aircraft with a 2 percent shift to passenger/cargo aircraft by 1980 and a 4 percent shift by 1985. Accordingly, average length of haul has been adjusted to account for this shift. As a result, the base-case scenarios show a 48.2 percent increase in energy consumed for air cargo movements by 1980 if the marginal approach to cargo energy consumption is used,

TABLE 4-69

DISTRIBUTION OF BARREL-MILE CAPACITY BY PIPELINE SIZE CATEGORY*

PIPE SIZE	CRUDE		PRODUCTS	
	1972	1980/5	1972	1980/5
2-24"	75%	63%	74%	66%
26-48"	25%	37%	26%	34%

Source: Calculated based on scenario assumptions.

* Regulated Pipelines only.

TABLE 4-70

REGULATED PIPELINE TRAFFIC 1980, 1985

PRODUCT DESCRIPTION	1980		1985	
	Tons (Thousands)	Ton-Miles (Millions)	Tons (Thousands)	Ton-Miles (Millions)
CRUDE	701,793	296,157	834,952	352,350
PRODUCTS	559,141	225,334	665,230	268,088
TOTAL	1,260,934	521,491	1,500,182	620,438

TABLE 4-71

REGULATED PIPELINE ENERGY CONSUMPTION

Year: Scenario	Total BTU's 10^9	BTU's/Ton	BTU's/Ton-Mile
1980: Base Case			
Crude Oil	61,305	87,354	207
Products	85,402	152,737	379
Total	146,707	116,334	281
1980: Industry Change			
Crude Oil	58,343	83,134	197
Products	79,994	143,065	355
Total	138,337	109,710	265
1985: Base Case			
Crude Oil	72,936	87,354	207
Products	101,605	152,737	379
Total	174,543	116,334	289
1985: Industry Change			
Crude Oil	69,413	83,134	197
Products	95,171	143,065	355
Total	164,584	109,710	265

TABLE 4-72

AIR CARGO TRAFFIC AND ENERGY CONSUMPTION MEASURES

BASE CASE SCENARIO: 1980

COMMODITY	NET TONS
1. Agriculture	200,000
2. Metallic Ores	0
3. Coal and Coke	0
4. Petroleum	0
5. Non-Metallic Minerals	0
6. Food & Kindred Prod.	35,000
7. Textiles, Apparel & Leather	142,000
8. Lumber & Furniture	23,000
9. Pulp, Paper & Allied	50,000
10. Chemicals & Allied	239,000
11. Rubber & Plastics	171,000
12. Stone, Clay & Glass	33,000
13. Primary Metal	100,000
14. Fabricated Metal Prod.	206,000
15. Machinery ex. Elec.	350,000
16. Electrical Machinery	656,000
17. Transportation Equip.	223,000
18. Instruments & Misc. Mfg.	125,000
19. Waste & Scrap	0
20. Other	1,289,000
TOTAL	3,842,000

TYPE OF AIRCRAFT	NET TONS	NET TON-MILES 10**3
Cargo	998,920	1,129,779
Passenger/Cargo	2,843,080	1,194,094
TOTAL	3,842,000	2,323,873

AIR ENERGY CONSUMPTION MEASURES
1980

	FUEL USE BASED ON:	
MEASURES	INCREMENTAL ENERGY (1)	SHARED ENERGY (1)
BTUs $(x10^9)$		
Cargo	27,477	27,477
Passenger	4,284	67,228
TOTAL	31,761	94,705
CARGO AND PASSENGER PLANE WEIGHTED AVERAGE:		
BTUs per Ton $(x10^3)$	8,267	24,650
BTUs per Ton Mile	13,667	40,753

(1) Incremental assumes only energy related to extra weight. Shared energy implies that BTUs are split between passenger and freight on basis of weight.

TABLE 4-73

AIR CARGO TRAFFIC AND ENERGY CONSUMPTION MEASURES

BASE CASE SCENARIO: 1985

	COMMODITY	NET TONS
1.	Agriculture	223,000
2.	Metallic Ores	0
3.	Coal and Coke	0
4.	Petroleum	0
5.	Non-Metallic Minerals	0
6.	Food & Kindred Prod.	39,000
7.	Textiles, Apparel & Leather	162,000
8.	Lumber & Furniture	25,000
9.	Pulp, Paper & Allied	62,000
10.	Chemicals & Allied	298,000
11.	Rubber & Plastics	206,000
12.	Stone, Clay & Glass	39,000
13.	Primary Metal	121,000
14.	Fabricated Metal Prod.	242,000
15.	Machinery ex. Elec.	429,000
16.	Electrical Machinery	802,000
17.	Transportation Equip.	254,000
18.	Instruments & Misc. Mfg.	154,000
19.	Waste & Scrap	0
20.	Other	1,543,000
	TOTAL	4,599,000

TYPE OF AIRCRAFT	NET TONS	NET TON-MILES 10**3
Cargo	1,104,000	1,248,624
Passenger/Cargo	3,495,000	1,467,900
TOTAL	4,599,000	2,716,524

AIR ENERGY CONSUMPTION MEASURES 1985

MEASURES	FUEL USE BASED ON: INCREMENTAL ENERGY (1)	SHARED ENERGY (1)
BTUs ($x10^9$)		
Cargo	30,368	30,368
Passenger	5,267	82,643
TOTAL	35,635	113,011
CARGO AND PASSENGER PLANE WEIGHTED AVERAGE:		
BTUs per Ton ($x10^3$)	7,748	24,573
BTUs per Ton Mile	13,118	41,601

(1) Incremental assumes only energy related to extra weight. Shared energy implies that BTUs are split between passenger and freight on basis of weight.

TABLE 4-74

IMPACTS OF ENERGY CONSERVATION MEASURES ON AIR CARGO MOVEMENTS

ENERGY CONSERVATION CHANGES	WHICH IMPUT VARIABLES ARE IMPACTED	HOW CHANGES COULD BE ACCOMPLISHED		ENERGY SAVING SCENARIO ESTIMATES	
		INDUSTRY	GOVERNMENT	1980	1985
Heavier Loads	All Cargo BTU/Ton-Mile	Encourage Heavier Loads	Allow Intermodal Coordination	1%	2%
Reduced Speeds	BTU/Ton-Mile	Decrease Speed		1%	2%
Increased Altitude	BTU/Ton-Mile	Increase Altitude		.5%	1%

TABLE 4-75

AIR CARGO TRAFFIC AND ENERGY CONSUMPTION MEASURES

INDUSTRY CHANGE SCENARIO: 1980

COMMODITY	NET TONS
1. Agriculture	200,000
2. Metallic Ores	0
3. Coal and Coke	0
4. Petroleum	0
5. Non-Metallic Minerals	0
6. Food & Kindred Prod.	35,000
7. Textiles, Apparel & Leather	142,000
8. Lumber & Furniture	23,000
9. Pulp, Paper & Allied	50,000
10. Chemicals & Allied	239,000
11. Rubber & Plastics	171,000
12. Stone, Clay & Glass	33,000
13. Primary Metal	100,000
14. Fabricated Metal Prod.	206,000
15. Machinery ex. Elec.	350,000
16. Electrical Machinery	656,000
17. Transportation Equip.	223,000
18. Instruments & Misc. Mfg.	125,000
19. Waste & Scrap	0
20. Other	1,289,000
TOTAL	3,842,000

TYPE OF AIRCRAFT	NET TONS	NET TON-MILES 10**3
Cargo	998,920	1,192,779
Passenger/Cargo	2,843,080	1,194,094
TOTAL	3,842,000	2,323,873

AIR ENERGY CONSUMPTION MEASURES
1980 - INDUSTRY CHANGE SCENARIO

MEASURES	FUEL USE BASED ON: INCREMENTAL ENERGY (1)	SHARED ENERGY (1)
BTUs ($x10^9$)		
Cargo	26,794	26,794
Passenger	4,219	66,225
TOTAL	31,013	93,019
CARGO AND PASSENGER PLANE WEIGHTED:		
BTUs per Ton ($x10^3$)	8,072	24,211
BTUs per Ton Mile	13,345	40,028

(1) Incremental assumes only energy related to extra weight. Shared energy implies that BTUs are split between passenger and freight on basis of weight.

TABLE 4-76

AIR CARGO TRAFFIC AND ENERGY CONSUMPTION MEASURES

INDUSTRY CHANGE SCENARIO: 1985

	COMMODITY	NET TONS
1.	Agriculture	223,000
2.	Metallic Ores	0
3.	Coal and Coke	0
4.	Petroleum	0
5.	Non-Metallic Minerals	0
6.	Food & Kindred Prod.	39,000
7.	Textiles, Apparel & Leather	162,000
8.	Lumber & Furniture	25,000
9.	Pulp, Paper & Allied	62,000
10.	Chemicals & Allied	298,000
11.	Rubber & Plastics	206,000
12.	Stone, Clay & Glass	39,000
13.	Primary Metal	121,000
14.	Fabricated Metal Prod.	242,000
15.	Machinery ex. Elec.	429,000
16.	Electrical Machinery	802,000
17.	Transportation Equip.	254,000
18.	Instruments & Misc. Mfg.	154,000
19.	Waste & Scrap	0
20.	Other	1,543,000
	TOTAL	4,599,000

TYPE OF AIRCRAFT	NET TONS	NET TON-MILES 10**3
Cargo	1,104,000	1,248,624
Passenger/Cargo	3,495,000	1,467,900
TOTAL	4,599,000	2,716,524

AIR ENERGY CONSUMPTION MEASURES
1985 - INDUSTRY CHANGE SCENARIO

MEASURES	FUEL USE BASED ON: INCREMENTAL ENERGY (1)	SHARED ENERGY (1)
BTUs ($x10^9$)		
Cargo	28,870	28,870
Passenger	5,109	80,180
TOTAL	33,979	109,050
CARGO AND PASSENGER PLANE WEIGHTED:		
BTUs per Ton ($x10^3$)	7,388	23,712
BTUs per Ton Mile	12,508	40,143

(1) Incremental assumes only energy related to extra weight. Shared energy implies that BTUs are split between passenger and freight on basis of weight.

and a 56.9 percent increase if the average approach is adopted. For 1985, energy consumption is estimated to increase by 66.2 percent based on the marginal approach and by 87.2 percent based on the average approach.

Table 4-74 shows the operating changes which could result in energy conservation in air cargo movements and estimates the impact from implementing each of them. Tables 4-75 and 4-76 show the scenario results of the combined impacts of implementing these measures. For 1980, a decrease in energy intensity of 2.4 percent is projected based on the marginal approach to energy consumption, while a decrease of 1.8 percent is projected based on the average approach. For 1985, a decrease in energy intensity of 4.7 percent is projected based on the marginal approach, while a 3.5 percent decrease is projected based on the average approach.

4.3 ECONOMIC IMPACTS

Most of this study relates to the impacts of operational and technological change upon energy intensity and consumption by various transportation modes. Accompanying these changes are potential economic impacts--impacts which may accelerate or hinder adoption of energy conservation, and impacts which may be accelerated or retarded by government influence. Though the scope of study did not permit a detailed determination of economic impacts, the following subsection illustrates possible economic effects in the motor carrier and railroad industries.

4.3.1 Operational Changes

The economic implications of energy conservation alternatives are quite complex, and the lack of data seriously hinders the ability to estimate industry impacts. In general, the operational changes which save energy are almost always accompanied by other direct reductions in incremental cost--usually labor. In the case of motor carriers, the reduced labor costs would be attributable to either fewer truck-miles or the heavier loading of trucks (which reduces truck-miles for a given volume of freight). For large trucks (70,000-lbs. GVW), these incremental savings will vary from approximately $.30 to $.35 per trailer for each mile not operated (both loaded and empty). For lighter (smaller) trucks, savings are not correspondingly less, since labor costs (about 75-85 percent of incremental costs) are not materially less for smaller vehicles. Most non-self-employed intercity truckers are paid on a mileage rate basis. Current national teamster driver rates are about $.18 per mile, plus approximately 35 percent for fringe benefits.

On a long-term basis, operational changes that promote energy conservation also tend to promote greater equipment productivity (in terms of shipments handled) and capacity utilization and, hence, the need for fewer vehicles. In these cases, fully allocated operational costs (which include vehicle ownership costs, taxes, insurance, etc.) may be considered a proper basis for savings. These savings are approximately $.35 per truck-mile for smaller vehicles and up to $.75 per truck-mile for expensive rigs (such as refrigerated trucks), which average 70,000 miles per year or less.

Capital investments apart from technology are rarely tied to motor carrier operating changes that promote fuel conservation. Thus, operational savings in the motor carrier industry can be reasonably estimated based on vehicle mileage avoided to carry a given volume (i.e., ton-miles).

Operational savings may be realized by motor carriers by:

substitution of TOFC for line haul;

greater capacity utilization (at the expense of service in some instances);

pooling of freight, pricing incentives, reciprocal agreement, relaxation of regulatory restrictions, etc., to reduce empty backhauls;

higher weight limits;

reductions in circuity (for which significant regulatory relaxation has already occurred);

centralized terminals and pooled LTL pick up and delivery; and

reduced engine idling between trips (now a relatively common practice).

The perceived economics of rail-TOFC service to motor carriers are essentially minimal. Plan I rates (i.e., railroad performs line-haul service at a negotiated fee) are often not materially different from the costs saved by a motor carrier which uses the substitute service. Rail

TOFC service also entails some loss of control, frequently poorer service, and extra terminal costs.

Adjustments were made to the 1972 base data for the operational improvements made by motor carriers in reaction to the fuel shortages of 1973. Many of these changes have continued since the passage of the crisis. Therefore no new assumptions regarding operational changes were made, since PMM&Co. could not establish a likely basis for such change. Since operational changes usually have greater economic benefits (or consequences) than just fuel use savings (or increases), and these changes can significantly affect service, the conservative approach was to assume no new significant operational change from 1973-1974 methods.

In this study, PMM&Co. has prepared basic data to estimate operating economic (and energy) impacts. These data can be used to estimate economic impacts of significant operational changes in the motor carrier industry not anticipated by PMM&Co. (such as major regulatory change to allow greater flexibilities to reduce empty or lightly loaded backhauls).

Table 4-77 summarizes vehicle mileages for the 1972 base case and for each of the 1980 and 1985 scenarios. These vehicle-miles were estimated by dividing ton-miles for each commodity by each truck type by the product of truck commodity capacity (in tons), capacity utilization, and the estimated proportion of that truck type assigned to the commodity. The number of vehicles was estimated by dividing the total vehicle-miles by the average annual miles per vehicle, according to the following schedule:

Truck Types	Gross Vehicle Weight (in 1,000 lbs.)	Annual Miles[1]
1, 2, 11, 12	10 - 19	24,000
3, 4, 13, 14	19+ - 32	31,100
5, 6, 15, 16, 21, 22	32+ - 50	38,100
7, 8, 17, 18, 23, 24	50+ - 70	45,200
9, 10, 19, 20, 25	70+	52,200

---

[1] Estimated from long-haul and short-haul average annual miles per truck, from <u>1972 Truck Inventory and Use Survey</u>.

TABLE 4-77

TOTAL ANNUAL VEHICLE-MILES AND VEHICLES BY TRUCK TYPE

TRUCK TYPE	VEHICLE WEIGHT AND BODY TYPE (1, 000 lbs., GVW)		D=DIESEL G=GAS	ANNUAL VEHICLE MILES x 10^6							NUMBER OF VEHICLES x 10^3						
				1972	1980			1985			1972	1980			1985		
				BASE CASE	BASE CASE	INDUSTRY CHANGE SCENARIO	GOVERN-MENT CHANGE SCENARIO	BASE CASE	INDUSTRY CHANGE SCENARIO	GOVERN-MENT CHANGE SCENARIO	BASE CASE	BASE CASE	INDUSTRY CHANGE SCENARIO	GOVERN-MENT CHANGE SCENARIO	BASE CASE	INDUSTRY CHANGE SCENARIO	GOVERN-MENT CHANGE SCENARIO
1.	10-19	Box	G	1,500	2,057	1,910	1,836	2,669	1,984	1,791	62	86	79	76	111	83	74
2.	10-19	Box	D	888	1,271	1,174	1,127	1,476	1,236	1,116	37	53	49	47	61	51	46
3.	19-32	Box	G	1,528	2,095	1,274	1,511	2,412	1,035	1,228	49	67	41	49	78	33	40
4.	19-32	Box	D	421	590	1,229	900	681	1,604	1,180	14	19	40	29	22	52	38
5.	32-50	Box	G	685	981	272	439	1,138	191	257	18	26	7	12	30	5	7
6.	32-50	Box	D	1,211	1,691	2,204	1,942	1,965	2,414	2,094	32	44	58	51	52	63	55
7.	50-70	Box	G	449	641	0	56	744	0	0	10	14	--	1	16	--	--
8.	50-70	Box	D	4,377	6,415	6,437	6,072	7,494	6,718	5,953	97	142	142	134	166	149	132
9.	70	Box	D	9,983	14,309	12,866	8,939	16,646	13,416	6,297	191	274	25	171	319	257	121
10.	70	Twin Box	D	0	0	340	3,216	0	352	5,202	--	--	7	62	--	6	100
11.	10-19	Irregular	G	704	1,052	986	951	1,231	1,065	966	29	44	41	40	51	44	40
12.	10-19	Irregular	D	601	902	844	814	1,059	915	644	25	38	35	34	44	38	35
13.	19-32	Irregular	G	1,223	1,815	1,108	1,315	2,095	909	1,086	39	58	36	42	67	29	35
14.	19-32	Irregular	D	366	550	1,105	820	644	1,451	1,085	12	18	36	26	21	47	35
15.	32-50	Irregular	G	704	1,074	298	473	1,263	212	282	18	28	8	12	33	6	7
16.	32-50	Irregular	D	563	840	1,484	1,235	987	1,680	1,431	15	22	39	32	26	44	38
17.	50-70	Irregular	G	422	629	0	55	730	0	0	9	14	--	1	16	--	--
18.	50-70	Irregular	D	2,303	3,502	3,839	3,634	4,080	4,088	3,727	51	78	85	80	90	90	83
19.	70	Irregular	D	5,445	8,084	7,536	5,495	9,437	8,356	4,487	10	155	144	105	181	160	86
20.	70	Twin Irr.	D	0	0	188	1,819	0	206	3,241	--	--	4	35	--	4	62
21.	32-50	Tank	G	238	344	101	169	399	77	114	6	9	3	4	10	2	3
22.	32-50	Tank	D	381	544	775	705	643	941	891	10	14	20	18	17	25	23
23.	50-70	Tank	G	112	162	0	16	193	0	0	2	4	--	--	4	--	--
24.	50-70	Tank	D	516	774	916	887	925	1,064	1,037	11	17	20	20	20	24	23
25.	70	Tank	D	2,356	4,311	4,180	4,095	5,189	4,864	6,140	45	83	80	78	99	93	118
TOTAL				36,976	54,633	51,066	48,521	64,100	54,768	50,446	792	1,307	999	1,159	1,534	1,305	1,201

TABLE 4-78

APPROXIMATE 1976 OPERATING COSTS PER VEHICLE MILE BY TRUCK SIZE

TRUCK WEIGHT (In 1,000 lbs. -GVW)	INCREMENTAL COST PER VEHICLE MILE (1) (Cents)	LONG-TERM VARIABLE COST PER VEHICLE MILE (2) (Cents)	GALLONS PER MILE	
			GASOLINE EMPTY-LOADED	DIESEL EMPTY-LOADED
10-19	26-30	33-38	.09-.19	.07-.15
19-32	27-32	34-40	.10-.22	.08-.18
32-50	28-33	35-41	.12-.23	.09-.18
50-70	30-37	38-46	.13-.23	.10-.19
70	31-38	39-48	- -	.12-.21
70 (Twin)	32-40	40-50	- -	.12-.22

Average miles for newer vehicles are generally 1.5 to 3 more than for all vehicles. Diesel trucks typically operate over 60,000 miles per year and gasoline vehicles typically under 50,000 (with a mixture of gasoline/diesel vehicles in between the two mileage figures). Average annual-miles per vehicle may be expected to increase slightly in the future as vehicles become even more expensive to run. Table 4-78 summarizes estimated incremental and long-term variable operating costs per vehicle-mile. These costs may be multiplied by the estimates of miles saved by each truck type under assumed mileage reductions achieved through operational savings. Fuel savings are shown separately in terms of gallons per mile using 1972 base-case estimates without benefits of technological improvements (which would reduce gallons per mile).

Table 4-79 illustrates the operating economics of a 10 percent mileage savings for all truck types. This table was developed using diesel vehicle costs estimated at 10 percent of the range difference below the median of the cost range summarized in Table IV-80, gasoline vehicle costs at 10 percent of the range difference above the median, gasoline at $.60 per gallon, diesel fuel at $.55 per gallon, and median fuel consumption rates.

Railroad economic operating impacts are even more difficult to evaluate. Potential operational savings range from as little as the cost of fuel saved to as high as $10 per train-mile. Since estimates are, at best, somewhat arbitrary, savings are assumed to be equal to reductions in car-miles times ICC 1972 variable car-mile costs,[1] times a 1.57 index (estimated from an extension of AAR's wage-price indices trends)[2] to convert to 1976 dollars. Estimated operating savings for the 1980 industry-change scenario are shown in Table 4-80.

Contrary to motor carriers, operating changes which involve changes in right-of-way can result in substantial, direct capital investments which can rarely be justified on the basis of fuel savings alone.

The economic impacts of operational changes among the other modes (water, pipelines, and air) are small relative to truck and rail and were not included in this study.

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[1] "1972 Carload Mileage Costs Scales" Statement 1C1 published by the Interstate Commerce Commission, Region V-Western Region.

[2] Indexes of Railroad Material Prices and Wage Rates, Series QMPW-91 (May 5, 1976). Association of American Railroads, Economics and Finance Department, Washington, D.C. 20036.

TABLE 4-79

ILLUSTRATION OF OPERATING SAVINGS WITH TEN PERCENT REDUCTION IN VEHICLE MILEAGE (1)

INDUSTRY CHANGE SCENARIO: 1980					TOTAL SAVINGS @10% OF SCENARIO MILEAGE ($ Millions)	
TRUCK WEIGHT (In 1,000 lbs.-GVW)	TOTAL SCENARIO MILES (x 10^6)	TYPE OF FUEL	INCREMENTAL PER-MILE SAVINGS, INCL. FUEL (1976 Cents)	LONG-TERM VARIABLE PER-MILE SAVINGS, INCL. FUEL (1976 Cents)	INCREMENTAL	LONG-TERM VARIABLE
10-19	2,896	G	36.8	44.4	107	129
10-19	2,018	D	33.7	41.1	68	83
19-32	2,382	G	39.6	47.2	94	112
19-32	2,334	D	36.2	43.6	84	102
32-50	671	G	41.5	49.2	28	33
32-50	4,463	D	37.4	44.8	167	200
50-70	0	G	45.0	53.6	0	0
50-70	11,192	D	40.8	49.2	457	551
70	24,582	D	42.9	51.7	1,055	1,271
70 (Twin)	528	D	44.6	53.4	24	28
TOTAL	51,066		40.8	49.1	2,084	2,509

(1) Assumptions:

- 1972 base case miles per gallon (without technological change to improve mpg's, which would reduce total savings estimated);
- gasoline vehicle costs estimated at 10 percent of the range difference above the median of the cost ranges shown in Table IV-79, diesel vehicles estimated at 10 percent below; and
- gasoline at 60¢/gallon; diesel fuel at 55¢/gallon.

TABLE 4-80

RAIL OPERATING SAVINGS THROUGH REDUCTIONS IN CAR MILES (1975 Dollars)

CAR TYPE	SCENARIO CAR MILES WITHOUT SAVINGS (1) (x 10^6)	SCENARIO CAR MILES WITH SAVINGS (2) (x 10^6)	CAR MILES "SAVED" (x 10^6)	APPROXIMATE VARIABLE CENTS/CAR-MILE	APPROXIMATE VARIABLE COSTS ANNUAL SAVINGS (x 10^6)
Boxcar	15,182	13,573	1,609	44	708
Covered Hopper Car	5,645	5,046	599	49	294
Flat Car	4,183	3,740	443	55	244
Condola	2,180	1,949	231	46	106
Open Hopper	5,857	5,236	621	47	292
Tank Car	3,004	2,686	318	72	229
Miscellaneous	4,124	3,687	437	71	310
	40,175	35,917	4,258	51	2,183

(1) 1980 net ton-miles divided by 1972 average tons per car, multiplied by the sum of 1 plus the empty return ratio.

(2) Assumptions:
- 1% increase in load per car;
- 5% reduction in empty backhaul; and
- 5% reduction in circuity.

Compound improvements = 10.6% reduction in car miles.

4.3.2 Technological Changes

Table 4-81 summarizes the technological improvements and approximate costs applicable to a 72,000-lb. GVW, conventional box trailer and tractor combination. Costs are in 1976 dollars and relate to vehicles in the different "conservation classes" used in this study. To achieve an 8 percent improvement for a new truck (which also has a derated engine compared to its 6 percent retrofit counterpart) will cost $300. To gain a full 30 percent improvement in fuel consumption costs about $3,900.

To examine the behavior of costs relative to technological improvements for new vehicles, Figure 4-2 was constructed from the cost estimates shown in Table 4-81. (The index was approximated by dividing $300 by 8 percent, or 1 index point is equal to $37.50). Although a "good fit" was not observed, the general shape of the technological cost/benefit curve for trucks (at least in the higher-weight category for box-type vehicles) is approximately as shown. The curve shows, not unexpectedly, that the costs of technological improvements increase exponentially with linear increases in energy savings.

Table 4-82 estimates the technological costs for all vehicle types by conservation class, estimated from the base developed for a 72,000-lb. GVW vehicle. The last column estimates the additional cost to purchase a diesel-powered truck over the cost of a gasoline-powered truck. For truck types 10 and 20, an additional cost of $5,000 is estimated as the increased cost for twin, 27-foot trailers over a single trailer.

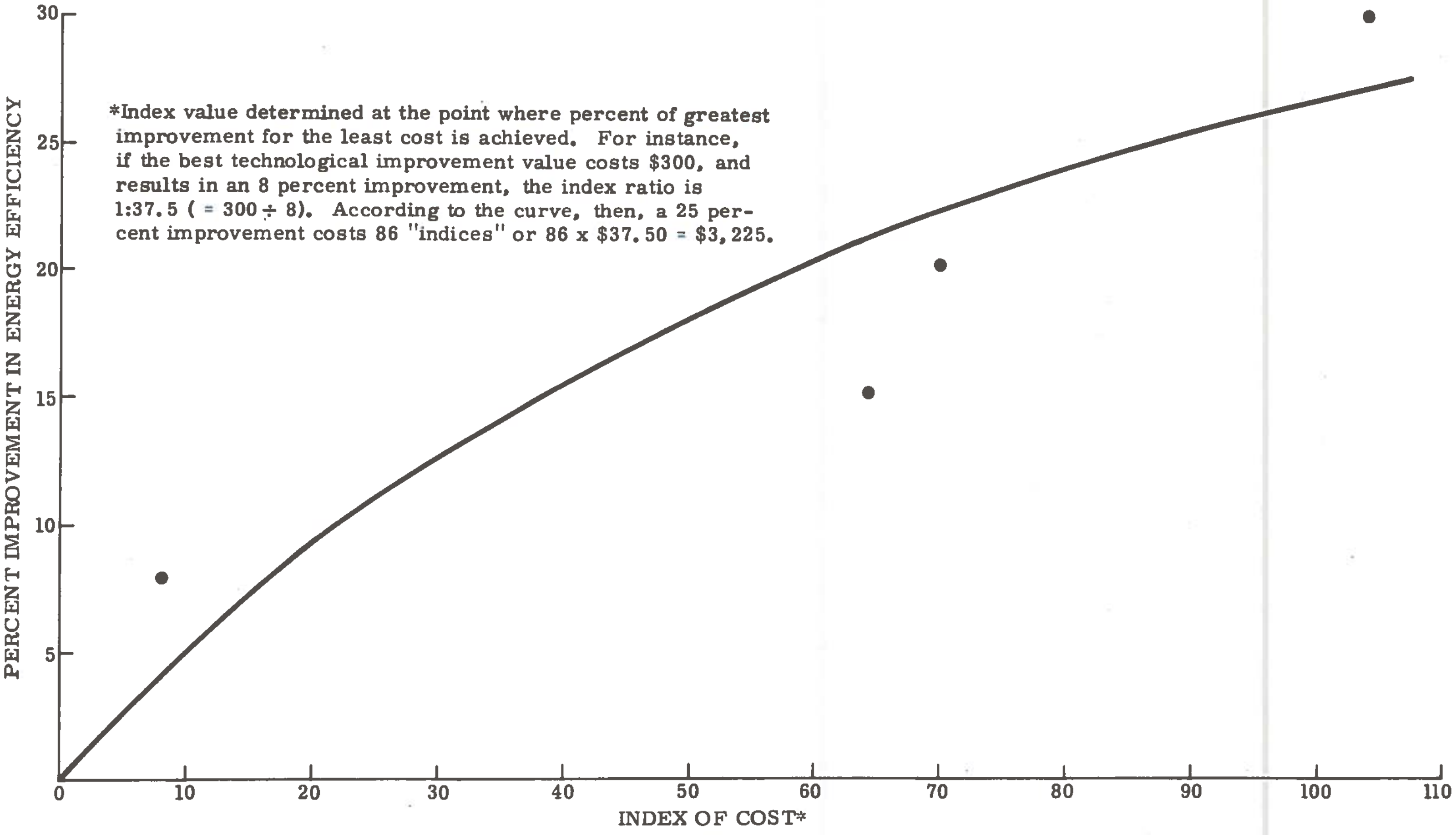
The economic impact on the truck industry cannot be determined without a better understanding of the energy savings which technology generates. The marginal point of diminishing returns for the industry is dependent on the opportunity cost, the life of technology improvements, percent energy savings, energy cost per service unit, and the number of service units operated. The order in which technology improvements are applied also affects their relative cost/benefit. For instance, a thermostatic clutch is not as cost-effective when it is the last technology device to be applied, since the absolute energy savings are less than if it is the first technology device to be applied. The logical order of procession for technology application is determined by the cost per percent of improvement in energy efficiency. When successive applications of technology packages result in a decline in cost-benefit below perceived opportunity costs, the marginal goal of industry motivation has been reached. The same is true in any industry.

TABLE 4-81

INCREMENTAL COSTS OF TRUCK TECHNOLOGICAL IMPROVEMENTS TO CONSERVE ENERGY

(1976 Dollars, 72,000 lb. GVW Tractor/Trailer)

	PERCENT MPG IMPROVEMENT OVER 1972 BASE VEHICLE				
	6% (Retrofitted)	8% (New)	15% (New & Retrofit)	20% (New)	30% (New)
Thermostatic Fan	$300	$300	$300	$300	$300
Engine Derating		0	0	0	0
Cab Spoiler			500	500	
Trailer Modifications				200	
Radial Tires			1,600	1,600	1,600
Complete Streamlining					2,000
TOTAL	$300	$300	$2,400	$2,600	$3,900



*Index value determined at the point where percent of greatest improvement for the least cost is achieved. For instance, if the best technological improvement value costs $300, and results in an 8 percent improvement, the index ratio is 1:37.5 (= 300 ÷ 8). According to the curve, then, a 25 percent improvement costs 86 "indices" or 86 x $37.50 = $3,225.

FIGURE 4-2: INDEX OF TECHNOLOGICAL COST FOR TRUCK ENERGY CONSERVATION

TABLE 4-82

ESTIMATE OF PER VEHICLE COSTS FOR TRUCK TECHNOLOGY IMPROVEMENTS FOR MAJOR IMPROVEMENT CATEGORIES

(1976 $)

TRUCK TYPE	VEHICLE WEIGHT AND BODY TYPE (In 1,000 lbs. -GVW)		TYPE OF FUEL	PERCENT MPG IMPROVEMENT OVER 1972 BASE VEHICLES				INCREMENTAL COST FOR DIESEL ENGINE
				6/8	15	20	30	
1.	10-19	Box	G	200	1,100	1,300	1,700	
2.	10-19	Box	D	200	1,100	1,300	1,700	$4,000
3.	19-32	Box	G	200	1,100	1,300	1,700	
4.	19-32	Box	D	200	1,000	1,300	1,700	$5,000
5.	32-50	Box	G	300	1,500	1,700	3,200	
6.	32-50	Box	D	300	1,500	1,700	3,200	$9,000
7.	50-70	Box	G	300	1,500	1,700	3,200	
8.	50-70	Box	D	300	1,500	1,700	3,200	$11,000
9.	70	Box	D	300	2,400	2,600	3,900	
10.	10-19	Twin Box	D	300	2,400	2,600	3,900	$5,000*
11.	10-19	Irregular	G	200	700	800	800	
12.	10-19	Irregular	D	200	700	800	800	$4,000
13.	19-32	Irregular	G	200	700	800	800	
14.	19-32	Irregular	D	200	700	800	800	$5,000
15.	32-50	Irregular	G	300	1,000	1,000	1,200	
16.	32-50	Irregular	D	300	1,000	1,000	1,200	$19,000
17.	50-70	Irregular	G	300	1,000	1,000	1,200	
18.	50-70	Irregular	D	300	1,000	1,000	1,200	$11,000
19.	70	Irregular	D	300	1,900	1,900	1,900	
20.	70	Twin Irr.	D	300	1,900	1,900	1,900	$5,000*
21.	32-50	Tank	G	300	1,500	1,700	3,200	
22.	32-50	Tank	D	300	1,500	1,700	3,200	$9,000
23.	50-70	Tank	G	300	1,500	1,700	3,200	
24.	50-70	Tank	D	300	1,500	1,700	3,200	$11,000
25.	70	Tank	D	300	2,400	2,600	3,900	

*Cost increase of twin trailers over single trailers.

For a single truck, a 20 percent before-tax opportunity cost, a 5-mpg pretechnology application energy use rate, a 7-year technology life (no salvage value, zero maintenance cost), and diesel fuel at \$.55 per gallon, the approximate annual miles to break even (that is, point of indifference to other investment opportunity) may be developed using the following formula:[1]

$$VM_1 = \frac{I}{BPC} \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \qquad (4\text{-}1)$$

Where:

VM_1 = Annual break-even miles per vehicle

I = initial "package cost"

B = 1,000 Btus per vehicle-mile (5 miles per gallon = 27.74×10^3 Btu/vehicle-mile)

P = net resultant improvement in energy efficiency (miles per gallon or reduction in Btus per vehicle-mile), expressed as a decimal

C = Cost per 1,000 Btu (\$.55/gal. = \$.004 /1000 Btu for diesel fuel)

i = opportunity rate (20 percent before tax), expressed as a decimal

n = number of years life (7)

Using values from Table 4-82, the following annual miles are estimated for Vehicle Type 9 (72,000-lbs. GVW, box trailer):

Break-Even Annual Miles (VM)	Percent Conservation Class (P)	Incremental Package Capital Cost I
9,500	8	\$300
40,400	15	\$2400
32,800	20	\$2600
32,800	30	\$3900

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[1] Adopted from the present value formula of a stream of equal annual payments, where the initial investment, "I," is equal to the present value of the payment (saving) X, over n years ($= X (1 - (1+i)^{-n})/i$)

However, conversion to diesel is not always attractive. For instance, assume the following simple scenario for a small truck:

n = 7

i = .2

ΔC = .4797¢ - .39656¢ - .08314¢ (the difference in fuel cost per 1,000 Btu, gas versus diesel, at \$.60/gallon and \$.55/gallon and 125,070 Btu/gallon and 138,690 Btu/gallon, respectively)

ΔB - 8.6 mpg for diesel, 7.2 mpg for gasoline or saving of 1.244×10^3 Btu/vehicle-mile

ΔI = \$4,000

Also, since diesel engines reduce maintenance costs, assume an arbitrary savings of an additional \$.01 per vehicle-mile, (M). Thus, formula (IV-1) becomes:

$$VM_1 = \frac{I}{\Delta B \, \Delta C + M} \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \qquad (4\text{-}2)$$

Solving for VM, annual miles is equal to 54,400 miles, or about 220 miles per working day. Many small trucks operate fewer miles than this, suggesting that less expensive technological alternatives to save energy may be economically preferable.

To include both engine substitution and additional technological improvements, equations (IV-1) and (IV-2) can be combined:

$$VM_1 = \frac{I_{\text{diesel}} + I_{\text{other}}}{(\Delta B \, \Delta C + M) + (BPC)} \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \qquad (4\text{-}3)$$

The analyses discussed above could be technically improved by considering nonconstant cash flows and recognizing reductions in annual vehicle-miles as a vehicle gets older. The validity of the data and assumptions used in this study, however, do not justify a more sophisticated analysis.

By influencing the economics of capital investment (such as by tax incentive) or the cost of fuel (fuel tax) or both, the government can influence the attractiveness of adopting energy saving technology by the transportation industry. The sensitivity of focusing on one alternative or the other, and how they vary with different values of the variables, was not examined, and could be a study within itself. Estimating the economic impact of technological change on the motor carrier industry as a whole would require:

number of vehicles in each vehicle class;

vehicle age distribution by each vehicle class;

propagation rate of technological retrofits to each vehicle class;

propagation rates of technological implementation to new vehicles by each class;

annual vehicle turnover rates (scrappage) by each vehicle class;

annual mileage utilization by each vehicle class by age and fuel type; and

rate of fleet additions (versus replacement) by vehicle class.

Although such a study could be performed, PMM&Co. believes the break-even mileage approach per vehicle is simpler. The estimated cost per vehicle (positive or negative) is determined by the difference in actual annual miles versus break-even annual miles:

$$AC = (VM_1 - VM_2)BPCN \qquad (4\text{-}4)$$

where AC = annual vehicle cost

VM_2 = actual vehicle-miles per vehicle

N = number of vehicles

However, using the implementation schedule outlined in Appendix A (see Table A-28) and Table 4-77, the number of vehicles in each efficiency improvement class is estimated as shown in Table 4-83.

To estimate the total cost of improvements, each cell in Table 4-83 can be multiplied by the associated cell expense by truck type and by percent improvement (see Table 4-82).

The cost of converting to diesel must be added to the above improvements. The cost of dieselization is the cost attributable to a shift in the proportion of diesel trucks within a weight and body-type class. Diesel shifts were projected to occur in trucks of 19,000 to 32,000-lbs. GVW, 32,000 to 50,000-lbs. GVW, and 50,000 to 70,000-lbs. GVW. A certain amount of growth in the number of diesel trucks may be expected to handle growth in traffic volume. The increase in diesel trucks to handle this traffic was assumed proportionate to the percentage growth in the number of trucks (gasoline and diesel) within each weight and body-type class. For instance, the growth from 1972 to 1980 (industry-change scenario) for truck types 3 and 4 is 29 percent (as shown in the third column of Table IV-84), while the growth in diesel trucks (truck type 4) in that same weight and body-type class was 185 percent (see second column). Therefore, 156 percent of the growth in diesel trucks represents investment over base-line conditions (diesel trucks which would have otherwise been gasoline trucks). Multiplying 1.56 times the 1972 number of trucks in truck type 4 yields 22,000 diesel trucks attributable to technological change under this scenario. The cost of dieselization in this weight class is $5,000 per truck. Similar analyses can be performed for each scenario and for each weight and body-type class for which there is a shift, and the total cost of dieselization is computed for each scenario.

To obtain the total cost for twin trailers, the number of trucks in truck categories 10 and 20 are multiplied by $5,000 for each scenario. The total cost for each scenario is then equal to the sum of the technological costs, twin-trailer costs, and incremental dieselization costs. These costs are the original purchase price of the above items for each truck in the fleet, irrespective of the age of the trucks.

Table 4-85 summarizes the total net investment as of 1980 under the industry-change scenario.

Assuming a seven-year life and no salvage value, the average annual capital cost at a 20-percent opportunity rate is approximately $515 million (or $265 million at zero-opportunity rate). The Btu savings per ton-mile were estimated to be 7.6 percent in the 1980 industry-change scenario, or 88.1 x 10 Btus (1071/.924 - 1071, from Table 4-8). At a nominal cost of $.004/1,000 Btus (diesel

TABLE 4-83

THOUSANDS OF VEHICLES BY PERCENT IMPROVEMENT OVER 1972 BASE CASE VEHICLES (1980 INDUSTRY CHANGE SCENARIO)

TRUCK TYPE	PERCENT MPG IMPROVEMENT OVER 1972				TOTAL (100% of Fleet)
	6% RETROFIT (40% of Fleet)	8% (25% of Fleet)	15% (22% of Fleet)	20% (13% of Fleet)	
1 - 4	84	52	46	27	209
5 - 8, 21 - 24	100	63	55	33	251
9, 10, 25	133	84	73	43	333
11 - 14	59	37	32	19	147
15 - 18	53	33	29	17	132
19, 20	59	37	33	19	148
	488	305	268	158	1219

TABLE 4-84

CALCULATION OF SHIFT TO DIESEL 1980 BASE CASE TO 1980 INDUSTRY CHANGE SCENARIO*

TRUCK TYPE	% INCREASE IN DIESEL (A) $\frac{(1980 - 1972)}{1972}$	% FLEET INCREASE (B) $\frac{(1980-1972)}{1972}$	1972 BASE CASE DIESEL VEHICLES (C) (1,000)	SCENARIO CHANGE, $\frac{A-BxC}{100}$ (1,000)	UNIT COST PER CONVERSION
3 4	- 185	29	14	22	5,000
5 6	- 81	30	32	16	9,000
7 8	- 46	33	97	13	11,000
13 14	- 200	41	12	19	5,000
15 16	- 160	42	15	18	9,000
17 18	- 67	42	51	13	11,000
21 22	- 100	44	10	6	9,000
23 24	- 82	54	11	3	11,000

*Calculated from Table IV-79.

TABLE 4-85

ESTIMATED TRUCK TECHNOLOGICAL INVESTMENT
1980 INDUSTRY CHANGE SCENARIO
($ Millions)

TRUCK TYPE	PERCENT MPG IMPROVEMENT CATEGORY				DIESEL CONVERSION AND TWIN TRAILER	TOTAL
	6% RETROFIT	8%	15%	20%		
1 - 4	17	10	51	35	110	223
5 - 8, 21 - 24	30	19	83	56	374	562
9, 10, 25	40	25	175	112	35	387
11 - 14	18	11	22	15	95	161
15 - 18	16	10	29	17	305	377
19, 20	18	11	63	36	20	148
	139	86	423	271	939	1858

fuel), the annual energy savings amount to approximately $352 million. Adding maintenance savings of $.01 per mile for diesel vehicles under 50,000-lbs. GVW and $.015/per mile over 50,000-lbs. GVW, adds a minimum of $50 million (calculated from Table 4-84 and miles-per-vehicle in each vehicle class). However, diesel vehicles will receive much higher utilization, so that the cost differences narrow. Thus, for the industry-change scenario, cost benefits approximate a 12 percent return on before-tax capital--a level which the industry can probably accept.

Using the illustration above, other estimates of economic impacts may be calculated by using different assumptions.

The economic principles discussed in this section apply to other modes. In the railroad industry, technological economic impacts are not likely to be as positive as with motor carriers because:

fuel consumption is significantly lower per ton-mile;

fuel is 30 percent less expensive (no federal excise taxes); and

technological improvements save less energy in absolute terms.

Partially offsetting this, however, is the longer life of the improvement (even this benefit begins to lose significance after 15 years, depending on the opportunity rate).

To illustrate the benefit of a technological change in the railroad industry, assume the following technological improvement to a typical boxcar:

I = $1,200 improvement (such as streamlining)

n = 27 years (car life)

i = 20 percent

C = Cost/1,000 Btu ($.35/gal.) = $.0025

B = Average Btu/car-mile = 29,400 (Table II-7 Btus times Table B-2 tons per car), divided by Table II-4 net ton-miles

P = 5 percent reduction in BTU/car-mile

Break-even annual mileage, according to equation (IV-1), will be nearly 66,000 miles per year, or nearly 190 miles per serviceable car day, which is at least three times the average daily car-miles for this type of equipment. Only at a low before-tax opportunity rate of about 2 or 3 percent will break even car-miles be achieved by the average boxcar (about 18,000 miles per year).

As another example, assume a locomotive capable of handling 2,000 trailing (gross-train) tons at an average speed of 55 miles per hour, and the energy required per train mile is 7.0 gallons (441 Btu/gross ton-mile, or 706 Btu per net ton-mile), assuming a fully loaded train (25:80 net-to-tare ratio). If the incremental investment for locomotive streamlining is $25,000 and an 11 percent fuel savings is achieved as a result, the break-even miles using equation (IV-1) and the following inputs:

I = $25,000

n = 25 years life

B = 970,830 Btu/Train-mile

P = 11 percent reduction in BTU/Train-mile

C = .25¢/1,000 Btu

is about 19,000 miles--a fraction of the 100,000 - 150,000 annual miles recorded by modern road locomotives. Thus, in high-speed service, streamlining locomotives can be very attractive. At lower speeds and with heavier trains, savings are diminished.

Because of the many variables of operation, it is not possible to develop railroad industry economic impacts as a result of technological changes to promote energy conservation. In general, they are attractive only where the cost is relatively small in relation to potential energy saved, and then, confined to equipment with high-mileage utilization and high-speed service. The examples illustrate, however, that selective technological opportunities do exist, and to the extent railroad management is aware of them, and initiates action to capitalize on the most promising alternatives (relative to the great need for cash in many other areas), a positive economic and energy impact may result.

To evaluate the potential economic impact to the industry, equation (IV-1) can be solved for the annual capital investment cost, I, if it is assumed that technological improvements result in 30 percent of the Btu savings per net ton-mile developed in the 1980 industry scenario, as compared to the 1980 base case. The modified equation becomes:

$$\text{Btus saved x cost/Btu} = \text{Annual Capital Cost x} \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad (4\text{-}5)$$

where:

Btus saved = (.3 x (684-607) Btu/ton-mile) x 1101.34 x 10^9 ton-miles

(calculated from data in Tables IV-20, IV-28, IV-32)

Cost/Btu = $.0025/1,000 Btu

n = 25 years

i = 20 percent

Solving for annual capital cost, the industry can spend approximately $315 million per year in capital costs for technological improvements in 1980 (1976 dollars) at a 20 percent opportunity rate, if such technological improvements reduce energy intensity by 3.4 percent, relative to estimated 1980 base-case energy use. While perhaps feasible, the railroad industry can probably achieve relatively better savings at a lower cost by instituting operating changes, particularly those which reduce empty car-miles.

As with operating changes, no economic impacts of technological changes were estimated for other modes.

5. CONCLUSIONS

An immediate conclusion of this study is that, in spite of the national preoccupation with collecting statistics on every facet of the economy, data on energy use (at least in freight transportation) is a major void. The availability of only gross or macroenergy statistics in freight transportation is indicative of the pre-1973 concern for a national freight transportation data base and its use in policy-making. Since 1973, national interest in energy conservation has assumed a high priority, witnessed by the creation of federal agencies and departments whose purposes are to focus on energy conservation opportunities in various economic sectors. Based on this study and other PMM&Co. energy studies (as well as our review of energy studies conducted by many others), we believe that national goals in freight transportation energy conservation could be accelerated by developing an improved data base to evaluate energy consumption tradeoffs and, more importantly, to predict the impacts of policy implementation to conserve energy.

This study has attempted to probe deeper into energy consumption characteristics by transportation mode, by commodity, and even by certain vehicle types than any previous published study. To a large degree, this study represents the plowing of virgin ground, with the attendant possibility of opportunities for greatly refining and improving the validity of research findings. Many of the assumptions and procedures used to estimate energy consumption and the impacts of operational and technological change may be questioned by other experts in the field. We do not defend the methods, procedures, and assumptions used in this study as unchallengable--nor do we portend that, given the existing state of the art, there are no better procedures and techniques available. The objectives of this study were not to promote analytical techniques but to establish bases upon which government and industry planners may formulate more effective strategies for achieving energy conservation which are consistent with national interests. To the extent that this study assists in this goal, it will have achieved its purpose.

An eminent danger with pioneering research efforts such as this study is that there is a tendency for some parties, whose interest may be served by this study, to give these "statistics" a greater significance than is intended by the researchers who are familiar with the accuracy and validity of these statistics. We caution readers of this research study that the results of this study are only as good as the reliability of the data base and the validity of the many assumptions which had to be made.

In evaluating energy and economic impacts of energy conservation, the study team developed 1972 base-case estimates by commodity, mode, and certain vehicle types. Base-case estimates for 1980 and 1985 were developed from the 1972 base case using historical growth trends and projected gross national product and other available information. In addition to 1980 and 1985 base cases, "industry change" and "government influence" scenarios were projected based on assumptions defined in the report. These assumptions included operational and technological change and modal shifts from highway to rail (which includes moving motor carrier freight via TOFC). Projections in this study relied heavily upon a large number of assumptions which are very difficult to factually substantiate. Thus, because of many possible alternative interpretations and assumptions which may be equally as valid, this study describes in detail the development and build up of 1980 and 1985 scenarios so that the same procedures may be used to evaluate other alternatives.

To perform the research in this study, an intercity freight transportation energy consumption (TRANSEN) model was developed. The TRANSEN model systematically details energy consumption and energy intensiveness patterns for the base year 1972 and calculates the energy and economic impacts of specific assumptions for projected changes in technology and operating conditions in 1980 and 1985. It is strictly a calculator to simplify data processing, and enabled the study team to make refinements to outputs as new data became available or revised assumptions were made. The model is not a forecasting tool.

Energy consumption estimates are not intended to provide a basis for intermodal comparisons. Energy intensity values do not reflect differences in the quality of service between modes, differences in operating environments, or the incremental energy cost of shifting movements of one mode to another. Because strict modal comparisons are not always proper, corrections for circuity were not made (especially since no commodity and vehicle-type circuity data were available). In some cases, implied velocity profiles were used to calculate energy requirements in the absence of actual velocity profiles (which, in the case of pipelines, substantially reduces apparent energy requirements).

The 1972 base-case traffic estimates in terms of gross volume and net ton-miles agree fairly well with other data sources, yet significant variances in commodity details occur, principally because of subcommodity detail levels included in the commodity definitions. Projections for 1980 and 1985 traffic statistics vary significantly from other studies, except for rail and truck as a whole, principally because of forecasting assumptions and techniques used. Commodity details also vary for the same reasons in the 1972 base case. These differences are discussed in Section 4.

5.1 ENERGY CONSERVATION MEASURES

Substantial opportunities for energy conservation exist in intercity freight transportation. The greatest opportunity for conservation lies with industry itself, and return-on-investment opportunities are sufficiently attractive in specific instances to encourage the industry to explore and adopt operating and technological changes which promote energy conservation. Government influence to improve energy conservation practices is not as potentially significant as industry opportunities. Government can, however, accelerate industry trends by making energy conservation measures financially more attractive (or conversely, the failure to change more expensive) through taxing mechanisms. Other government influence could include regulatory changes which impact directly or indirectly on transportation energy conservation. The danger in major regulatory changes, however, is unknown adverse economic side effects to some carriers and possibly users of transportation. Major regulatory changes could also cause restructuring of the transportation industry and result in large capital needs in one area of transportation and excess capacity in another, with the potential danger that economic consequences may outweight the benefits of energy conservation. Because of the many unknowns associated with substantial regulatory changes, no significant changes to established regulatory policies were assumed in this study.

Table 5-1 summarizes energy conservation opportunities in the truck and rail modes. This table summarizes the opportunities and upper range limits of opportunity described in Section 3. For trucks, the theoretical maximum opportunity is estimated to be a 30-percent energy intensity reduction due to operational changes and a 42-percent savings involving technological change or, compounded, approximately a 59-percent reduction in energy intensity (miles per gallon or Btus per ton-mile). From a feasible and practical viewpoint, only a small percentage of these savings (reduction in Btus per ton-mile) is assumed to be realizable, as discussed for each scenario.

For rail, the potential energy savings in relative terms appear to be much greater than with truck, up to 40 percent maximum for operational change and 44 percent in the technological change area or a two-thirds compound reduction in energy intensity.

Changes in the inland, coastal, and great lakes waterway mode are not as potentially significant as opportunities in rail and truck and therefore were not studied. If waterway channels are deepened and locks enlarged, the combination of larger and deeper tows could significantly reduce energy intensity of the inland waterway system in percentage

TABLE 5-1

SUMMARY OF ENERGY CONSERVATION OPPORTUNITIES - TRUCK AND RAIL

OPERATIONAL		
ITEM	PERCENT REDUCTION IN ENERGY INTENSITY	COMMENT
Truck		
Increased Capacity Utilization (Heavier loads, reduced empty miles)	Up to 15%	Potential savings proportionate to vehicle-miles saved and vehicle energy intensity (mpg). Tariff incentives can help. No improvements assumed in study.
Reduced Circuity	Up to 10%	See above.
Speed Reduction	Up to 7%	Estimated from 55 mpg to 50 mpg average (Figure III-2). No improvement assumed in study. Affects service and control.
Use of Rail TOFC	Special Situations	Affects service and control.
Total	Up to 29%	
Rail		
Reduce Speed	4-10%	4-5% improvement assumed in this study.
Reduced Circuity	Up to 2%	Requires mergers or shipper short routing. Elimination of reverse routing.
Reduced Empty Movements	Up to 20%	Tariff incentives can help.
Loading Increases	Up to 5%	See above.
Reduce Stops and Delays	1%	Limited opportunity.
Change Train Configuration	Up to 4%	Applicable in special situations.
Reduce Yardswitching	1-2%	
Reduce Locomotive Idling	1-2%	Requires use of anti-freeze or block heaters in winter.
Eliminate Cabooses	2%	Requires major labor union concession.
Total	Up to 40%	
TECHNOLOGICAL		
Tailoring Engine Size To Operating Needs	Up to 8%	
Parasitic Load Reduction (Primarily Clutched Fan)	3, 3-8	6% assumed in study
Drive train Optimization	Undetermined	
Radial Tires	Up to 8	
Streamlining	5-12%	Varies from simple shield-up to full streamlining. Up to 20% fuel savings possible at 55 mpg.
Change in Fleet Makeup	5-15%	Use of larger vehicles for smaller vehicles.
Total	Up to 42%	
Locomotive Streamlining	3-12	Influenced by size of train and speed.
Miscellaneous Locomotive Improvements	Up to 23% (1)	Use of 4 cycle engines, improved injector spray type, improved air filtration,(1) supercharging, parasitic load reduction, weight reduction.
Reduction In Car Tare Weights	Up to 10%	Improved net-to-tare ratio
Car Streamlining	3-10%	Including narrowing gap between cars.,
Other Car Charges	1-3%	Elimination of truck "hunting" (oscillations), truck steering.
Electrification	None	Substitute alternate fuel.
Total	Up to 44	

(1) Felt by some railroad industry personnel to be high or not practical.

terms, but much less significantly in absolute terms, especially when compared to the potential for truck (and even rail).

Energy conservation measures for pipelines center on the use of larger diameter pipes, slower pumping velocities, and more efficient pumps. As discussed in this study, pipeline energy requirements are extremely sensitive to product velocity, pipe diameter, and fluid viscosity (friction factor).

Conservation opportunities for air cargo are relatively large in terms of potential percent reduction in energy requirements, but very small in the total picture of freight transportation energy. The amount of savings is also largely influenced by whether freight is considered to be an "add-on" to passenger traffic, or whether freight carried in passenger planes is assumed to use a pro-rata share of total energy consumption. The use of more efficient jet engines, slower speeds, larger aircraft, or even the return to turbo-prop aircraft for freight movements can have substantial impact on reducing air freight energy intensity. Because of its claimed advantage of expedited service, air freight capacity is generally operated at a relatively low load factor to assure availability of service when needed. Increases in load factors (at the expense of readily available service) can significantly reduce energy requirements per net ton-mile.

Independent of operational and technological changes to conserve energy are the opportunities of modal shift in specific instances where one mode is less energy intensive than another. These opportunities lie principally in the area of shifting truck traffic to rail in specific circumstances, at least for line-haul position of movement. Some energy conservation opportunities also exist for shifting rail traffic to water and coastal movement--specifics which were not examined. For a modal shift from truck to rail to be most energy effective, freight should move in box cars (or other appropriate cars) and not in TOFC service. Although TOFC service in line haul over long distances is generally believed to be more energy efficient than highway movements, some recent studies have indicated that the advantage may not be as great as originally believed, and in some cases may actually be less energy efficient. Studies sponsored by the Department of Transportation are currently underway with the Illinois Central Gulf Railroad to generate additional test data for evaluation.

Although modal shift may be desirable from an energy conservation viewpoint, it may not be advantageous from an economic or shipper viewpoint. For a modal shift to occur and to be most effective, it should be voluntary on behalf of shippers and sufficiently attractive to the railroads to provide the economic and service incentives for shippers to make the change. Though selected change in economic regulation and policy treatments towards modes, the government can encourage greater use of railroads as a primary means of providing line-haul transportation in specific circumstances.

5.2 ENERGY CONSERVATION SCENARIOS

Tables 5-2 to 5-5 summarize energy conservation scenarios for 1980 and 1985 under base-case conditions, industry change, and government influence. Table 5.2 summarizes resultant Btus per ton-mile by mode and scenario. Under the most favorable conditions (government influence), we believe that total transportation energy requirements per net ton-mile can be reduced by nearly 14 percent by 1980 and up to 25 percent by 1985, as compared to 1972. This includes operational and technological change as well as modal shift. Under the industry-change scenario, total energy requirements per net ton-mile can be reduced up to 10 percent and 16 percent, respectively, compared with the 1972 base case. The percent savings range from a maximum of 20 percent for truck (1972 to 1985 government-influence scenario) to 35 percent for rail under the same circumstances (excluding modal shift freight). In terms of absolute energy saved, the impact will be substantially greater for motor carriers than rail because of the larger energy intensity base. Absolute Btu savings are 439 for truck and 239 for rail. Energy consumption per net ton-mile is assumed to be substantially minimal for water movements, pipeline traffic, and air freight under the assumptions made in this study.

Table 5-3 summarizes total annual Btu consumption by mode and scenario. The most significant savings in both industry-change and government influence scenarios for 1980 and 1985 are in the motor carrier field, due in part to modal shift. Total industry trends are such that compared to the 1980 base case of energy consumption (projected from a 1972 traffic and energy intensity base), the industry itself will effect a 14-percent savings in energy consumption. Government influence could effect a further 7-percent savings. By 1985, the industry is projected to effect a 25-percent savings compared to the 1985 base case, with the potential of government effecting a further 13-percent savings. By 1985, according to our assumptions, government influence could actually affect an absolute savings in total energy consumption compared to 1980 scenarios, in spite of continued anticipated growth in total net ton-miles of transportation service.

A comparison of the percent of total net ton-miles produced and the percent of total energy use by mode and scenario is summarized in Table 5-4. In terms of percent of total net ton-miles and percent of

TABLE 5-2

ALL COMMODITIES

BTUs PER TON-MILE BY MODE AND SCENARIO

SCENARIO \ MODE	TRUCK	MODAL SHIFT (TRUCK TO TOFC/COFC)	RAIL	INLAND WATER	COASTAL & GREAT LAKES SHIP	COASTAL & GREAT LAKES BARGE	PIPELINE	AIR	AVERAGE
1972 BASE	2,343	0	687	272	226	274	281	39,949	800
1980 BASE	2,294	0	684	278	226	274	281	40,753	795
INDUSTRY CHANGE	2,119	1,589	617	265	225	271	265	40,028	717
GOVERNMENT INFLUENCE	2,036	1,462	570	265	225	271	265	40,028	685
1985 BASE	2,287	0	682	280	226	274	281	41,601	788
INDUSTRY CHANGE	2,014	1,522	540	270	223	269	265	40,143	671
GOVERNMENT INFLUENCE	1,904	1,117	442	267	223	269	265	40,143	600

TABLE 5-3

TOTAL BTU ANNUAL CONSUMPTION BY MODE AND SCENARIO

(Percent Changes: Industry/Base; Government/Industry)

BTU x 10^{12}

MODE / SCENARIO	TRUCK (1)	MODAL SHIFT (TRUCK TO TOFC/COFC)	RAIL (1)	INLAND WATER	COASTAL & GREAT LAKES SHIP	PIPELINE	AIR	TOTAL
1972 BASE	850	0	519	48	86	102	60	1,665
1980 BASE	1,246	0	760	74	135	147	95	2,457
INDUSTRY CHANGE	1,071	58	668	70	133	138	93	2,232
	-14%	-	-12%	-5%	-1%	4%	-2%	-9%
GOVERNMENT INFLUENCE	992	79	624	70	133	138	93	2,129
	-7%	+27%	-7%	0%	0	0%	0%	-5%
1985 BASE	1,456	0	886	87	162	175	113	2,879
INDUSTRY CHANGE	1,096	136	692	84	155	165	109	2,437
	-25%	-	-22%	-4%	-5%	5%	-4%	-15%
GOVERNMENT INFLUENCE	951	149	558	83	155	165	109	2,170
	-13%	+9%	-19%	-1%	0%	0%	0%	-11%

(1) Excludes modal shift BTU's.

TABLE 5-4
ALL COMMODITIES

PERCENT OF TON-MILES/PERCENT OF ENERGY USE BY MODE AND SCENARIO

SCENARIO	MODE	TRUCK	MODAL SHIFT (TRUCK TO TOFC/COFC)	RAIL	INLAND WATER	COASTAL & GREAT LAKES SHIP	COASTAL & GREAT LAKES BARGE	PIPELINE	AIR	TOTAL (Ton: 10^6) (BTU: 10^{12})
1972 BASE	%TM	18	0	37	9	19	3	14	*	2,087
	%BTU	51	0	31	3	5	1	5	4	1,665
1980 BASE	%TM	18	0	37	9	19	3	14	*	3,090
	%BTU	51	0	31	3	4	1	6	4	2,457
INDUSTRY CHANGE	%TM	16	1	36	8	19	3	17	*	3,080
	%BTU	48	3	30	3	5	1	6	4	2,232
GOVERNMENT INFLUENCE	%TM	16	2	36	8	18	3	17	*	3,072
	%BTU	46	4	30	3	5	1	7	4	2,129
1985 BASE	%TM	18	0	37	9	19	3	14	*	3,654
	%BTU	51	0	31	3	4	1	6	4	2,879
INDUSTRY CHANGE	%TM	15	2	35	9	19	3	17	*	3,631
	%BTU	45	6	28	4	5	1	7	4	2,437
GOVERNMENT INFLUENCE	%TM	14	4	35	8	19	3	17	*	3,614
	%BTU	44	7	26	4	6	1	7	5	2,170

*Insignificant

energy use, all base cases (1972, 1980, and 1985) are the same by definition. It is interesting to note, however, potential trends in each of the various scenarios. In 1972, railroads produced 3.4 times the net ton-miles per Btu as motor carriers. However, the nature of commodities and services in each mode are characteristically quite different. By 1985 under the government-influence scenario, railroads could produce approximately 4.2 times the net ton-miles, compared to motor carriers, for the same energy input--a 24-percent relative improvement--again emphasizing that a net ton-mile of average rail freight is characteristically different from a net ton-mile of the average motor carrier freight. The significant conclusion is the potential relative improvement between the modes--not the quantitative difference. Similar comparisons among the other modes can be made using the following simple formula:

$$\%\text{ Relative Improvement (Mode 1)} = \frac{\overbrace{\left(\frac{TM_1}{TM_2} \times \frac{BTU_2}{BTU_1}\right)}^{\text{Year 2}} \times \overbrace{\left(\frac{TM_1}{TM_2} \times \frac{BTU_2}{BTU_1}\right)}^{\text{Year 1}}}{\underbrace{\left(\frac{TM_1}{TM_2} \times \frac{BTU_2}{BTU_1}\right)}_{\text{Year 2}}} \times 100 \qquad (5-$$

where: TM = Net Ton-Miles (or percent of)
Btu = Total Energy (or percent of)
1 = Mode 1
2 = Mode 2

Using the output of the TRANSEN model and summarizing across all modes, Table 5-5 summarizes the total energy consumption by commodity and scenario for each of the 19 study commodities. The lower part of the table compares the relative percent change in total Btu consumption from the base case to industry and from the industry to government scenarios for 1980 and 1985. The amount of change by each commodity is heavily influenced by the relative amount of that commodity shipped by each mode and the energy savings which occur within that mode by vehicle type. Potential savings range from negligible amounts for petroleum products up to 41 percent for instruments and miscellaneous manufacturing commodities in the 1985 base to industry scenario. Again, the reader is cautioned that commodity changes are likely to be less reliable than traffic as a whole.

TABLE 5-5

TOTAL BTU CONSUMPTION BY COMMODITY AND SCENARIO (1)

BTU x 10^{12}

	AGRICULTURE	METALLIC ORES	COAL & COKE	PETROLEUM	NON-METALLIC MINERALS	FOOD PRODUCTS	TEXTILES	LUMBER & FURNITURE	PULP & PAPER	CHEMICALS	RUBBER & PLASTICS	STONE, CLAY & GLASS	PRIMARY METAL PRODUCTS	FABRICATED METAL PRODUCTS	NON-ELECTRIC MACHINERY	ELECTRICAL MACHINERY	TRANSPORTATION EQUIPMENT	INSTRUMENTS & MISC. MFG.	SCRAP	TOTAL
1972 Base	246	22	65	237	40	189	49	118	53	120	42	88	62	70	48	51	116	40	11	1,667
1980 Base	337	47	90	341	70	236	67	140	95	208	56	120	103	99	80	80	197	64	17	2,456
Industry	308	45	80	321	64	209	61	125	85	188	58	108	93	93	72	73	174	57	15	2,232
Government	295	44	79	317	62	197	57	117	79	178	55	103	89	88	69	70	163	54	14	2,129
1985 Base	376	60	100	406	87	264	76	158	118	260	80	138	125	116	98	97	224	78	19	2,879
Industry	323	55	84	374	75	213	63	128	92	215	64	116	105	101	83	83	183	63	16	2,436
Government	296	52	70	370	70	184	57	110	78	190	54	103	92	87	72	74	146	51	14	2,170
SCENARIO PERCENT CHANGES																				
1980 Base to Industry	-9	-3	-10	-6	-9	-11	-10	-11	-11	-10	+4	-10	-10	-6	-10	-9	-12	-11	-12	-9
Industry to Government	-4	-3	-3	-1	-3	-6	-6	-6	-7	-5	-2	-5	-4	-5	-4	-4	-6	-5	-7	-5
1985 Base to Industry	-14	-7	-16	-8	-13	-13	-17	-19	-22	-17	-20	-16	-16	-13	-15	-14	-18	-19	-15	-15
Industry to Government	-8	-7	-17	-1	-7	-14	-10	-14	-15	-12	-16	-11	-12	-14	-13	-11	-20	-19	-13	-11

(1) Air energy consumption based on pro rata distribution between freight and passenger traffic. Distribution by commodity made on basis of

Table 5-6 summarizes changes in net ton-miles and energy consumption by mode and by scenario, assuming a 1972 index of 100 for both Btus and net ton-miles. Base case energy indices vary from base case ton-mile indices due largely to the different rates of projected commodity growth, where each commodity has a different energy intensity average. Thus, base cases for both 1980 and 1985 recognize a weighted total Btu consumption for all commodities which is different than total ton-mile growth.

In the case of changing ton-miles within each scenario for 1980 and 1985 for truck and rail, the decrease in truck ton-miles is attributable to modal shift to rail. The addition of this traffic to rail, however, is more than offset by assumed circuity reductions which contribute to an overall reduction in rail ton-miles.

Changes in Btu indices within each scenario are the result of assumed operational and technological changes discussed in previous sections.

5.3 ECONOMIC IMPACTS

Based on available information and the scope of this study, it is very difficult to make projections as to economic impacts within each transportation mode. Our analysis indicates that for many technological changes to conserve energy in specific circumstances--particularly for motor carriers--there is an economic return on investment. As the number of technological improvements are added, the more expenseive these improvements tend to become relative to the energy saved, which indicates a fairly rapidly diminishing marginal rate of return for improvements, at least at the given price level for energy. Base energy intensity vehicle utilization, vehicle life (and improvement), opportunity rate, maintenance costs, and energy costs are the chief factors governing return on investment. Operational changes to save energy in most modes are frequently coupled with correspondent and larger changes in reductions of other costs. Operational changes, however, may result in decreasing service levels, particularly availability of service and service speed. Technological changes generally do not adversely impact service yet provide significant savings.

Economic impacts among transportation modes can be influenced by government policy. Increasing the price of energy will have the greatest impact among those modes with the highest energy intensity levels. Increasing tax incentives to promote technological change will have the greatest impact upon those modes which are capital intensive. Between the two principal modes of overland transportation--truck and rail--increasing energy costs will promote the greatest likely change and apparent

TABLE 5-6

INDEX OF NET TON-MILES AND ENERGY CONSUMPTION BY MODE AND SCENARIO
(1972 = 100)

SCENARIO		MODE	TRUCK	RAIL (1)	INLAND WATER	COASTAL & GREAT LAKES SHIP	COASTAL & GREAT LAKES BARGE	PIPELINE	AIR	AVERAGE
1980	Base Case	Ton-Miles	150	147	147	155	155	144	154	149
		BTUs	147	146	154	157	147	144	157	148
	Industry Change	Ton-Miles	139	151	147	155	155	144	154	148
		BTUs	126	140	145	154	147	135	154	134
	Government Influence	Ton-Miles	134	152	147	155	155	144	154	148
		BTUs	117	135	145	154	147	135	154	128
1985	Base Case	Ton-Miles	175	172	174	187	187	171	180	170
		BTUs	171	171	181	189	176	171	187	173
	Industry Change	Ton-Miles	150	181	174	187	187	171	180	174
		BTUs	129	160	175	180	171	162	181	137
	Government Influence	Ton-Miles	137	185	174	187	187	171	180	174
		BTUs	112	136	173	180	171	162	181	119

(1) Includes Modal Shift Ton-Miles and BTU's.

increased incentive for technological change among motor carriers. Increasing capital tax credits incentives for energy conservation will have the greatest impact on (profitable) railroads where technological change is relatively more expensive to adopt.

Operating savings in the motor carrier industry can be reasonably estimated on a vehicle mileage reduction basis to handle a given volume of service (ton-miles). Operating savings for railroads are not so easy to estimate because of the much greater variation in cost per vehicle-mile, which is greatly influenced by the nature and characteristic of rail service being provided.

Relative to railroads, motor carriers are generally more responsive to opportunities to change. Investment requirements are usually substantially less, and turnover rates among motor carrier equipment is higher relative to rail. In addition, generally smaller companies (frequently family owned or controlled) help motor carrier management to react quicker to opportunities to change.

The opportunity rate, or internal rate of return, is a key factor influencing energy conservation alternatives. For very profitable transportation companies, which have a relatively high rate of return and continuing opportunities to employ limited capital at this rate of return, opportunities to improve energy conservation may not be very attractive. For industries with relatively low opportunity rates and available cash (or financing), the adoption of energy conservation measures may be very attractive. Left alone, industry will proceed at its own rate to adopt energy conservation improvements which will yield favorable economic impacts consistent with corporate goals and policies. The most effective way for government to accelerate the adoption of energy conservation improvements is to operate on these economic incentives, specifically by increasing energy costs and providing capital tax incentives for the adoption of energy conservation measures. The government should be cautious, however, since excessive emphasis on these costs can upset and disturb the delicate economic balance between modes, and significantly impact individual carriers within each mode. Operating in the regulatory environment to promote operational and technological changes could result in adverse net industry economic impact with the resultant necessity to increase the cost of transportation services provided. This is not to say, however, that regulatory changes will promote negative economic impact. There are many areas where regulatory changes can, and perhaps should, be made to reduce waste of transportation resources. The Federal Energy Administration is currently conducting studies to identify to what extent regulation contributes to transportation and energy waste among motor carriers.

Some relaxation of regulatory practices that contribute to this waste (particularly relating to operative rights, backhaul privileges, and commodity exemptions, etc.) and corresponding, offsetting, relaxation of regulatory requirements relating to railroads (such as mergers, rate flexibilities and incentives, commodity exemptions, car-service rules, contract rates, etc.) could promote energy conservation without adversely affecting economic health of the industry, increasing costs of transportation, or significantly altering competitive balance between modes.

In concluding this study, PMM&Co. believes that there are substantial opportunities for improving and understanding freight transportation energy behavior and characteristics among the various modes and the economic and energy impacts that result from operational and technological change. Because of the breadth of this study and the tremendous volume of data and information generated, we believe that substantial opportunities for improvement exist, which should best begin by improving the national data base relating to energy consumption in freight transportation. To the extent that this study sheds light on the behavior and energy use characteristics of modes vehicles by commodities, this study will have made a positive contribution. Only by developing a better data base for performing studies and using methods of evaluation as described in this study can a better understanding relating to the use of energy and freight transportation be obtained. This better understanding may lead to the development and refinement of alternatives to achieve energy conservation and help the government select alternatives which are in the national interest with minimum adverse impact upon the effected transportation modes.

APPENDIX A

TRUCK MOVEMENTS

A. 1 METHODOLOGY

The truck related outputs of the TRANSEN model include truck fuel use calculations for each commodity truck types. This methodology is illustrated in Figure A-1 and is described below.

The methodology begins with a calculation of maximum load weight for each commodity group for each truck type:

$$CAP_{jk} = (GVW_j - TWT_j)FLR_k \qquad \text{(A-1)}$$

where:

CAP_{jk} = Maximum load weight (short tons) for truck type, j, and commodity group, k

GVW_j = Gross vehicle weight (short tons) for truck type, j

TWT_j = Vehicle tare weight (short tons) for truck type, j

FLR_k = Full load-to-net weight capacity ratio for commodity group, k, for density variations between commodities

The full load-to-net weight capacity ratio is used to account for density variations between commodities in terms of pounds per cubic foot to reflect whether a vehicle would be "cubed out" before the net weight capacity of the truck is reached. For example, some commodities, such as furniture, have a low density factor ranging from 6 to 10 pounds per cubic foot. At the other extreme, minerals, such as ore, have a density factor ranging from 80 to 110 pounds per cubic foot. A standard 40 foot semitrailer tractor combination which has a gross vehicle weight of 36 tons, a tare weight of 12.9 tons, and a loading space of about 2,700 cubic feet. This trailer would be "cubed out" when it is fully loaded (95 percent of cube) with a low density commodity weighing less than 18 pounds/cubic feet.

The maximum load weight (CAP_{jk}) computed by equation A-1 is combined with estimates of total truck miles by truck type and commodity group to estimate the annual maximum capacity, in ton-miles, available for intercity freight transportation by trucks.

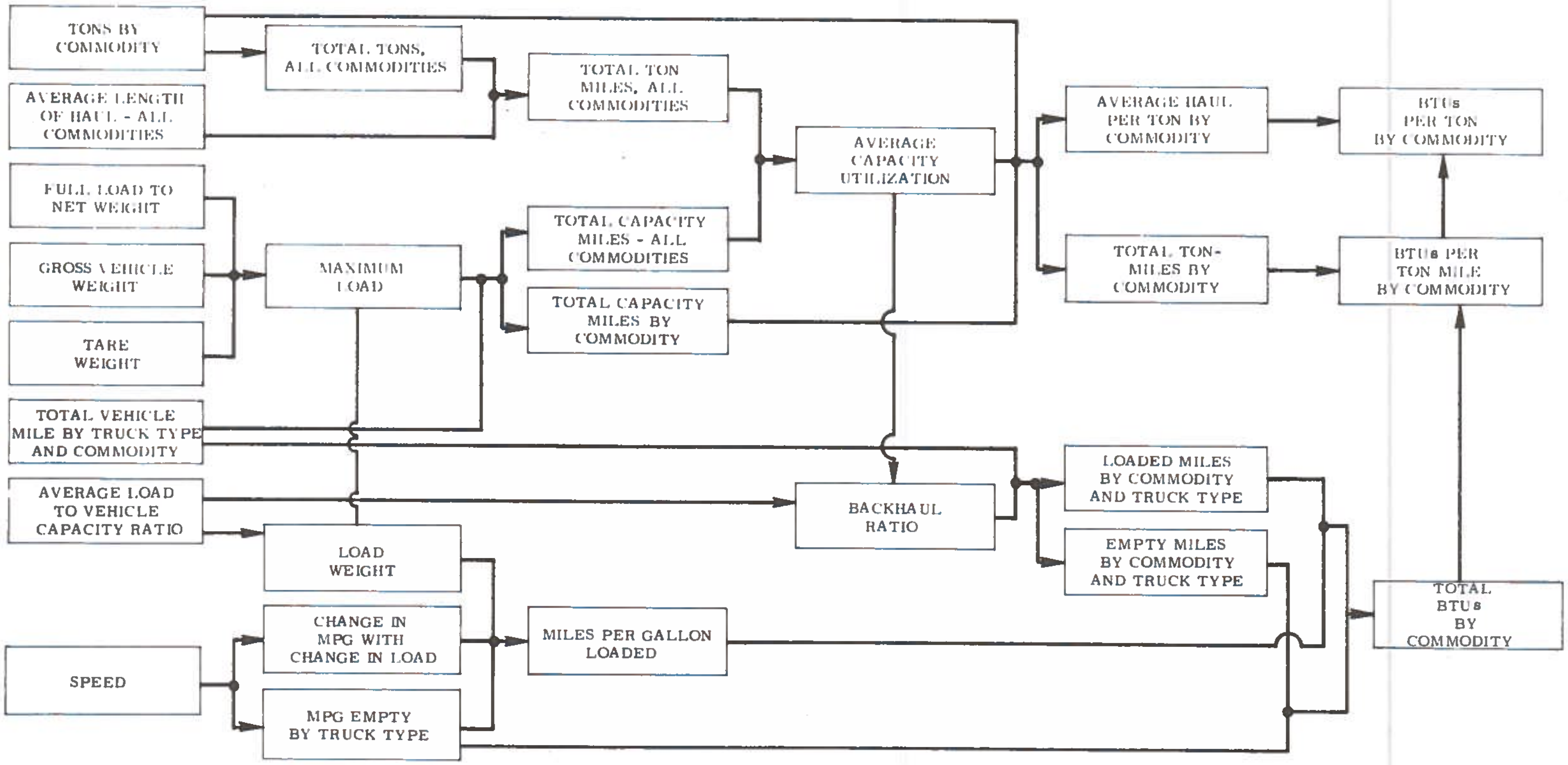

FIGURE A-1: CONCEPTUAL DESIGN OF THE INTERCITY TRUCK TRANSPORTATION COMPONENT OF THE TRANSEN MODEL

TABLE A-3 (cont.)

Census Principal Product / Weight Class (1000 lbs. GVW) \ Census Body Type	Pickup, Panel, Multistop or Walkin	Platform with added Device	Other Platform	Cattlerack	Nonrefrigerated Van	Refrigerated Van	Furniture Van	Open-Top Van	Other Vans	Beverage Truck	Utility Truck	Garbage Truck	Winch or Crane	Wrecker	Pole or Logging	Auto Transport	Dump Truck	Tank Truck for Liquids	Tank Truck for Dry Bulk	Concrete Mixer	Other
Study body type *	B	I	I	I	B	B	B	B	B	B	X	I	X	X	I	I	I	T	T	I	I
Textiles & Apparel																					
Less than 6	86								4												
6 to 10	112				3		1		5												
10 to 14	37						4		31												
14 to 16	8								63												
16 to 19	1						3		17				5								
19 to 26	3		5		1			61	27												
26 to 32			1				5		31												
32 to 40					10		14		14												
40 to 50							2		16												
50 to 60					5				29												
60 to 70					7			5	129												
70 to 80			9		7	15	1		207									2	3		
80 to 100																					
100 to 130									1												
Greater than 130																					
Building Materials																					
Less than 6	1563		22	10				1			1						1				
6 to 10	174	6	36				2	1	7		5						33				4
10 to 14	9	4	103		1		1		14		1					1	24		6		
14 to 16		5	29				6	5	60								25	2	4		
16 to 19		8	50		1			1	17								17		1		
19 to 26	1	22	92		8		12	3	30				12				64	1			
26 to 32		16	60		7				8				3				43		3		
32 to 40		11	52		7			1	16				3				13			1	
40 to 50		31	80		2		3	8	45				5		2		115	2	4	6	
50 to 60		13	103		2		1	5	36		2						67	3		5	
60 to 70		23	261		2		3	10	42				10		1		82	25	6	2	
70 to 80		85	778		22	5	3	36	117				5		7		431	10	249		
80 to 100			17										1				23		19		
100 to 130			2				6										1		4		
Greater than 130																	5				

*I = Irregular shape body   B = Box type   X = Not included in this study (basically nonfreight vehicle)

TABLE A-3 (cont.)

Census Principal Product / Weight Class (1000 lbs. GVW) \ Census Body Type	Pickup, Panel, Multistop or Walkin	Platform with added Device	Other Platform	Cattlerack	Nonrefrigerated Van	Refrigerated Van	Furniture Van	Open-Top Van	Other Vans	Beverage Truck	Utility Truck	Garbage Truck	Winch or Crane	Wrecker	Pole or Logging	Auto Transport	Dump Truck	Tank Truck for Liquids	Tank Truck for Dry Bulk	Concrete Mixer	Other
Study body type *	B	I	I	I	B	B	B	B	B	B	X	I	X	X	I	I	I	T	T	I	I
Electrical Machinery																					
Less than 6	241	4	3						26		66										
6 to 10	184	2	7		3				1		31										
10 to 14	24		1						11		1		2								
14 to 16			103				1		4						1						
16 to 19	1		3						8		3										
19 to 26	1		11						7		4						1				
26 to 32			3				33		6				1								
32 to 40			5								3		7								
40 to 50			5						9		5										
50 to 60			2					1	44		2								3		
60 to 70			22						15												
70 to 80			6		15		15	12	74				2								
80 to 100													1								
100 to 130																					
Greater than 130																					
Transportation Eq.																					
Less than 6	764		6											1							3
6 to 10	263		1								1			10		50		1			70
10 to 14	45		3						7					2		18					20
14 to 16	3	8	5						12					1		11					
16 to 19		2	14	2							1			1							51
19 to 26			48						6		11		3	1		17	1				96
26 to 32		1	29			1		4	1		5					9					56
32 to 40	2		11					4	5				3			37					13
40 to 50			4													139					8
50 to 60			8	2	5			2	10							320					
60 to 70			22						11							155					
70 to 80			27		3				9							97					
80 to 100																					
100 to 130																					
Greater than 130						1															

*I = Irregular shape body   B = Box type   X = Not included in this study (basically nonfreight vehicle)

TABLE A-3 (cont.)

Census Principal Product / Census Body Type / Weight Class (1000 lbs. GVW)	Pickup, Panel, Multistop or Walkin	Platform with added Device	Other Platform	Cattlerack	Nonrefrigerated Van	Refrigerated Van	Furniture Van	Open-Top Van	Other Vans	Beverage Truck	Utility Truck	Garbage Truck	Winch or Crane	Wrecker	Pole or Logging	Auto Transport	Dump Truck	Tank Truck for Liquids	Tank Truck for Dry Bulk	Concrete Mixer	Other
Study body type*	B	I	I	I	B	B	B	B	B	B	X	I	X	X	I	I	I	T	T	I	I
Scrap, Refuse & Garb																					
Less than 6	58																				
6 to 10	21		5					2								2					
10 to 14	3		3									3					2				
14 to 16			1																		
16 to 19			1									3					1				
19 to 26			19		4			2				6					3	10			
26 to 32		2	7					1	2								5				
32 to 40																					
40 to 50			6														1				
50 to 60		2	3					3	10			2					1				
60 to 70			10					5	1							1	1				
70 to 80		3	12					8	8								9				
80 to 100																					
100 to 130																					
Greater than 130																	2				
Mixed Cargos																					
Less than 6	693		1					49	36												
6 to 10	102	18	69	2	1		8	1	43												40
10 to 14	45		3				3	1	72				1				1				
14 to 16	2	7	18		17	12			84				1			3					
16 to 19	1		5		15	7	4		46								1				
19 to 26	2	7	18	4	11	2	2	3	82		1		2								
26 to 32		1	29			1			59												
32 to 40	37		5		17	2		5	165		1		2								
40 to 50			7		23	4	15	7	152												
50 to 60			37		33		9	3	613									3			
60 to 70			70		84	29		37	1170		3						9		5		
70 to 80	3		335	13	501	176		45	3665				2			4	20	18	17		10
80 to 100									33									2			
100 to 130									11												
Greater than 130			1																		

*I = Irregular shape body B = Box type X = Not included in this study (basically nonfreight vehicle)

TABLE A-3 (cont.)

Census Body Type / Census Principal Product / Weight Class (1000 lbs. GVW)	Pickup, Panel, Multistop or Walkin	Platform with added Device	Other Platform	Cattlerack	Nonrefrigerated Van	Refrigerated Van	Furniture Van	Open-Top Van	Other Vans	Beverage Truck	Utility Truck	Garbage Truck	Winch or Crane	Wrecker	Pole or Logging	Auto Transport	Dump Truck	Tank Truck for Liquids	Tank Truck for Dry Bulk	Concrete Mixer	Other
Study body type*	B	I	I	I	B	B	B	B	B	B	X	I	X	X	I	I	I	T	T	I	I
Personal Transport																					
Less than 6	7036		5						1		150			18							
6 to 10	1407	3	50			26	1		2		203		2	17							1
10 to 14	323	1	8						2		113		3								23
14 to 16	14		1						2		16		3								1
16 to 19	10	2	10						13		22		10	2				4			
19 to 26		6	26		3				10		12		8	5	1						
26 to 32	39		2					1	2		2		3								
32 to 40	30		4								1										2
40 to 50		25	3										2				1				1
50 to 60	13	3	1						7					2		1					
60 to 70									12							5					
70 to 80			8						29		3			1							
80 to 100			2																		
100 to 130																					
Greater than 130																					
Other																					
Less than 6	1549	2	9		5	2	1	.	116		94							1			
6 to 10	377	4	34		1		40	10	125		25							1			5
10 to 14	84	5	30	4	4	6	13	4	92		5		16	1	1			10	4		11
14 to 16	9	2	21		23	9	4		53		10						2	11			25
16 to 19	8	8	49	1	18	2	14	2	72		15		9	1			1	2			53
19 to 26	15	13	78	1	5	9	25	1	87	1	17	1	10	4		5	4	8	4		43
26 to 32		9	41		12	5	14	1	2		2		3				1	2			19
32 to 40	3	6	61		10	5	12		105		6		1	2			4	4			2
40 to 50	2	14	31	13	7	5	12	4	164		2		8			6	8	3	5		1
50 to 60		3	99	1	26		2	3	181	1			3		2	15		1	3		
60 to 70		4	99	14	30	4	3	4	232				14		1		3	14	25		
70 to 80		8	280	1	141	148	20	89	454				10		13		7	90	143		2
80 to 100			18			3							7				1				
100 to 130			13										1								
Greater than 130						2															

*I = Irregular shape body B = Box type X = Not included in this study (bascially nonfreight vehicle)

TABLE A-3 (cont.)

Census Principal Product / Weight Class (1000 lbs. GVW) \ Census Body Type	Pickup, Pannel, Multistop or Walkin	Platform with added Device	Other Platform	Cattlerack	Nonrefrigerated Van	Refrigerated Van	Furniture Van	Open-Top Van	Other Vans	Beverage Truck	Utility Truck	Garbage Truck	Winch or Crane	Wrecker	Pole or Logging	Auto Transport	Dump Truck	Tank Truck for Liquids	Tank Truck for Dry Bulk	Concrete Mixer	Other
Study body type *	B	I	I	I	B	B	B	B	B	B	X	I	X	X	I	I	I	T	T	I	I
Forest Products																					
Less than 6	36														2						
6 to 10	4	1	6						2				3		38						
10 to 14			20												8		2				
14 to 16			12					4							7						
16 to 19		1	7												12						
19 to 26	1	52	12										1		18		1				
26 to 32		2	20					1	1						3						
32 to 40			12								1				7						
40 to 50		2	33					4	3				1		50						
50 to 60		1	20												31		2				
60 to 70			75		1										68				1		
70 to 80		1	174	1	1			43	8						257		2				
80 to 100			6												3						
100 to 130															5						
Greater than 130																					
Food & Kindred Prd.																					
Less than 6	275				1	19	5		2												
6 to 10	98		1		22	42	58		43	5			3								
10 to 14	83		7		62	110	11		41	23											
14 to 16	39				46	63			16	31											
16 to 19	29		2		31	52	1	1	30	44								2			
19 to 26	18		2		47	159		5	85	62								9			
26 to 32	4		1		25	110	23		59	37		1						1			
32 to 40					17	68			63	9								1			
40 to 50			2		37	75	13		52	5											
50 to 60					31	83	14		74	8								3			
60 to 70		1			105	254	3		152	22								10			
70 to 80			25		266	1399	7	5	411	76								75	27		
80 to 100					5	18			2	3								1			
100 to 130																					
Greater than 130						2															

*I = Irregular shape body B = Box type X = Not included in this study (basically nonfreight vehicle)

TABLE A-4

PROPORTIONAL FUEL TYPES BY PRODUCT AND GROSS VEHICLE WEIGHT CLASS

Product	WEIGHT CLASS*	% Gasoline	% Diesel
Farm	2	.51	.49
	3	.84	.16
	4	.59	.41
	5	.17	.83
Mining	2	.78	.22
	3	.67	.33
	4	.67	.33
	5	.14	.86
Forest	2	.60	.40
	3	.84	.16
	4	.42	.58
	5	.19	.81
Foods	2	.74	.26
	3	.84	.16
	4	.39	.61
	5	.13	.87
Textiles	2	.91	.09
	3	.62	.38
	4	.38	.62
	5	.04	.96
Build	2	.59	.41
	3	.71	.29
	4	.51	.49
	5	.19	.81
Furniture	2	.82	.18
	3	.75	.25
	4	.16	.84
	5	.08	.92

*CLASS 1 = 10,000 to 19,000 lbs. GVW
CLASS 2 = 19,001 to 32,000 lbs. GVW
CLASS 3 = 32,001 to 50,000 lbs. GVW
CLASS 4 = 50,001 to 70,000 lbs. GVW
CLASS 5 = over 70,000 lbs. GVW

TABLE A-4 (cont.)

PRODUCT	WEIGHT CLASS*	% GASOLINE	% DIESEL
Paper	2	.72	.28
	3	.76	.24
	4	.40	.60
	5	.06	.94
Chemicals	2	.47	.53
	3	.79	.21
	4	.67	.33
	5	.09	.91
Petroleum	2	.44	.56
	3	.73	.27
	4	.21	.79
	5	.22	.78
Pr. Metal	2	.45	.55
	3	.42	.58
	4	.36	.64
	5	.15	.85
Fab. Metal	2	.54	.46
	3	.77	.23
	4	.36	.64
	5	.07	.93
Machinery	2	.64	.36
	3	.87	.13
	4	.75	.25
	5	.08	.92
Elec. Mach.	2	.34	.66
	3	.90	.10
	4	.55	.45
	5	.03	.97
Transportation	2	.79	.21
	3	.74	.26
	4	.68	.32
	5	.15	.85

*CLASS 1 = 10,000 to 19,000 lbs. GVW
CLASS 2 = 19,001 to 32,000 lbs. GVW
CLASS 3 = 32,001 to 50,000 lbs. GVW
CLASS 4 = 50,001 to 70,000 lbs. GVW
CLASS 5 = over 70,000 lbs. GVW

TABLE A-4 (cont.)

PRODUCT	WEIGHT CLASS*	% GASOLINE	% DIESEL
Scrap	2	.72	.28
	3	.89	.11
	4	.67	.33
	5	.38	.62
Mixed	2	.23	.77
	3	.57	.43
	4	.28	.72
	5	.05	.95
Other	2	.75	.25
	3	.84	.16
	4	.39	.61
	5	.16	.84

*CLASS 1 = 10,000 to 19,000 lbs. GVW
CLASS 2 = 19,001 to 32,000 lbs. GVW
CLASS 3 = 32,001 to 50,000 lbs. GVW
CLASS 4 = 50,001 to 70,000 lbs. GVW
CLASS 5 = over 70,000 lbs. GVW

TABLE A-5

TABLE 24. DESCRIPTION OF ASSUMED TRUCK TYPES

TRUCK TYPE	BODY TYPE	GROSS VEHICLE WEIGHT CLASS	FUEL TYPE
1	Box	10,000-19,000 lbs.	Gasoline
2	Box	10,000-19,000 lbs.	Diesel
3	Box	19,000-32,000 lbs.	Gasoline
4	Box	19,000-32,000 lbs.	Diesel
5	Box	32,000-50,000 lbs.	Gasoline
6	Box	32,000-50,000 lbs.	Diesel
7	Box	50,000-70,000 lbs.	Gasoline
8	Box	50,000-70,000 lbs.	Diesel
9	Box	over 70,000 lbs.	Diesel
10	**Box (Twin)**	**over 70,000 lbs.**	**Diesel**
11	Irregular	10,000-19,000 lbs.	Gasoline
12	Irregular	10,000-19,000 lbs.	Diesel
13	Irregular	19,000-32,000 lbs.	Gasoline
14	Irregular	19,000-32,000 lbs.	Diesel
15	Irregular	32,000-50,000 lbs.	Gasoline
16	Irregular	32,000-50,000 lbs.	Diesel
17	Irregular	50,000-70,000 lbs.	Gasoline
18	Irregular	50,000-70,000 lbs.	Diesel
19	Irregular	over 70,000 lbs.	Diesel
20	**Irregular (Twin)**	**over 70,000 lbs.**	**Diesel**
21	Tank	32,000-50,000 lbs.	Gasoline
22	Tank	32,000-50,000 lbs.	Diesel
23	Tank	50,000-70,000 lbs.	Gasoline
24	Tank	50,000-70,000 lbs.	Diesel
25	Tank	over 70,000 lbs.	Diesel

The vehicle miles from Table A-3 were combined for the body and weight classes used in the study, which were then split into gasoline and diesel according to the percents in Table A-4. The vehicle miles by the 24 study truck types and principal products were distributed into commodity classes by the percents calculated in Table A-1.

The Census reported that certain commodities such as textiles, furniture, and machinery were moved in tank trucks which does not appear logical (see Table A-3). In these cases, Census information was assumed to be correct as to truck type but incorrect as to principal product. Therefore, these tank truck miles were assigned to the chemicals and allied products category. Because of these shifts, and the rounding of numbers at the millions level, the table of truck miles by truck type and commodity was expanded to match the totals calculated for each commodity in Table A-2. Table A-6 shows the truck miles by the 24 truck types and 19 commodities used for the 1972 calculations of truck fuel consumption.

A.2.4 Truck Characteristics

A.2.4.1 Truck Tare Weight and Gross Vehicle Weight

To develop estimates of truckload capacity for each truck category, the tare weight and gross vehicle weight were developed for a representative truck for each truck category. The weights assumed for each truck category are outlined in Table A-7. The data for the tare weight assumptions were obtained from a Federal Highway Administration report[1] and discussions with several truck dealers.

A.2.4.2 Miles per Gallon by Truck Type

Fuel consumption rates used in this study are calculated from the horsepower requirements of the various truck types at different operating speeds and the specific fuel consumption rate of the engine. The method used is the SAE J-688 truck performance method.[2] The theoretical calculations were found to correlate reasonably well with actual road tests of fuel consumption.

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[1] Federal Highway Administration, Road User Property Taxes on Selected Motor Vehicles, 1973, U.S. Government Printing Office, Washington, D.C., pp. 10-11.

[2] Society of Automotive Engineers, "Truck Ability Prediction Precedure-SAE J-688" pp. 790-2. 1962 SAE Handbook, Society of Automotive Engineers, Inc., New York, 1962.

TABLE A-6

CONDENSED VEHICLE MILES BY TRUCK TYPE AND COMMODITY
MILLIONS OF VEHICLE MILES

TRUCK TYPE	STUDY COMMODITY GROUP NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	214	0	0	17	0	535	165	127	46	33	36	50	4	29	5	24	65	146	2
2	198	0	0	22	0	186	52	34	20	56	43	48	4	53	16	52	52	49	1
3	301	0	0	12	0	541	52	174	70	32	40	41	4	73	12	51	28	89	8
4	56	0	0	4	0	103	35	58	22	15	21	19	6	30	6	11	17	17	1
5	133	0	0	4	1	135	42	61	37	39	33	36	2	50	10	15	27	60	0
6	99	0	0	13	1	212	84	287	51	50	57	50	4	106	19	30	55	93	0
7	96	0	0	5	1	99	25	27	10	20	25	20	2	28	16	10	21	37	7
8	470	3	2	18	6	659	530	284	148	303	290	196	10	465	235	217	339	191	11
9	1607	4	2	56	9	2231	940	116	211	654	699	458	46	931	355	481	758	399	16
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	202	4	2	4	24	7	4	28	10	20	7	105	44	28	35	40	54	75	11
12	179	1	1	5	15	2	12	19	8	28	10	78	53	34	23	80	25	24	4
13	466	3	2	11	18	4	7	39	15	24	17	157	30	52	72	16	191	61	38
14	89	1	1	4	11	1	4	16	5	8	7	58	42	18	12	3	69	12	5
15	177	4	2	0	22	1	0	26	14	32	10	103	18	22	93	6	142	27	5
16	155	1	1	2	19	1	0	25	17	17	6	99	32	40	31	5	68	41	3
17	136	1	1	1	11	0	0	18	8	3	6	71	42	11	11	0	76	18	8
18	639	8	6	3	58	1	0	76	50	33	44	309	239	140	128	16	445	95	13
19	1886	46	31	24	210	25	0	227	85	91	57	923	841	297	291	39	186	160	26
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	121	0	0	70	4	5	0	0	0	37	0	0	0	0	0	0	0	0	1
22	84	0	0	264	3	7	0	0	0	23	0	0	0	0	0	0	0	0	0
23	19	0	0	75	2	2	0	0	0	14	0	0	0	0	0	0	0	0	0
24	93	4	0	266	20	12	0	0	0	121	0	0	0	0	0	0	0	0	0
25	199	5	0	1681	86	104	0	0	0	281	0	0	0	0	0	0	0	0	0

TABLE A-7
CHARACTERISTICS OF REPRESENTATIVE TRUCKS

TRUCK TYPE	GROSS VEHICLE WEIGHT* (Tons)	TARE WEIGHT (Tons)	NET CAPACITY
1	7.0	4.2	2.8
2	7.3	4.5	2.8
3	12.0	4.7	7.3
4	12.3	5.0	7.3
5	21.5	7.4	14.1
6	21.8	7.7	14.1
7	27.5	10.1	17.4
8	27.6	10.2	17.4
9	36.0	12.9	23.1
10	40.0	13.9	26.1
11	7.0	2.8	4.2
12	7.3	3.1	4.2
13	12.0	3.9	8.1
14	12.3	4.2	8.1
15	20.0	6.0	14.0
16	20.3	6.3	14.0
17	27.5	9.7	17.8
18	27.8	10.0	17.8
19	36.0	12.6	23.4
20	40.0	13.6	26.4
21	20.0	7.5	12.5
22	20.3	7.8	12.5
23	27.5	10.2	17.3
24	27.8	10.5	17.3
25	36.0	13.1	22.9

*Data which helped in making the tare weight data were obtained from Federal Highways Administration, Road User Property Taxes on Selected Motor Vehicles, 1973, U.S. Government Printing Office, Washington, D.C. p-10-11, and conversations with a General Motors Truck dealer in the Washington area and Freuhauf trailers in Detroit.

Tables A-8 through A-12 outline the calculations for standard, or benchmark, trucks in each of the weight classes used in the study. The values calculated in Tables A-8 through A-12 are plotted in Figures A-2 through A-6, respectively. Values for empty vehicles were read from the graphs for speeds of 45, 50, 55, 60, 65, and 70 miles per hour. These values are the underlined numbers in Table A-13. Table A-14 shows the changes in miles per gallon with each ton of load. For the benchmark trucks, these are obtained by dividing the difference between the empty mile per gallon curve and the loaded mile per gallon curve by the maximum ton capacity of the truck. This linear assumption is not strictly correct; however, it was felt that the effort to introduce additional accuracy would not be justified given other study assumptions.

The remaining numbers in Tables A-13 and A-14 are obtained by indexing the benchmark trucks as follows:

> Irregular body trucks were assumed (for lack of aerodynamic data) to be the same as box-body trucks.
>
> Diesel trucks were given 1.2 times the miles per gallon as gasoline trucks within the same weight class. Gasoline trucks were, in turn, .83 (the inverse of 1.2) times the miles per gallon of diesel where diesel trucks were used as benchmark.
>
> Diesel truck "slope" figures (i.e., change in miles per gallon per ton change in GVW or load) were obtained by multiplying the gasoline benchmark slopes by the following factors for each speed: 45 mph - 1.078; 50 mph - 1.0724; 55 mph - 1.0668; 60 mph - 1.0612; 65 mph - 1.0556; and 70 mph - 1.05. If a gasoline truck figure was developed from a diesel benchmark, the inverse of these figures was used.
>
> Because tank trucks have smooth bodies and smaller frontal areas than "box" trucks, miles per gallon for both gasoline and diesel trucks were increased by the following factors: 45 mph - 1.005; 50 mph - 1.044; 55 mph - 1.085; 60 mph - 1.124; 65 mph - 1.129; and 70 mph - 1.136. In one case, the benchmark truck was a tank truck. From this case, to estimate the "box" truck fuel consumption rate in the corresponding weight class, these same factors were used as divisors instead of multipliers.

TABLE A-8

CALCULATION OF FUEL CONSUMPTION
(14,000-LB., GVW, GASOLINE-POWERED TRUCK)*

EMPTY:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/H	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	6.92	7.8	10.63	25.35	.51	1.846	16.25
40	10.03	8.6	25.21	43.84	.5	3.13	12.78
50	13.55	9.4	49.25	72.20	.5	5.16	9.69
60	12.47	10.2	85.1	112.80	.525	8.46	7.09
70	21.80	11.0	135.0	167.80	.55	13.18	5.31

LOADED:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/H	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	11.53	7.8	10.63	29.96	.51	2.18	13.76
40	16.73	8.6	25.21	50.54	.5	3.61	11.08
50	22.58	9.4	49.25	81.23	.5	5.80	8.62
60	29.12	10.2	85.1	124.42	.525	9.42	6.36
70	36.33	11.0	135.0	182.33	.55	14.32	4.89

* Assumes: 8,400 lb. tare weight, 80 sq. ft. frontal area, 190 rated HP engine.

TABLE A-9

CALCULATION OF FUEL CONSUMPTION
(24,000-LB., GVW, GASOLINE-POWERED TRUCK)*

EMPTY:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	7.74	10.1	11.82	29.66	.51	2.16	13.89
40	11.23	12.0	28.0	51.23	.5	3.66	10.92
50	15.2	13.8	54.75	83.75	.5	5.98	8.36
60	19.6	15.8	94.6	130.0	.53	9.84	6.10
70	24.4	17.4	150.2	192.0	.55	15.09	4.63

LOADED:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	19.77	10.1	11.82	41.69	.51	3.03	9.9
40	28.68	12.0	28.0	68.68	.5	4.91	8.15
50	38.71	13.8	54.75	107.26	.5	7.66	6.52
60	49.92	15.8	94.6	160.32	.53	12.14	4.94
70	62.3	17.4	150.2	229.90	.55	18.06	3.875

* Assumes: 9,400 lb. tare weight, 88 sq. ft. frontal area, 230 rated HP engine.

TABLE A-10

CALCULATION OF FUEL CONSUMPTION (40,000-LB., GVW, DIESEL-POWERED TRUCK)*

EMPTY:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	12.2	11.0	11.82	35.02	.6	3.0	10.0
40	17.7	13.1	28.0	58.8	.43	3.61	11.08
50	23.9	15.1	54.75	93.8	.39	5.23	9.56
60	30.8	17.1	94.6	142.4	.37	7.52	7.97
70	38.4	19.1	150.2	207.6	.38	11.27	6.21

LOADED:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	33.0	11.0	11.8	55.8	.6	4.78	6.27
40	47.8	13.1	28.0	88.9	.43	5.46	7.32
50	64.5	15.1	54.8	134.4	.39	7.48	6.68
60	83.2	17.1	94.6	194.9	.37	10.30	5.83
70	103.8	19.0	150.2	272.0	.38	14.77	4.73

* Assumes: 14,800 lb. tare weight, 88 sq. ft. frontal area, 280 rated HP engine.

TABLE A-11

CALCULATION OF FUEL CONSUMPTION
(55,000-LB., GVW, DIESEL-POWERED TRUCK)*

EMPTY:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	16.6	12.2	12.96	41.76	.5	2.98	10.06
40	24.7	14.6	30.7	70.0	.42	4.2	9.52
50	32.6	17.8	60.0	110.4	.38	5.99	8.34
60	42.0	19.0	103.7	164.7	.37	8.94	6.71
70	52.4	21.0	165.0	238.0	.38	12.92	5.40

LOADED:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
30	45.32	12.2	12.96	70.48	.48	4.83	6.21
40	65.72	14.6	30.7	111.0	.415	6.58	6.07
50	88.72	17.8	60.0	166.5	.375	8.92	5.61
60	114.4	19.0	103.7	237.1	.367	12.42	4.83
70	142.7	21.0	165.0	328.7	.38	17.84	3.92

* Assumes: 20,200 lb. tare weight, 96 sq. ft. frontal area, 330 rated HP engine.

TABLE A-12

CALCULATION OF FUEL CONSUMPTION
(70,000-LB., GVW, DIESEL-POWERED TRUCK)*

EMPTY:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
10	5.85	10	.52	16.4	.6	1.405	7.117
20	12.93	12.5	4.1	29.5	.55	2.317	8.63
30	21.5	15	14.4	50.9	.46	3.34	8.98
40	30.8	17.5	33.4	81.7	.40	4.668	8.56
50	41.6	20	65.3	126.9	.37	6.707	7.45
60	53.7	22.5	112.7	188.9	.36	9.714	6.18
70	67.0	25	179.0	271.0	.38	14.71	4.76

LOADED:

VELOCITY (MPH)	HP REQUIRED BY RESISTANCE TYPE				SPECIFIC FUEL CONSUMPTION LBS/BHP/HR	GALLONS PER HOUR	MILES PER GALLON
	ROLLING	MECHANICAL	AIR	TOTAL			
10	15.89	10	.52	26.4	.6	2.26	4.4
20	35.07	12.5	4.1	51.67	.47	3.47	5.76
30	57.68	15	14.1	86.78	.42	5.21	5.75
40	83.65	17.5	33.4	134.55	.39	7.50	5.33
50	112.9	20	65.3	198.2	.36	10.19	4.91
60	145.6	22.5	112.7	280.8	.36	14.44	4.16
70	181.7	25	179.0	385.7	.38	20.94	3.34

* Assumes: 25,800 lb. tare weight, 104 sq. ft. frontal area, 390 rated HP engine.

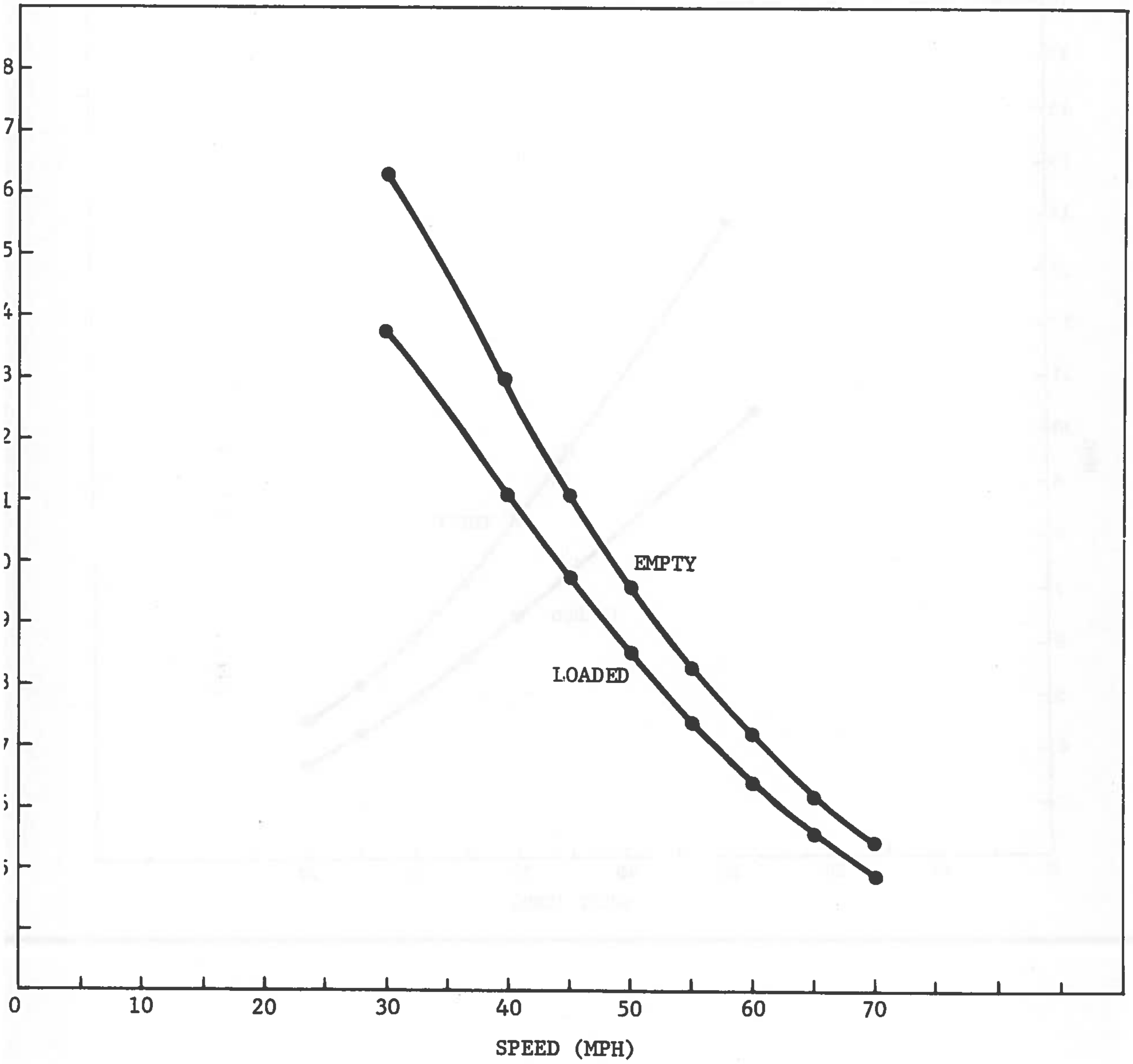

FIGURE A-2: FUEL CONSUMPTION RATE BY SPEED
(14,000-LB., GVW, GASOLINE-POWERED TRUCK)

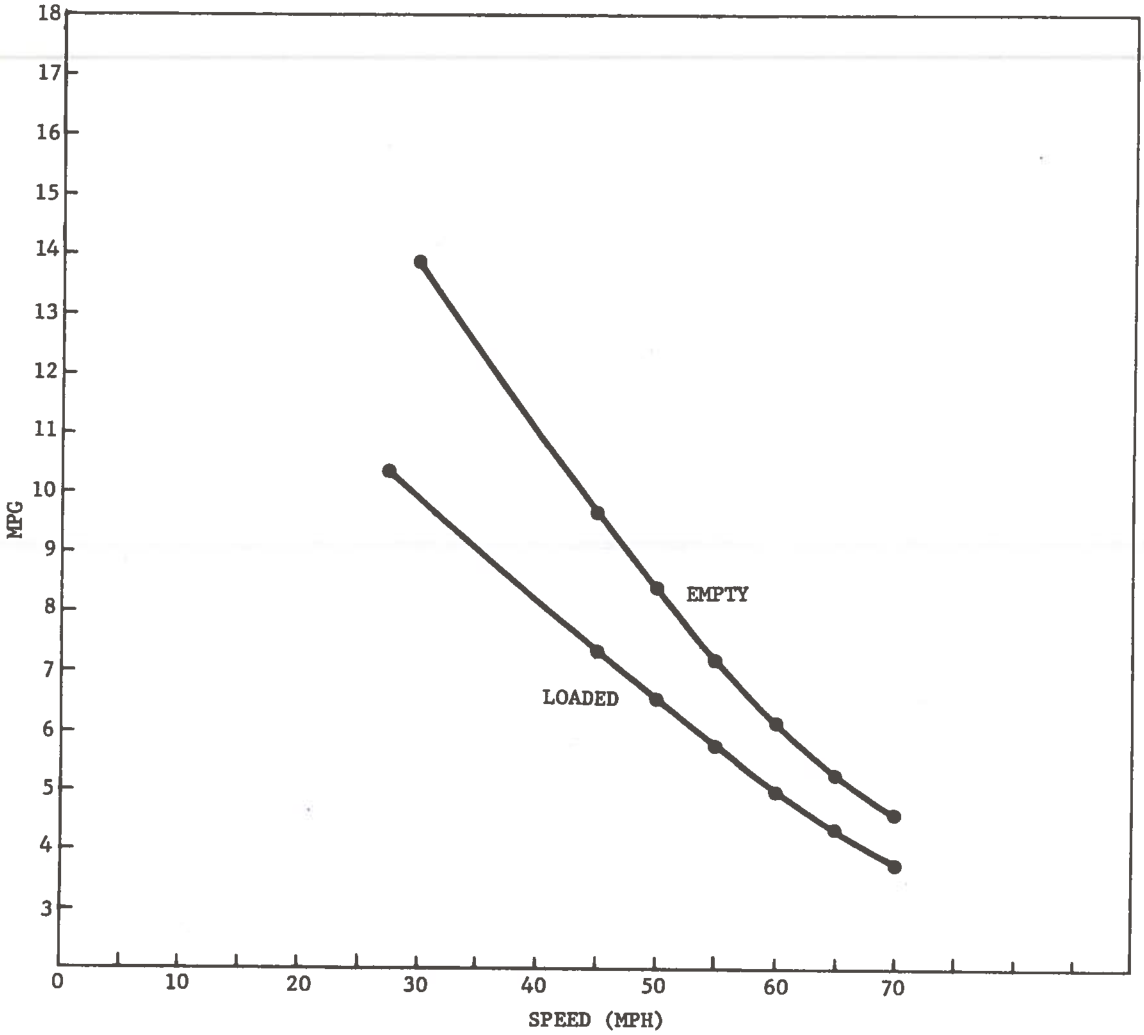

FIGURE A-3: FUEL CONSUMPTION RATE BY SPEED
(24,000-LB., GVW, GASOLINE-POWERED TRUCK)

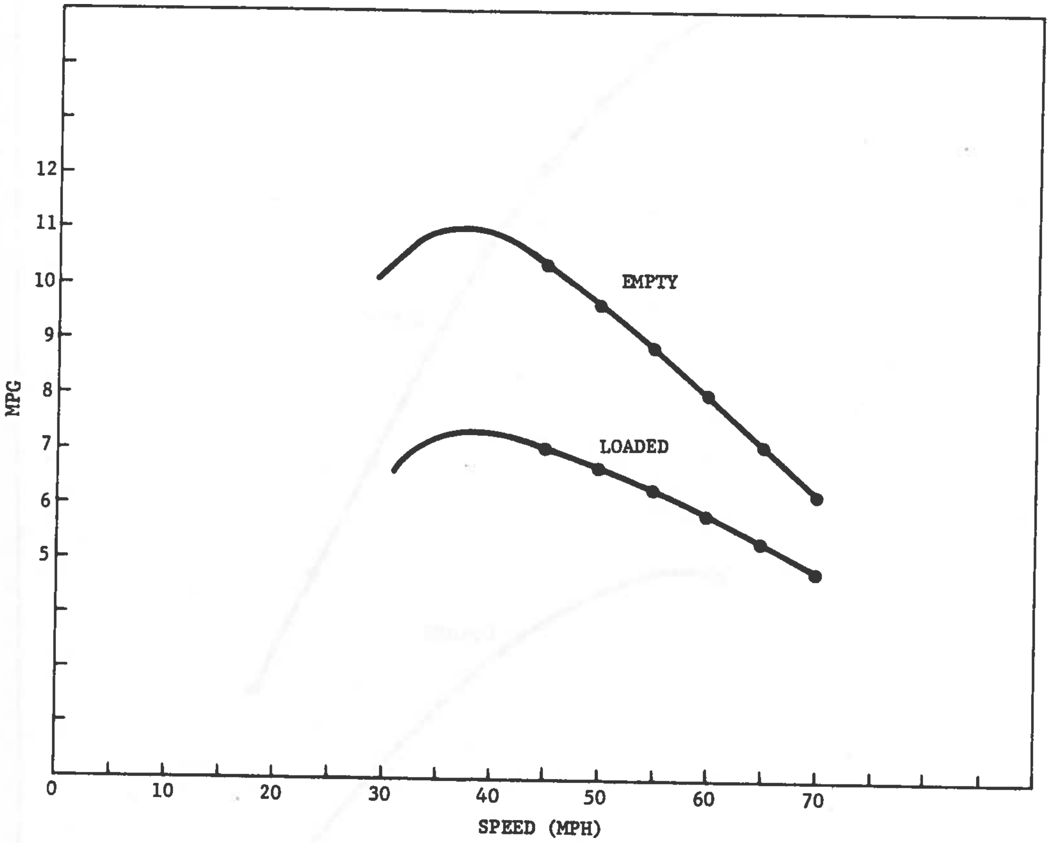

FIGURE A-4: FUEL CONSUMPTION RATE BY SPEED
(40,000-LB., GVW, DIESEL-POWERED TRUCK)

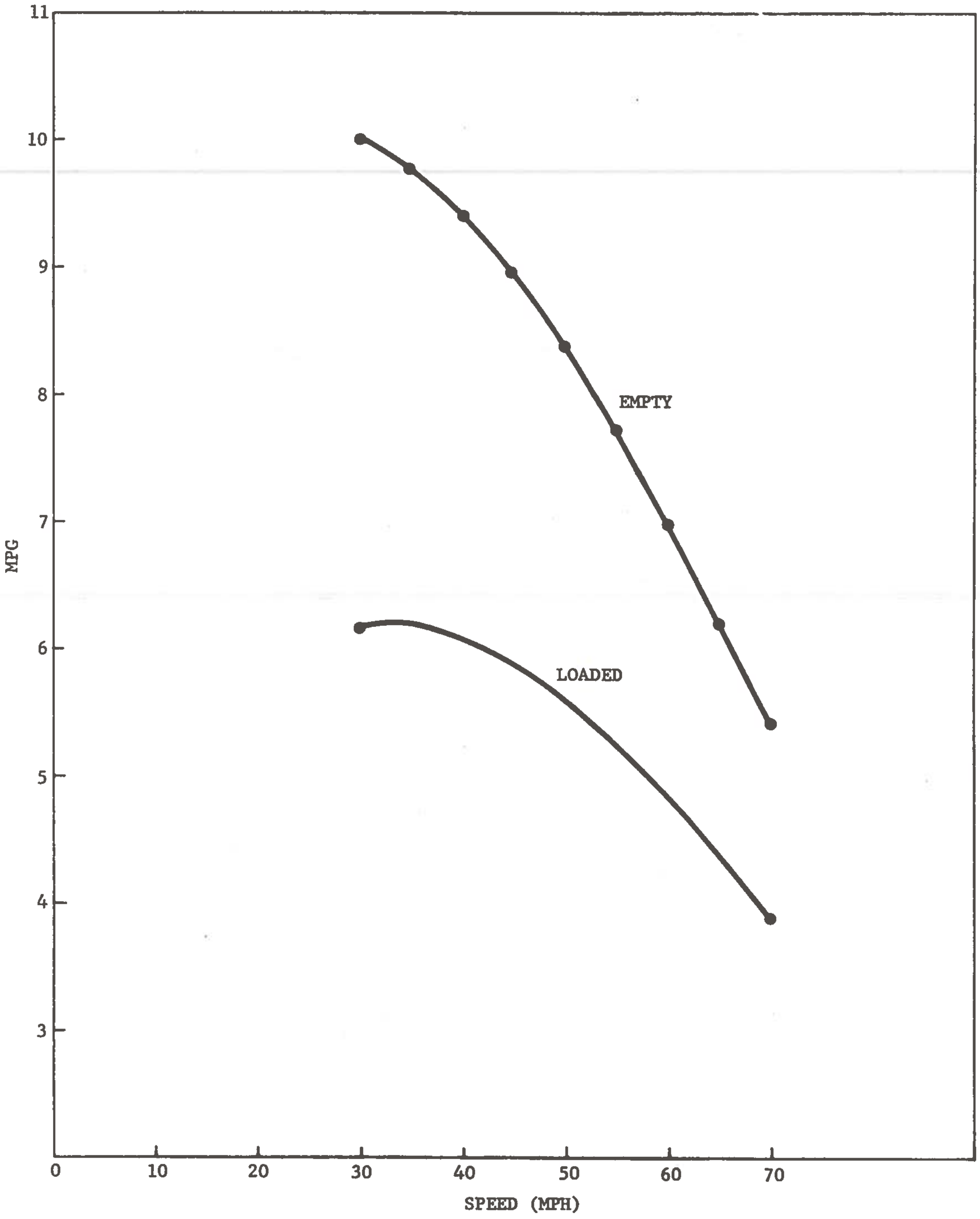

FIGURE A-5: FUEL CONSUMPTION RATE BY SPEED
(55,000-LB., GVW, DIESEL-POWERED TRUCK)

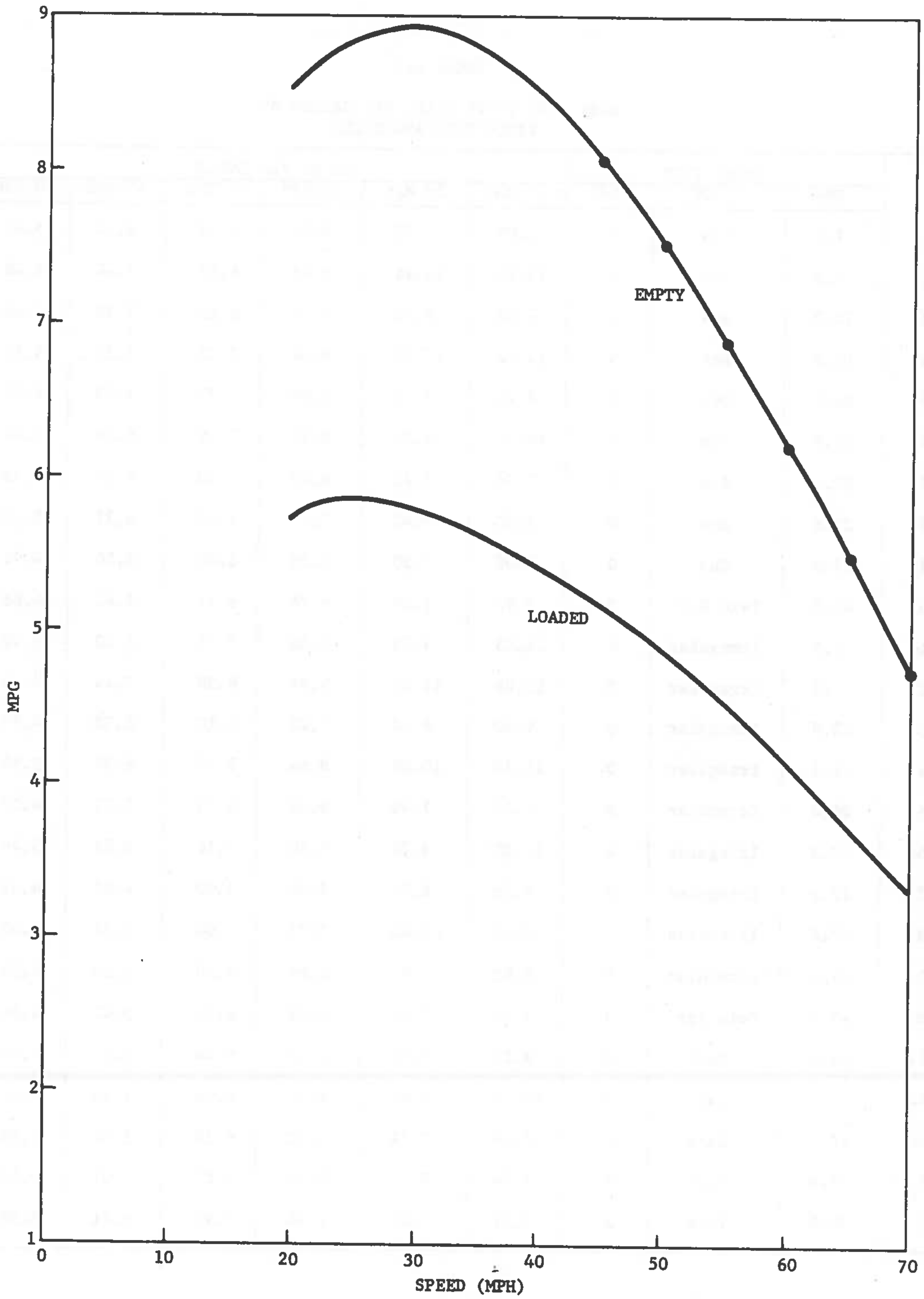

FIGURE A-6: FUEL CONSUMPTION RATE BY SPEED (70,000-LB., GVW, DIESEL-POWERED TRUCK)

TABLE A-13

BASE CASE EMPTY MILES PER GALLON BY TRUCK TYPE AND SPEED

	TRUCK TYPE			MILES PER GALLON					
	GVW	BODY	FUEL	45 MPH	50 MPH	55 MPH	60 MPH	65 MPH	70 MPH
1.	7.0	Box	G	11.05	9.55	8.30	7.15	6.20	5.40
2.	7.3	Box	D	13.26	11.46	9.96	8.58	7.44	6.48
3.	12.0	Box	G	9.60	8.40	7.20	6.10	5.30	4.60
4.	12.3	Box	D	11.52	10.08	8.64	7.32	6.36	5.52
5.	21.5	Box	G	8.24	7.40	6.56	5.73	5.03	4.37
6.	21.8	Box	D	10.30	9.24	8.20	7.16	6.29	5.46
7.	27.5	Box	G	7.36	6.72	6.20	5.60	4.97	4.32
8.	27.6	Box	D	9.20	8.40	7.73	7.00	6.21	5.40
9.	36.0	Box	D	8.05	7.50	6.86	6.20	5.50	4.72
10.	40.0	Twin Box	D	7.92	7.38	6.76	6.11	5.42	4.66
11.	7.0	Irregular	G	11.05	9.55	8.30	7.15	6.20	5.40
12.	7.3	Irregular	D	13.26	11.46	9.96	8.58	7.44	6.48
13.	12.0	Irregular	G	9.60	8.40	7.20	6.10	5.30	4.60
14.	12.3	Irregular	D	11.52	10.08	8.64	7.32	6.36	5.52
15.	20.0	Irregular	G	8.24	7.40	6.56	5.73	5.03	4.37
16.	20.3	Irregular	D	10.30	9.24	8.20	7.16	6.29	5.46
17.	27.5	Irregular	G	7.36	6.72	6.20	5.60	4.97	4.32
18.	27.8	Irregular	D	9.20	8.40	7.75	7.00	6.21	5.40
19.	36.0	Irregular	D	8.05	7.50	6.86	6.20	5.50	4.72
20.	40.0	Twin Irr.	D	7.92	7.38	6.76	6.11	5.42	4.66
21.	20.0	Tank	G	8.28	7.72	7.12	6.44	5.68	4.96
22.	20.3	Tank	D	10.35	9.65	8.90	8.05	7.10	6.20
23.	27.5	Tank	G	7.39	7.02	6.73	6.30	5.61	4.90
24.	27.8	Tank	D	9.24	8.77	8.41	7.87	7.01	6.13
25.	36.0	Tank	D	8.09	7.83	7.44	6.97	6.21	5.36

TABLE A-14

BASE CASE "SLOPE"* VALUES FOR LOADED MILES PER GALLON BY TRUCK TYPE AND SPEED

	TRUCK TYPE			SPEED (MILES PER HOUR)					
	GVW	BODY	FUEL	45	50	55	60	65	70
1.	7.0	Box	G	.464	.392	.321	.285	.214	.160
2.	7.3	Box	D	.500	.420	.342	.302	.226	.168
3.	12.0	Box	G	.315	.253	.198	.157	.123	.109
4.	12.3	Box	D	.340	.271	.211	.167	.130	.114
5.	21.5	Box	G	.228	.207	.179	.152	.122	.095
6.	21.8	Box	D	.246	.222	.191	.161	.129	.100
7.	27.5	Box	G	.165	.149	.131	.115	.097	.082
8.	27.6	Box	D	.178	.160	.140	.122	.103	.086
9.	36.0	Box	D	.130	.117	.104	.094	.078	.063
10.	40.0	Twin Box	D	.130	.117	.104	.094	.078	.063
11.	7.0	Irregular	G	.464	.392	.321	.285	.214	.160
12.	7.3	Irregular	D	.500	.420	.342	.302	.226	.168
13.	12.0	Irregular	G	.315	.253	.198	.157	.123	.109
14.	12.3	Irregular	D	.340	.271	.211	.167	.130	.114
15.	20.0	Irregular	G	.228	.207	.179	.152	.122	.095
16.	20.3	Irregular	D	.246	.222	.191	.161	.129	.100
17.	27.5	Irregular	G	.165	.149	.131	.115	.097	.082
18.	27.8	Irregular	D	.178	.160	.140	.122	.103	.086
19.	36.0	Irregular	D	.130	.117	.104	.094	.078	.063
20.	40.0	Twin Irr.	D	.130	.117	.104	.094	.078	.063
21.	20.0	Tank	G	.242	.222	.193	.165	.134	.106
22.	20.3	Tank	D	.261	.238	.206	.175	.142	.111
23.	27.5	Tank	G	.175	.159	.142	.125	.107	.090
24.	27.8	Tank	D	.189	.171	.151	.133	.113	.095
25.	36.0	Tank	D	.138	.125	.112	.102	.086	.070

* The "Slope" variable is defined as the reduction in miles per gallon with the addition of each ton of load.

A.2.5 Commodity Characteristics

A.2.5.1 Truck Tons by Commodity

Truck tons, distributed by commodity group, form the basis for calculating truck traffic measures. Although data on the tonnage of each commodity shipped by trucks in intercity service are scarce, an estimate of total tons by commodity was developed. The development of model inputs from various data sources is discussed below.

A two-stage procedure was used to estimate total truck tons by commodity. The first stage involved developing estimates based on information in the Census of Transportation Commodity Survey.[1] The second stage involved modifying and extending that estimate by multiple regression analysis.

First-Stage Extension. The Census of Transportation Commodity Survey reports tonnage by commodities and modes, as represented in Table A-15. These figures are estimates of total shipments from manufacturing plants by the principal mode used to points beyond the local area. The shippers are classified according to the Standard Industrial Classification (SIC) Codes which have some correspondence to the Standard Transportation Commodity Codes (STCC) used in this study. Although the SIC commodity may not constitute a majority of a shipper's products, at the two-digit STCC level, the correspondence is within the accuracy needed for the method used.

The Census estimates of tons and ton-miles by commodity represent movements from manufacturing plants, and they represent the full population of the traffic. To extend the Census estimates to the total population of movements for the commodities surveyed, Census estimates for rail and water were compared to known data for these two modes, assuming representation for all modes is about the same. Table A-16 compares the study commodities with the Census shipper groups. Table A-17 gives the tons of the study commodity groups shipped by the various modes as computed from the Census commodity groups.

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[1] Bureau of the Census, Census of Transportation 1972, Transportation Commodity Survey, U.S. Government Printing Office, Washington, D.C., 1975.

TABLE A-15

Tons by Shipper Groups and Modes

(1972)

Shipper group	TOTAL TONS	Means of transport							
		All means of transport	Rail	Motor carrier	Private truck	Air	Water	Other	Unknown
	Thousands	Percent distribution							
Total tons	1,484,492	100.0	31.7	31.1	18.3	–	18.3	0.2	0.3
Meat and dairy products	42,616	100.0	18.8	41.7	39.1	–	.1	.1	.2
Canned and frozen foods and other food products, except meat and dairy products	154,015	100.0	50.7	20.3	23.0	–	5.5	–	.5
Candy, cookies and crackers, beverages, and tobacco products[1]	57,996	100.0	15.4	25.7	58.4	–	.2	–	.2
Basic textiles and leather products	14,209	100.0	9.7	61.4	27.7	0.1	–	.9	.2
Apparel and related products	5,798	100.0	8.5	69.4	15.6	2.0	–	4.3	.2
Paper and allied products	89,410	100.0	51.7	28.0	17.9	–	2.1	.1	.1
Basic chemicals, plastics materials, synthetic resins, rubber, and fibers	111,853	100.0	48.6	30.1	12.1	–	8.6	.4	.2
Drugs, paints, and other chemical products	56,902	100.0	37.8	38.6	15.7	–	7.4	.3	.2
Petroleum and coal products	348,137	100.0	9.7	16.0	8.4	–	65.3	.2	.3
Rubber and plastics products	15,877	100.0	24.4	59.1	15.2	.7	–	.3	.2
Lumber and wood products, except furniture	70,991	100.0	45.8	16.2	36.3	–	1.3	–	.3
Furniture, fixtures, and miscellaneous manufactured products	14,371	100.0	22.0	41.4	34.7	.3	.2	1.2	.2
Stone, clay, and glass products	178,122	100.0	21.9	47.2	23.7	–	6.4	–	.8
Primary iron and steel products	139,461	100.0	43.7	44.4	6.7	–	4.8	.3	.1
Primary nonferrous metal products	29,954	100.0	51.6	31.4	15.1	–	1.5	.2	.2
Fabricated metal products, except metal cans and miscellaneous fabricated metal products	14,870	100.0	17.3	55.3	25.1	.2	1.3	.5	.3
Metal cans and miscellaneous fabricated metal products	23,695	100.0	36.8	44.1	17.8	.3	.3	.4	.3
Industrial machinery, except electrical	8,699	100.0	19.6	59.4	18.9	.6	.1	1.2	.1
Machinery, except electrical and industrial	16,222	100.0	26.5	53.4	17.7	.6	.2	1.0	.5
Communications products and parts	2,327	100.0	13.0	64.5	12.4	6.1	–	3.4	.5
Electrical products and supplies	13,131	100.0	35.0	49.3	14.1	.4	–	.7	.2
Motor vehicles and equipment	56,716	100.0	59.3	37.3	3.0	–	–	.2	.2
Transportation equipment, except motor vehicles	6,506	100.0	19.5	23.0	54.8	.4	.4	.5	.5
Instruments, photographic equipment, watches, and clocks	1,603	100.0	20.9	63.8	10.9	2.0	.1	2.1	.2

urce: Ibid., Shipper Groups TC72C3-3, p. 9.

TABLE A-16

CENSUS SHIPPER GROUPS COMPARED TO STUDY COMMODITY GROUPS

STUDY COMMODITIES	CENSUS SHIPPER GROUPS
1. Agriculture	Not Surveyed
2. Metallic Ores	Not Surveyed
3. Coal & Coke	9 Petroleum Coal Prod. (299)*
4. Petroleum	9 Petroleum Coal Prod. (less 299)
5. Non-Metallic Minerals	Not Surveyed
6. Food & Kindred Products	1. Meat & Dairy Products 2. Canned & Frozen Foods & Other 3. Candy, Cookies, Crackers, Bev. & Tobacco
7. Textile Apparel & Leather	4. Basic Textile & Leather 5. Apparel & Related
8. Lumber & Furniture	11. Lumber & Wood Products ex. Furniture Commodity Series 251,253,254
9. Pulp, Paper & Allied	6. Paper and Allied Products
10. Chemicals & Allied	7. Basic Chemicals Plastics 8. Drugs, Paints & Other Chemicals
11. Rubber & Plastics	10. Rubber & Plastic Products
12. Stone, Clay & Glass	13. Stone, Clay & Glass Products
13. Primary Metal Products	14. Primary Iron & Steel 15. Primary Non-Ferrous Metal
14. Fabricated Metal Prod.	16. Fabricated Metal ex. Metal Cans 17. Metal Cans & Misc.Metal Prod.
15. Machinery Except Elec.	18. Machinery ex. Elec. & Indust. 19. Industrial Machinery ex. Elec.
16. Electrical Machinery	20. Communication Products & Ports 21. Electrical Products & Supplies
17. Transportation Equip.	22. Motor Vehicles & Equip.
18. Instruments & Misc. Mfg.	23. Other Transportation
18. Instruments & Misc. Mfg.	24. Instruments, Photo Equip. 12. Misc. (less 251, 253,254)*
19. Waste & Scrap	Not Surveyed

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* These calculations made with data from the Commodity Series: U.S. Bureau of the Census, Census of Transportation 1972: COMMODITY TRANSPORTATION SURVEY - COMMODITY SERIES: TC72C1-2. TC72C1-8, Washington D.C. 1975.

TABLE A-17

CENSUS TONS BY STUDY COMMODITY GROUP AND MODE*
(thousands)
(1972)

COMMODITY STCC STUDY GROUPS	TRUCK	RAIL	WATER
1. Agriculture	-	-	-
2. Metallic Ores	-	-	-
3. Coal and Coke	1,673	9,083	2,177
4. Petroleum	83,272	24,686	225,156
5. Non-Metallic Minerals	-	-	-
6. Food & Kindred Prod.	149,897	95,029	8,629
7. Textiles, Apparel & Leather	17,588	1,871	-
8. Lumber & Furniture	48,835	38,950	1,044
9. Pulp, Paper & Allied	38,744	46,225	1,878
Chemicals & Allied	80,246	76,626	13,978
Rubber & Plastics	11,796	3,874	-
Stone, Clay & Glass	126,289	39,009	11,400
Primary Metal Prod.	85,194	76,401	7,143
Fabricated Metal Prod.	26,622	11,292	264
Machinery ex. Elec.	18,345	6,004	41
Electrical Machinery	10,115	4,898	
Transportation Equip.	27,976	34,901	26
Instruments & Misc. Mfg.	5,727	1,183	25
Waste & Scrap	-	-	-
TOTAL	-	-	-

*Represents a survey of an unknown percentage of the total population.

Source: Calculated from Table A-15, according to relationships outlined in Table A-16.

The figures in Table A-16 represent a portion of all the tons of given commodities shipped by trucks, railroads, and water carriers. For trucks, it is not possible to estimate the size of that portion relative to total tons, which is a serious national data deficiency. However, for rail and water, published statistics are available of all tons shipped in intercity traffic by commodity. A comparison was made between the Census population and the total tons for rail and water. Table A-18 shows the intercity tons for rail and water (water includes inland, lakewise, and coastwise for domestic traffic) and the portion of the total which was surveyed in the Census of Transportation.

The tons shipped from manufacturers as reported by the Census could be greater than the tons reported carried by railroads because of (1) sampling variability (largely double counting) and (2) inconsistency in data classification. The Census data are based on Standard Industrial Classification (SIC) which identifies plants, while the ICC rail and the Corps of Engineers water statistics are compiled by the Standard Transportation Commodity Code system, which identify commodities produced. Since this study uses STCC codes at the two-digit level, it would be necessary for a two-digit plant to produce three or more different two-digit commodities for that plant's major commodity shipments to be less than half of its total shipments for the STCC commodity corresponding to its SIC code. Nonetheless, this is an important source of error in using the Census estimates.

An average between the water proportion and the rail proportion was used to scale, or index, the Census truck estimates to the total population of truck movements for each commodity. Table A-19 shows the expanded Census figures and the expansion factor used. This indexing factor is derived by the expression:

$$\frac{1}{.5\left(\frac{\text{Census rail}}{\text{Total rail}}\right)+.5\left(\frac{\text{Census water}}{\text{Total water}}\right)} \qquad \text{(A-11)}$$

It would not be correct to sum the tons in column 1 of Table A-17 to find the proportion because (1) the proportion of the Census to total will vary from commodity to commodity and (2) the Census does not cover all commodities which make the numerator of a different order than the denominator.

TABLE A-18

TOTAL TONS FOR RAIL AND WATER COMPARED TO CENSUS TONS
(thousands)

Commodity	Rail		Water	
	Tons[1]	Census Tons ÷ Total Tons	Tons[2]	Census Tons ÷ Total Tons
Agriculture	130,758	-	56,365	-
Metallic Ores	110,034	-	74,749	-
Coal and Coke	386,098	.02352	147,982	.01471
Petroleum	38,301	.64928	367,479	.61270
Non-Metallic Minerals	164,695		121,840	-
Food & Kindred	106,747	.89019	11,497	.75054
Textiles	1,709	1.09479	33	0
Lumber & Furniture	111,988	.34781	20,900	.04995
Pulp, Paper & Allied	44,299	1.04348	3,944	.47617
Chemicals & Allied	95,163	.80521	44,244	.31593
Rubber & Plastics	4,037	.95962	108	0
Stone, Clay & Glass	73,457	.53105	14,625	.77949
Primary Metal Prod.	60,883	1.25488	10,673	.66926
Fabricated Metal Prod.	9,380	1.20384	1,132	.23322
Machinery ex. Elec.	3,748	1.60192	610	.06721
Elec. Machinery	4,550	1.07684	196	0
Transportation Equip.	31,373	1.11245	833	.03121
Instruments & Misc.	665	1.77895	1,225	.02041
Waste & Scrap	39,795	-	13,186	-

Interstate Commerce Commission, <u>Freight Commodity Statistics of Class I Railroads in the United States, Calendar Year 1972</u>, U.S. Government Printing Office, Washington D.C. pp2-9

U.S. Army Corps. of Engineers, <u>Waterborne Commerce of the U.S., Calendar Year 1972, Part 5</u>, U.S.A. Engineer Division, Vicksburg Mississippi, pp. 7-9.

TABLE A-19

FIRST STAGE ESTIMATES OF TRUCK TONS BY COMMODITY

COMMODITY	INDEXING FACTOR USED**	RESULTING FIRST STAGE THOUSANDS OF TONS**
1. Agriculture		
2. Metallic Ores		
3. Coal and Coke	52.3149*	87,523*
4. Petroleum	1.58481	131,970
5. Non-Metallic Minerals	-	-
6. Food & Kindred Prod.	1.21897	182,720
7. Textiles, Apparel & Leather	1.82683	32,130
8. Lumber & Furniture	5.02816	245,550
9. Pulp, Paper & Allied	1.31609	50,991
10. Chemicals & Allied	1.78390	143,151
11. Rubber & Plastics	2.08412	24,585
12. Stone, Clay & Glass	1.52609	192,728
13. Primary Metal Prod.	1.03943	88,553
14. Fabricated Metal Prod.	1.39173	37,051
15. Machinery ex. Elec.	1.19823	21,982
16. Electrical Machinery	1.85729	18,786
17. Transportation Equip.	1.74877	48,924
18. Instruments & Misc. Mfg.	1.1151	6,366
19. Waste & Scrap	-	-

* Coal was dropped in the regression because the Census estimate is for coke only, and it was felt that this value seriously biased the results.

** Calculated from Table A-18 ratios and the indexing factor formula.

The basis for this indexing is, at best, arbitrary, especially when applied to individual commodities, since there is no way to establish the validity of this approach without control totals. Considerable additional research is needed in this area to develop statistically reliable estimates of truck movements by vehicle type and commodity. With the current level of information and scope of study, no economical alternative approach exists which would yield more reliable information.

Second-State Estimate. To improve these estimates and compute values for the commodities not covered in the Census, second-stage estimates were made of truck tons, by commodity group, to maximize the use of available information. The second-stage procedure involved regression analysis and was based on two assumptions:

> that total tons of a commodity carried by all trucks would vary with the total mileage of trucks attributable to a commodity (given a constant average haul and empty return ratio); and
>
> that regulated traffic for regulated commodity groups was related to total truck traffic for that commodity.

Data from the Census of Transportation and the Interstate Commerce Commission exist for all commodity groups in the study for vehicle miles by commodity and tons of regulated carriage respectively. Table A-20 shows the vehicle miles and Class I tons by commodity used as independent variables in a multiple regression on the first-stage estimates of Table A-19.

The second-stage estimates are the fitted values to the coefficients calculated in the regression formula. These fitted values are given in Table A-21. The formula from which the final estimates were calculated is:

$$T_i = \underset{(48426)}{4456} + \underset{(17.326)}{25.564}M_i + \underset{(.61928)}{.62835}RT_i \qquad \text{(A-12)}$$

where:

T_i is the truck ton estimate for commodity, i
M_i is the vehicle miles attributable to commodity, i
RT_i is the Class I regulated tons of commodity, i

TABLE A-20

TRUCK MILES AND ICC CLASS I TONS BY COMMODITY

COMMODITY	TRUCK MILES (Million)[1]	CLASS I TONS (Thousand)[2] ORIGINATED BY CLASS I CARRIERS
1. Agriculture	9,259	8,431
2. Metallic Ores	103	858
3. Coal and Coke	65	725
4. Petroleum	2,656	129,480
5. Non-Metallic Minerals	696	8,276
6. Food & Kindred Prod.	5,460	33,830
7. Textiles, Apparel & Leather	2,339	6,571
8. Lumber & Furniture	2,084	7,358
9. Pulp, Paper & Allied	1,248	13,275
10. Chemicals & Allied	2,814	46,329
11. Rubber & Plastics	1,805	5,212
12. Stone, Clay & Glass	4,136	29,285
13. Primary Metal Prod.	1,512	32,827
14. Fabricated Metal Prod.	2,661	7,308
15. Machinery ex. Elec.	1,556	7,301
16. Electrical Machinery	1,764	4,110
17. Transportation Equip.	3,958	31,004
18. Instruments & Misc. Mfg.	2,713	3,779
19. Waste & Scrap	251	1,152
Total	47,080	377,111

[1] The derivation of truck miles by study commodity groups has been discussed previously.

[2] Interstate Commerce Commission, FREIGHT COMMODITY STATISTICS, MOTOR CARRIERS OF PROPERTY, YEAR ENDED DECEMBER 31, 1972, U.S. Government Printing Office, Washington, D.C., p.2-9.

TABLE A-21

FINAL ESTIMATE: TRUCK TONS BY COMMODITY

COMMODITY	TONS (Thousands)
1. Agriculture	246,451
2. Metallic Ores	7,628
3. Coal and Coke	6,573
4. Petroleum	153,713
5. Non-Metallic Minerals	27,449
6. Food & Kindred Prod.	165,293
7. Textiles, Apparel & Leather	68,379
8. Lumber & Furniture	62,355
9. Pulp, Paper & Allied	44,701
10. Chemicals & Allied	105,504
11. Rubber & Plastics	53,874
12. Stone, Clay & Glass	128,590
13. Primary Metal Prod.	63,736
14. Fabricated Metal Prod.	77,074
15. Machinery ex. Elec.	48,821
16. Electrical Machinery	52,133
17. Transportation Equip.	125,120
18. Instruments & Misc. Mfg.	76,186
19. Waste & Scrap	11,596
TOTAL	1,525,176

The regression had a multiple R of .52284 and an R square of .27337. The standard errors are in parentheses under the coefficient estimates. At best, the regression analysis is not conclusive.

Outcome of Two-Stage Analysis. The two-stage analysis was based on two assumptions:

> that the overall scale of the estimate and a portion of the variation between commodities can be based on the size of shipments from manufacturers, with shipments scaled upward by comparison with shipments by rail and water; and
>
> that additional variation between commodities may be adequately explained by the variation that exists between measures by commodity and of vehicle miles and regulated traffic.

Regression was used in this analysis as a estimate for only those five commodity groups not covered by the Census. For the remaining commodity groups, this procedure was viewed as an averaging process to weight the first-stage estimates with ICC data. An attempt was made to "smooth out" the sample variation observed in Census data with that reported by the ICC for regulated carriers and the Census estimates of vehicle miles. Unfortunately, the statistical confidence of this approach is not very high, because of low correlation, or high variances among the independent variables.

A.2.5.2 Capacity-to-Ton Ratio Commodity

A truck's load-carrying capacity is determined by its maximum rated or legal weight less the weight of the truck itself. However, to determine a truck's capacity with respect to a given commodity, it is important to know the density of that commodity (i.e., the weight per cubic foot) to know if the truck will fill up before the maximum weight is achieved. The load-capacity to net-weight-limit ratio by commodity, accounts for the density variations between commodities in terms of pounds per cubic foot to reflect whether a vehicle would be "cubed out" before the net weight capacity of the truck is reached. Table A-22 presents the estimates by experienced operators and the study team for this measure for the different commodities. More precise determination using sampling techniques was beyond the scope of study.

TABLE A-22

RATIO OF ACTUAL LOAD CAPACITY AS A PROPORTION OF MAXIMUM TON CAPACITY BY COMMODITY

COMMODITY	MAXIMUM LOAD CAPACITY TO NET WEIGHT LIMIT*
1. Agriculture	.90
2. Metallic Ores	1.00
3. Coal and Coke	.90
4. Petroleum	1.00
5. Non-Metallic Minerals	1.00
6. Food & Kindred Prod.	.90
7. Textiles, Apparel & Leather	.75
8. Lumber & Furniture	.90
9. Pulp, Paper & Allied	1.00
10. Chemicals & Allied	.90
11. Rubber & Plastics	.75
12. Stone, Clay & Glass	.75
13. Primary Metal Prod.	1.00
14. Fabricated Metal Prod.	.90
15. Machinery ex. Elec.	1.00
16. Electrical Machinery	1.00
17. Transportation Equip.	.90
18. Instruments & Misc. Mfg.	.90
19. Waste & Scrap	1.00

* PMM&Co. estimate.

A.2.6 Overall Truck Characteristics

The Census of Transportation, Commodity Survey,[1] served as a basis for calculating the average length of haul per ton by commodity group for the 15 commodity groups in the survey. Length of values for the four additional nonmanufacturing commodities in this study were estimated, since no other source was available.

When the estimated average length of haul per ton for some commodities was multiplied by commodity tons, ton-miles exceeded available capacity ton-miles. This indicates problems with the average length of haul, capacity ton-mile estimates, or both, which again highlights the unreliability of government statistics on motor carrier transportation.

Because none of the truck data appeared to be reliable, the average length of haul was calculated by commodity by assuming the same average capacity utilization factor for all commodities.

An overall average length of haul (all commodities, all truck types) of 238 miles was estimated based on tons and ton-miles reported to the Census.[2] An estimate of 367,166 million ton-miles for all trucking in 1972 was obtained by the product of 238 miles and total tons (1,542,715 thousand) from Table A-21. When this ton-mile estimate is divided by the maximum ton-mile capacity (as calculated in equation A-2), the result is an overall capacity utilization ratio of .621. Average hauls by commodity were calculated by the TRANSEN model based on this overall capacity utilization ratio truck capacity within that commodity group, and tons for that commodity. Table A-23 presents the resulting base case average hauls by commodity, which represents a compromise with the reliability of available data.

Another assumption made by the study team was that all trucks, when loaded, would be loaded to 90 percent of their maximum capacity (weight or cube limit converted to weight) for that commodity. Therefore, based on equation A-4 the assumed overall backhaul ratio for all commodities was computed to be 0.310.

---

[1] Bureau of the Census, Shipper Groups, Washington, D.C., 1974.

[2] Ibid., pp. 9-10.

TABLE A-23

BASE CASE AVERAGE HAUL BY COMMODITY
(Miles)

COMMODITY GROUP NUMBER	AVERAGE HAUL
1. Agriculture	278
2. Metallic Ores	137
3. Coal and Coke	86
4. Petroleum	209
5. Non-Metallic Minerals	224
6. Food and Kindred Products	270
7. Textiles, Apparel, & Leather	235
8. Lumber and Furniture	210
9. Pulp, Paper, and Allied Products	186
10. Chemicals and Allied Products	251
11. Rubber and Plastics	227
12. Stone, Clay, and Glass	183
13. Primary Metal Products	271
14. Fabricated Metal Products	323
15. Machinery, Nonelectrical	319
16. Electrical Machinery	221
17. Transportation Equipment	199
18. Instruments and Misc. Manufacturing	179
19. Waste and Scrap	121

The procedures and assumptions used in the development of this model were constrained by the study scope and the reliability and detail of data. Considerable more research and systematic data collection, preferably on a national scale, need to be performed before the time and expense required to develop a much more sophisticated model can be justified. Because the estimation of energy use is based on averages, these data can lead to erroneous conclusions if used to make judgment for specific situations. Although averages are used, they are refined to a level of detail by vehicle and commodity which includes characteristics of the vehicle, commodity, loading characteristics, empty backhaul of vehicle types used, and other relevant energy factors. Although considerable improvements are possible, they are predicated upon the need for better data, preferably national in scope. Nevertheless, this study and its detailed analysis represent a substantial contribution to the state of the art in understanding freight transportation energy consumption and sensitivities to operating and technological change.

A.3 SCENARIO DATA SOURCES

For the scenario analysis, the base-year variables change according to the year and scenario studied, with the exception of full-load to net-weight-capacity ratio (FLR) ratio and the load to capacity ratio (LOADCR).

A.3.1 Traffic Estimates

Base-case tonnage for 1980 and 1985 were obtained by assuming constant modal shares for the projected ton-miles. Table A-24 shows the base tonnage estimates derived from the ton-mile projections for 1980 and 1985 assuming the 1972 average haul. (See Section 4 for development of ton projections.)

For the industry change and government influence scenarios, it was assumed that some traffic would be attracted from truck to rail piggyback service. These modal shifts were assumed to involve 13 of the 19 commodity groups, with the extent of the shift varying by commodity group.

The basis for computing the size of the shift was a draft study of truck-rail competitive traffic by the American Trucking Association (ATA). The ATA study assumed that modal choice depended on the size of the shipment and the length of haul and that the critical values for these variables differed between commodities.

TABLE A-24

DISTRIBUTION OF COMPETITIVE AND CAPTURED FREIGHT BY COMMODITY AND MODE

(Percent of Total Traffic in Tons)

COMMODITY	COMPETITIVE		CAPTURED		TOTAL
	TRUCK	RAIL	TRUCK	RAIL	TRAFFIC
6. Food & Kindred Products	16	10	44	30	100
7. Textiles & Apparel	18	-	80	2	100
8. Lumber & Furniture	-	26	42	32	100
9. Pulp & Paper	20	11	30	39	100
10. Chemicals	16	3	37	44	100
11. Rubber & Plastics	44	5	49	2	100
12. Stone, Clay, & Glass Products	6	22	59	13	100
13. Primary Metal Products	6	18	45	31	100
14. Fabricated Metal Products	32	3	57	8	100
15. Machinery	40	-	52	8	100
16. Electrical Machinery	47	-	45	8	100
17. Transportation Equipment	35	-	23	42	100
18. Instruments & Misc. Manufacturing	33	-	59	8	100

Source: Calculated from data in ATA, (Draft) Intercity Freight Fuel Use Efficiencies - An Update, Jan. 1976, and base case modal shares in the TRANSEN model.

The ATA used data from the ICC and divided all rail traffic and regulated truck traffic into a matrix defined by shipment size and length of haul blocks for each commodity. If rail traffic (in tons) in a block exceeded 90 percent of the total traffic in that block, the total traffic in that block was considered "captured" by rail, that is, not subject to significant truck competition. In the same manner, captured traffic was defined for truck. The total traffic (truck plus rail) in those blocks in which neither mode exceeded 90 percent was considered to be competitive traffic. PMM&Co. further divided the ATA competitive traffic by subtracting the "captured" freight for truck from truck's base case percent share of total truck-rail traffic. (See Table A-24 for the results of this calculation.) For example, for commodity group 6, food and tobacco, in the base case, trucks carried 60 percent of the truck/rail total, and rail carried 40 percent. ATA found 44 percent of total truck/rail traffic to be truck captive and 30 percent of the total rail captive. The remaining 26 percent of the total was considered truck/rail competitive, which represents 16 percent (60 minus 44) moving by truck and 10 percent (40 minus 30) by rail.

Modal shifts assumed for future year scenarios were taken from the truck competitive traffic, that is, the traffic which trucks carried in the base case and for which, because of shipment size and length of haul, railroads could reasonably compete.

The assumed shifts for the industry change scenarios were 20 percent of the competitive traffic in 1980 and 40 percent of the competitive traffic in 1985. The government influence scenarios are characterized by shifts of 30 percent and 60 percent, respectively. For example, of all food and kindred products, 16 percent moves by truck which is considered competitive and 44 percent moves by truck which is considered captured. Thus, 16/60 (.27) of all food and kindred product truck tons (shown in Table A-25 for the 1980 base case) may be considered competitive, of which 20 percent is assumed to shift to rail by 1980 in the industry change scenario [(.27)(.2)(205,929) = 11,120]. This leaves 194,809 (205,929-11,120) for truck in the 1980 industry change scenario, as shown in Table A-26. Similar procedures were used for other calculations. For the sake of energy conservation, no reverse shifts from rail to truck were assumed. Whether any shifts actually occur is highly dependent on the impact of energy availability and fuel costs, and the ability of less energy intensive modes to satisfy the transportation needs of those who would prefer to ship by more energy intensive means.

TABLE A-25

BASE CASE ANNUAL TRUCK TONNAGE BY YEAR AND COMMODITY
(Thousands)

COMMODITY GROUP NUMBER	1980	1985
1. Agriculture	363,212	405,342
2. Metallic Ores	16,460	20,905
3. Coal and Coke	9,093	10,116
4. Petroleum	220,784	263,399
5. Non-Metallic Minerals	47,644	59,413
6. Food and Kindred Products	205,929	231,052
7. Textiles, Apparel, & Leather	92,970	104,681
8. Lumber and Furniture	73,185	82,697
9. Pulp, Paper, and Allied Products	80,176	98,679
10. Chemicals and Allied Products	182,000	226,227
11. Rubber and Plastics	85,110	102,982
12. Stone, Clay, and Glass	174,533	200,714
13. Primary Metal Products	106,619	129,222
14. Fabricated Metal Products	115,065	134,742
15. Machinery, Nonelectrical	81,163	99,668
16. Electrical Machinery	80,937	98,825
17. Transportation Equipment	211,064	240,403
18. Instruments and Misc. Manufacturing	118,604	145,879
19. Waste and Scrap	17,301	19,919
Total	2,281,849	2,674,865

Source: Adopted from ton-mile projections described in Chapter IV.

TABLE A-26

ANNUAL TRUCK TONNAGE BY YEAR, SCENARIO, AND COMMODITY
(Thousands)

COMMODITY GROUP NUMBER	INDUSTRY CHANGE		GOVERNMENT INFLUENCE	
	1980	1985	1980	1985
1. Agriculture	363,212	405,342	363,212	405,342
2. Metallic Ores	16,460	20,905	16,460	20,905
3. Coal and Coke	9,093	10,116	9,093	10,116
4. Petroleum	220,784	263,399	220,784	263,399
5. Non-Metallic Minerals	47,644	59,413	47,644	59,413
6. Food and Kindred Products	194,809	206,099	189,249	193,622
7. Textiles, Apparel, & Leather	89,624	97,144	87,950	93,735
8. Lumber and Furniture	73,185	82,697	73,185	82,697
9. Pulp, Paper, and Allied Products	73,762	82,905	70,555	75,010
10. Chemicals and Allied Products	171,080	199,080	165,620	185,506
11. Rubber and Plastics	77,110	84,033	73,110	73,942
12. Stone, Clay, and Glass	171,391	194,291	169,821	191,080
13. Primary Metal Products	104,061	123,019	102,781	119,918
14. Fabricated Metal Products	106,780	115,339	102,638	105,638
15. Machinery, Nonelectrical	74,183	82,525	70,693	73,954
16. Electrical Machinery	72,631	78,665	68,554	68,585
17. Transportation Equipment	185,736	182,706	173,072	153,858
18. Instruments and Misc. Manufacturing	110,065	110,868	105,795	93,363
19. Waste and Scrap	17,301	19,919	17,301	19,919
Total	2,178,961	2,418,465	2,127,517	2,290,002

Because the ATA study only presented the conclusions of the analysis without the backup data, it was necessary to make assumptions about the nature of the shifted traffic for the TRANSEN computations. The assumption was made that the shifted traffic was, on the average, carried 50 percent further than the truck overall average length of haul for that commodity. This assumption was made on the basis that the competitive traffic tended to have longer hauls than the overall average for truck. Using this assumption, it was possible to compute the ton-miles left to trucking after the shift.

By increasing the average hauls (see Table A-23) by 50 percent and multiplying by the number of tons shifted [(.054)(205,929)=11,120, in the above example] the assumed ton-miles shifted can be developed. The remaining ton-miles for trucks are obtained by subtracting the shifted ton-miles. A new average haul (all commodities) can then be calculated for each scenario by dividing the remaining ton-miles by the remaining tons (sum of all commodities). The "industry change" haul figures for truck are 232 miles in 1980 and 225 miles in 1985. The corresponding "government influence" figures are 229 and 218 miles.

Modal shift estimates and assumed average hauls are shown in Table A-27.

A.3.2 Vehicle Mile Calculation

Vehicle miles by truck type and commodity are the parameters extending individual truck performance to the total population of movements. Since 1980 and 1985 scenarios projections are given in ton-miles, these must be translated into vehicle miles by using assumptions consistent with the model.

First, the 1972 base case truck miles (TTM_{jk}) found in Table A-6 are reduced to an index which represents the proportional distribution, by truck type for each commodity, as found in Table A-28. The 1972 distribution of truck miles to truck types is the same distribution used for the 1980 and 1985 base cases. This distribution was assumed to change in the industry change and government influence scenarios. These changes reflect variations by truck types, with the variations occuring because the different scenarios analyzed shifts of traffic from one truck type to another (as from gasoline to diesel, or same to twin trailer). These shifts or "upgrading" estimates were made by the study team, because of inadequate source material. The last columns in the Table A-28 describe how each line item in the distribution matrix was modified. Decreases in one line item were added to the line item immediately below to preserve the total distribution as equal to 1.0.

TABLE A-27

ESTIMATE OF POTENTIAL MODAL SHIFT
TONS X 10^3

COMMODITY	1980		1985		AVERAGE HAUL PER TON
	INDUSTRY CHANGE	GOVERNMENT INFLUENCE	INDUSTRY CHANGE	GOVERNMENT INFLUENCE	
6 Food & Kindred Products	11,120	16,680	24,953	37,430	405
7 Textiles & Apparel	3,345	5,020	7,537	10,946	353
9 Pulp, Paper & Allied Prod.	6,414	9,621	15,774	23,669	279
10 Chemicals & Allied Prod.	10,920	16,380	27,147	46,721	377
11 Rubber & Plastics	8,000	12,000	18,949	29,040	341
12 Stone, Clay & Glass Prod.	3,142	4,712	6,423	9,634	275
13 Primary Metal Products	2,558	3,838	6,203	9,304	407
14 Fabricated Metal Products	8,285	12,427	19,403	29,104	485
15 Machinery, Nonelectrical	6,980	10,470	17,143	24,714	479
16 Electrical Machinery	8,256	12,383	20,160	30,240	332
17 Transportation Equipment	25,328	37,992	57,697	86,545	299
18 Instruments & Misc. Mfg.	8,538	12,809	35,011	52,516	269
Total	102,885	154,332	256,400	384,863	

CAPACITY TON-MILE DISTRIBUTION BY COMMODITY BY TRUCK TYPES

TRUCK TYPES			COMMODITIES	(DECIMAL FRACTION) BASE CASE																			FUTURE SCENARIOS - CHANGES IN DISTRIBUTION BY TRUCK TYPE			
				AGRICULTURE	METALLIC ORES	COAL & COKE	PETROLEUM	NONMET MINERAL	FOOD PRODUCT	TEXTILES	LUMBER & FURN.	PULP & PAPER	CHEMICALS	RUBBER & PLASTICS	STONE & GLASS	PRIMARY METAL	FABRIC. METAL	NON-ELEC MACH.	ELECTRIC MACH.	TRANSPORT EQUI.	INSTRUMENTS	SCRAP	INDUSTRY CHANGE		GOVERNMENT INFLUENCE	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1980	1985	1980	1985
1.	7.0	Box	G	.0045	-	-	.0009	-	.0188	.0134	.0151	.0096	.0019	.0038	.0028	.0004	.0018	.0006	.0037	.0041	.0168	.0027	No change	No change	No change	No change
2.	7.3	Box	D	.0042	-	-	.0012	-	.0066	.0042	.0040	.0042	.0033	.0045	.0027	.0004	.0033	.0018	.0079	.0032	.0056	.0013	No change	No change	No change	No change
3.	12.0	Box	G	.0167	-	-	.0017	-	.0495	.0110	.0541	.0381	.0049	.0111	.0060	.0010	.0119	.0035	.0203	.0046	.0267	.0255	35% decrease	50% decrease	20% decrease	35% decrease
4.	12.3	Box	D	.0031	-	-	.0006	-	.0094	.0074	.0181	.0120	.0023	.0058	.0027	.0016	.0049	.0017	.0044	.0027	.0051	.0031	Add above	Add above	Add above	Add above
5.	21.5	Box	G	.0142	-	-	.0011	.0014	.0239	.0171	.0366	.0389	.0115	.0177	.0101	.0010	.0158	.0056	.0115	.0085	.0347	-	70% decrease	80% decrease	50% decrease	70% decrease
6.	21.8	Box	D	.0106	-	-	.0035	.0014	.0374	.0343	.1723	.0536	.0149	.0306	.0141	.0020	.0335	.0106	.0230	.0174	.0538	-	Add above	Add above	Add above	Add above
7.	27.5	Box	G	.0127	-	-	.0017	.0017	.0216	.0126	.0200	.0130	.0073	.0165	.0070	.0013	.0109	.0110	.0095	.0082	.0264	.0536	100% decrease	100% decrease	100% decrease	100% decrease
8.	27.6	Box	D	.0620	.0308	.0341	.0060	.0105	.1436	.2669	.2104	.1920	.1110	.1920	.0683	.0062	.1815	.1628	.2055	.1323	.1364	.0840	Add above	Add above	Add above	Add above
9.	36.0	Box	D	.2825	.0546	.0462	.0294	.0210	.6456	.6285	.1141	.3635	.3185	.6148	.2117	.0382	.4823	.3268	.6047	.3929	.3781	.1628	3% decrease	3% decrease	30% decrease	50% decrease
10.	40.0	Twin Box	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Add above	Add above	Add above	Add above
11.	7.0	Irregular	G	.0064	.0100	.0087	.0003	.0102	.0004	.0005	.0050	.0031	.0018	.0011	.0088	.0066	.0026	.0058	.0092	.0051	.0129	.0202	No change	No change	No change	No change
12.	7.3	Irregular	D	.0057	.0024	.0044	.0004	.0063	.0001	.0015	.0034	.0025	.0025	.0016	.0068	.0080	.0032	.0038	.0183	.0023	.0042	.0074	No change	No change	No change	No change
13.	12.0	Irregular	G	.0287	.0143	.0165	.0017	.0147	.0004	.0017	.0134	.0090	.0041	.0052	.0254	.0087	.0094	.0232	.0071	.0347	.0202	.1355	35% decrease	50% decrease	20% decrease	35% decrease
14.	12.3	Irregular	D	.0054	.0047	.0077	.0006	.0090	.0001	.0009	.0056	.0029	.0014	.0022	.0094	.0122	.0033	.0038	.0013	.0125	.0040	.0175	Add above	Add above	Add above	Add above
15.	20.0	Irregular	G	.0188	.0332	.0275	-	.0311	.0002	-	.0155	.0146	.0094	.0053	.0289	.0090	.0069	.0519	.0046	.0445	.0155	.0308	70% decrease	80% decrease	50% decrease	70% decrease
16.	20.3	Irregular	D	.0165	.0083	.0143	.0005	.0268	.0002	-	.0149	.0178	.0050	.0032	.0278	.0161	.0125	.0173	.0038	.0213	.0235	.0185	Add above	Add above	Add above	Add above
17.	27.5	Irregular	G	.0184	.0106	.0176	.0003	.0198	-	-	.0136	.0106	.0011	.0040	.0253	.0268	.0044	.0078	-	.0303	.0131	.0624	100% decrease	100% decrease	100% decrease	100% decrease
18.	27.8	Irregular	D	.0862	.0842	.1055	.0010	.1041	.0002	-	.0576	.0663	.0123	.0298	.1100	.1529	.0559	.0907	.0155	.1777	.0693	.1016	Add above	Add above	Add above	Add above
19.	36.0	Irregular	D	.3347	.6379	.7175	.0108	.4961	.0073	-	.2263	.1483	.0449	.0508	.4322	.7076	.1559	.2713	.0497	.0977	.1537	.2674	3% decrease	3% decrease	30% decrease	50% decrease
20.	40.0	Twin Irr.	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Add above	Add above	Add above	Add above
21.	20.0	Tank	G	.0115	-	-	.0169	.0050	.0008	-	-	-	.0097	-	-	-	-	-	-	-	-	.0057	70% decrease	80% decrease	50% decrease	70% decrease
22.	20.3	Tank	D	.0079	-	-	.0638	.0038	.0011	-	-	-	.0060	-	-	-	-	-	-	-	-	-	Add above	Add above	Add above	Add above
23.	27.5	Tank	G	.0025	-	-	.0250	.0035	.0004	-	-	-	.0051	-	-	-	-	-	-	-	-	-	100% decrease	100% decrease	100% decrease	100% decrease
24.	27.8	Tank	D	.0122	.0409	-	.0889	.0349	.0026	-	-	-	.0441	-	-	-	-	-	-	-	-	-	Add above	Add above	Add above	Add above
25.	36.0	Tank	D	.0346	.0681	-	.7437	.1987	.0298	-	-	-	.3770	-	-	-	-	-	-	-	-	-	No change	No change	No change	No change
TOTAL				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Second, the ton-mile projections by commodities are distributed to truck types using the appropriate distribution matrix for the scenario in question. This gives a distribution of delivered ton-miles by truck type and commodity.

Third, the ton-miles for a truck type and a commodity are related to the capacity ton-miles (defined in equation A-1) by the capacity utilization ratio (defined in equation A-3). Dividing the delivered ton-miles (for each truck and commodity) by the capacity utilization ratio (.621 for all trucks and commodities) yields the capacity miles (as defined in equation A-2).

Fourth, the capacity miles by truck type and commodity are the product of vehicle miles times the truck capacity modified to reflect commodity density (see equations A-1 and A-2). Therefore, dividing capacity miles by the modified truck capacity gives vehicle miles for each truck type, for each commodity. The modified truck capacity reflected scenario changes in tare weight, which were assumed only in the government incentive scenario (200 pounds reduction for truck types 9, 10, 19, and 25). Weight savings were felt to be generally offset by weight increases of technological improvements.

A.3.3 Improvements in Fuel Efficiency of Trucks

Tables A-29 and A-30 show the schedule of changes to truck fleet mix which affect average mile-per-gallon performance achieved by the introduction of trucks described in Section 4.

The headings in Table A-29 stand for "old" truck vehicle miles, performed by trucks in service as of 1974. The column "6% retrofit" represents the percent of vehicle miles generated by old trucks retrofitted with technological changes (basically clutch fans) which result in a 6 percent improvement in miles per gallon. The other columns headed "X % New" represent percent of vehicle miles generated by new trucks with technological changes which improve fuel consumption by "X" percent.

In preparing this table, 10 percent of the vehicle miles generated by the "oldest trucks" are assumed to be replaced by newer, more efficient trucks, split between 8, 15, and 20 percent new trucks, and represent the development of improved technology and increased rates of adoption by the industry. Thus, in 1975 all 10 percent improvements were assumed in the 8 percent New category. In 1976 the 10+10 (=20) percent category was split as 17 percent in the 8 percent category and 3 percent in the 1 percent category.

TABLE A-29

INDUSTRY CHANGE SCHEDULE OF NEW TRUCK IMPROVEMENTS

YEAR	OLD	6% RETROFIT	DISTRIBUTION OF FLEET MIX 8% NEW	15% NEW	20% NEW	TOTAL %	ACCUM. FLEET % MPG IMPROVEMENTS
1974	100					100	
1975	65	25	10			100	
1976	39	41	17	3		100	
1977	19	51	22	8		100	
1978	4	56	25	12	3	100	
1979		50	25	17	8	100	
1980		40	25	22	13	100	10.3
1981		30	25	25	20	100	
1982		20	25	25	30	100	
1983		10	25	25	40	100	
1984			25	25	50	100	
1985			15	25	60	100	17.0

TABLE A-30

GOVERNMENT INFLUENCE SCHEDULE OF NEW TRUCK IMPROVEMENTS

				DISTRIBUTION OF FLEET MIX					
YEAR	OLD	6% RETROFIT	8% NEW	15% RETROFIT	15% NEW	20% NEW	30% NEW	TOTAL %	ACCUM. FLEET % MPG IMPROVEMENTS
1974	100							100	
1975	65	25	10					100	
1976	39	41	17		3			100	
1977	9	61	17		13			100	
1978		44	13	20	18	5		100	
1979		23	10	34	18	15		100	
1980		8	7	42	18	25		100	15.0
1981			1	46	18	32	3	100	
1982				36	18	32	13	100	
1983				26	18	32	23	100	
1984				16	18	32	33	100	
1985				6	18	32	43	100	22.9

The column "Accum fleet percent miles per gallon improvement" represents the net overall improvement in fuel economy (mpg) for the fleet in 1980 and 1985. It is the sum of the products of percent of distribution under each column times the percent miles-per-gallon savings each column represents. For instance, in Table A-29, the net fleet improvement of 10.3 is equal to:

$$\begin{array}{r} .40 \times 6 = 2.4 \\ .25 \times 8 = 2.0 \\ .22 \times 15 = 3.3 \\ .13 \times 20 = \underline{2.6} \\ 10.3 \end{array}$$

The headings on Table A-30 reflect the improved trucks in the government scenario. The system for calculating percent fleet improvement is otherwise similar to the industry change scenario.

APPENDIX B
RAIL MOVEMENTS

B.1 METHODOLOGY

The rail component of the TRANSEN model computes the energy consumed by both loaded and empty rail movements for each of the commodity groups. Because of differences in energy consumption by different car types, rail energy consumption is calculated separately for the following seven car type categories:

boxcar;

covered hopper;

flatcar (includes TOFC/COFC cars);

gondola;

open-top hopper;

tank car; and

miscellaneous (includes auto rack, refrigerator, and stock cars).

Figures B-1 and B-2 illustrate the process of calculating rail freight energy consumption for each commodity in two stages: computation of the ton-mile base and conversion of ton-miles to fuel consumption.

Loaded net ton-mile values form the basis for the loaded energy consumption calculations. Loaded ton-miles are the product of net tons and average haul per ton, adjusted for circuity, with values calculated separately for each car type category:

$$K_{ij} = T_j P_{ij} M_{ij} (1+Y_i) \qquad \text{(B-1)}$$

where:

i = car type
j = commodity
K_{ij} = net ton-miles for car type, i, for commodity, j

T_j = net tons for commodity, j

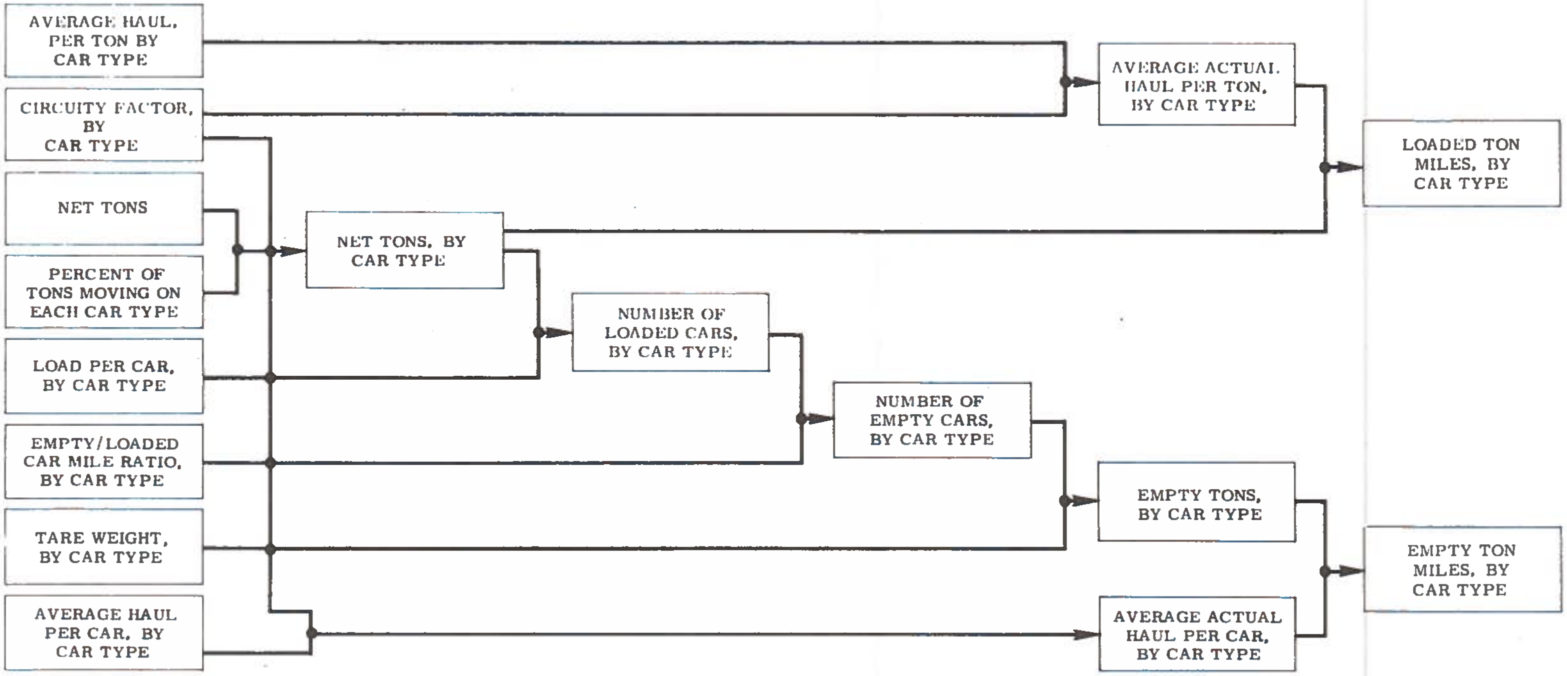

FIGURE B-1: CONCEPTUAL DESIGN OF THE RAILROAD COMPONENT OF THE TRANSEN MODEL FOR EACH COMMODITY GROUP - TON-MILE COMPUTATIONS

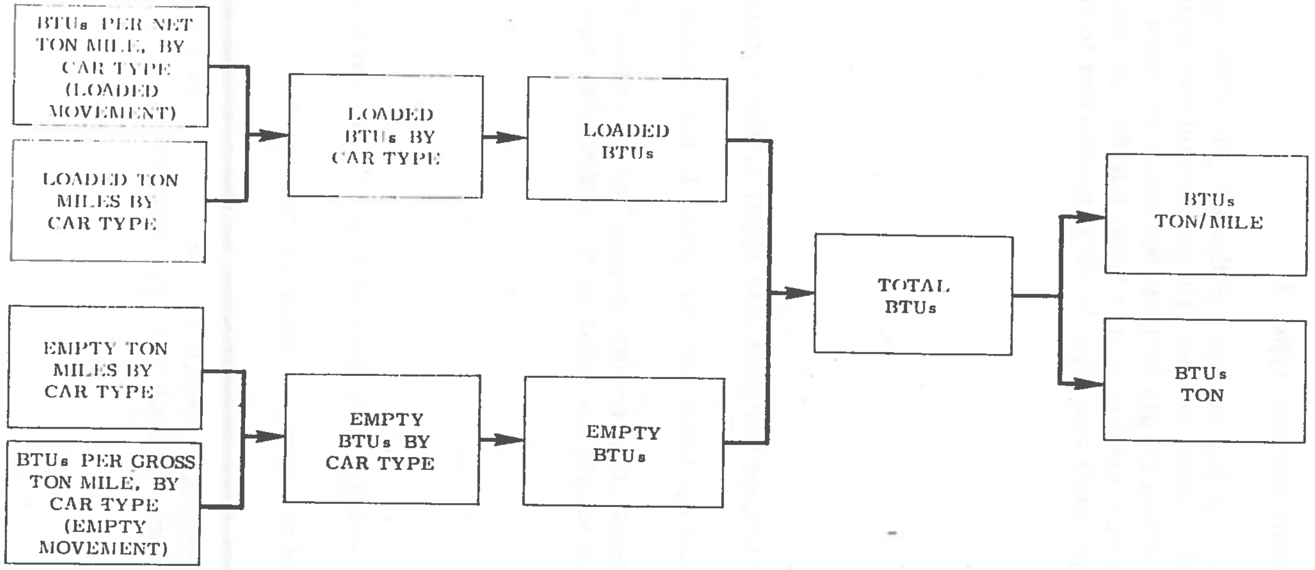

FIGURE B-2: CONCEPTUAL DESIGN OF THE RAILROAD COMPONENT OF THE TRANSEN MODEL FOR EACH COMMODITY GROUP-ENERGY COMPUTATION

P_{ij} = proportion of commodity, j, moving on car type, i

M_{ij} = average haul per ton of commodity, j, moving car type, i

Y_i = circuity factor for car type, i

Empty ton-miles are the product of the weight of the quantity of empty cars assigned to each commodity group and car type category multiplied by the average length of haul for each car type and commodity group. To compute this measure, the total number of tons for each commodity moving on each car type is first converted to the number of loaded cars:

$$D_{ij} = \frac{T_j P_{ij}}{L_{ij}} \tag{B-2}$$

where:

D_{ij} = number of loaded cars for car type, i, for commodity, j

L_{ij} = average load (in tons) for car type, i, for commodity, j

This value is then multiplied by the empty/loaded car-mile ratio to estimate the number of empty cars for each commodity and car type category:

$$A_{ij} = D_{ij} E_i \tag{B-3}$$

where:

A_{ij} = number of empty cars for car type, i, for commodity, j

E_i = empty/loaded car-mile ratio for car type, i

The number of empty cars is multiplied by the corresponding tare weight of each car type to obtain a measure of tons of empty cars moving for each commodity group and each car type category:

$$C_{ij} = A_{ij} W_i \tag{B-4}$$

where:

C_{ij} = tons of empty cars for car type, i, for commodity, j

W_i = tare weight for car type, i

Finally, empty tons are multiplied by average length of haul per car adjusted for circuity to get empty ton-miles:

$$B_{ij} = C_{ij} H_{ij} (1+Y_i) \qquad \text{(B-5)}$$

where:

B_{ij} = empty ton-miles for car type, i, for commodity, j

H_{ij} = average length of haul per car for car type, i, for commodity, j

The results of these calculations are a series of two values for each commodity and car type group--loaded ton-miles and empty ton-miles. Each ton-mile value is multiplied by the appropriate Btu/ton-mile value to obtain loaded and empty Btus, and the Btu values are summed for each commodity group:

$$Q_j = \sum_i (K_{ij} F_{ij}) \qquad \text{(B-6)}$$

$$R_j = \sum_i (B_{ij} G_{ij}) \qquad \text{(B-7)}$$

where:

Q_j = loaded Btus for commodity, j

F_{ij} = Btu/ton-mile for car type, i, moving loaded for commodity, j

R_j = empty Btus for commodity, j

G_{ij} = Btu/ton-mile for car type, i, moving empty for commodity, j

Finally, empty and loaded Btus for each commodity group are summed for each commodity group, and total Btu/net ton and Btu/net ton-mile values are computed for each commodity group and overall:

$$X_j = Q_j + R_j \qquad \text{(B-8)}$$

$$N_j = \frac{X_j}{T_j} \qquad \text{(B-9)}$$

$$Z_j = \frac{X_j}{K_j} \qquad \text{(B-10)}$$

where:

X_j = Btus for commodity group, j

N_j = Btus per net ton for commodity, j

Z_j = Btus per net ton mile for commodity, j

B.2 DATA SOURCES

The data sources for rail energy consumption calculations are discussed below for traffic data and for energy consumption estimates.

B.2.1 Traffic Data

Rail ton-miles comprise the basic measure of rail freight traffic. Ton-miles are computed separately for loaded and empty movements. The ton-mile estimates are distributed by 19 commodity groups and by the seven car type categories.

The distribution of rail freight tons by commodity groups appears in published Interstate Commerce Commission (ICC) data.[1] These data, aggregated into the 19 selected commodity groups, form the basis of the rail freight commodity computations. Originated tonnage has been selected as the most reliable measure of rail freight traffic because it has the fewest duplications or omissions. Table B-1 shows distribution of rail-originated tons by commodity for base year 1972.

Freight traffic data for each car type by commodity have been computed in a special computer run by the Federal Railroad Administration (FRA) based on data from the 1-percent waybill sample. The run provided data on tons per car, haul per car, and haul per ton; these data are summarized in Tables B-2, B-3, B-4. Separate values were obtained for haul per ton and haul per car because different loadings for different car types create different haul values. From the waybill sample data, percentages of each commodity moving in each car type have been computed to permit distribution of traffic by car type for individual analysis of energy consumption; the percent distribution by car type is summarized in Table B-5. Although the 1-percent waybill sample is not completely reliable, in the absence of better data, commodity/car type relations were assumed to be applicable to the whole

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[1] Freight Commodity Statistics-Class I Railroads, ICC Bureau of Accounts.

TABLE B-1

RAILROAD ORIGINATED TONNAGE FOR 1972 BY COMMODITY

COMMODITY	ORIGINATED TONNAGE (Thousands)
Agricultural products	130,758
Chemicals, applied products	95,163
Clay, concrete, glass, stone	73,457
Coal, coke produced from coal	386,098
Crude oil, petroleum	26,043
Electrical Machinery	4,550
Fabricated metal products	9,380
Food, kindred products, tobacco	106,747
Instruments, photo goods	665
Lumber, wood products, furniture	111,988
Metallic ores	110,034
Nonelectrical machinery	3,748
Nonmetallic minerals	164,695
Primary metal products	60,883
Pulp, paper, allied products	44,299
Rubber, plastic products	4,037
Textiles, apparel, leather	1,709
Transportation equipment	31,373
Waste, scrap materials	39,795
Subtotal	1,405,422
Other	41,781
Total	1,447,203

TABLE B-2

AVERAGE TONS PER CAR BY RAILROAD CAR TYPE AND COMMODITY: 1972

CAR TYPE / COMMODITY	BOXCAR	COVERED HOPPER	FLAT CAR@	GONDOLA	OPEN-TOP HOPPER	TANK CAR	MISC. CARS#
Agricultural products	53.1	87.0	27.6	61.4	46.8	*	25.2
Chemicals, allied products	46.4	77.0	28.0	*	*	65.8	40.8
Clay, concrete, glass, stone	39.3	78.5	44.4	59.7	71.7	*	39.6
Coal, coke produced from coal	*	*	*	94.1	76.7	*	*
Crude oil, petroleum	29.5	*	26.4	*	*	57.3	31.8
Electrical machinery	12.7	*	22.0	48.3	*		16.4
Fabricated metal products	16.3	*	26.6	43.3	*	*	26.4
Food, kindred products, tobacco	35.8	59.8	22.3	*	*	61.1	42.3
Instruments, photo goods	13.6	*	19.9	*			*
Lumber, wood products, furniture	30.2	63.4	44.0	48.0	42.5	*	42.0
Metallic ores	64.0	75.1	*	94.3	83.2	*	84.9
Nonelectrical machinery	19.0	*	24.3	34.1		*	*
Nonmetallic minerals	49.6	79.6	*	68.3	76.8	90.0	53.3
Primary metal products	53.6	109.6	64.6	63.0	71.4		51.2
Pulp, paper, allied products	38.1	*	27.3	*	*	60.6	32.7
Rubber, plastic products	15.7	*	24.5	*	*	*	22.9
Textiles, apparel, leather	17.9	*	25.5				*
Transportation equipment	23.9	29.1	21.8	37.5	*	22.6	*
Waste, scrap materials	35.5	62.2	*	55.9	62.0	67.6	46.9
Average for all commodities	35.8	74.9	32.5	62.5	76.4	62.8	42.8

*Omitted due to erroneous data or because sample too small to be reliable; generally attributable to a small number of car types or commodities improperly coded.

@Includes TOFC/COFC.

#Includes auto rack, refrigerator, and stock cars.

Source: Special computer analyses of the Department of Transportation one-percent carload waybill sample, run by the Federal Railroad Administration.

TABLE B-3

AVERAGE LENGTH OF HAUL PER CAR BY RAILROAD CAR TYPE AND COMMODITY: 1972
(miles)

COMMODITY / CAR TYPE	BOXCAR	COVERED HOPPER	FLAT CAR@	GONDOLA	OPEN-TOP HOPPER	TANK CAR	MISC. CARS#
Agricultural products	424.7	414.8	1,471.9	267.9	76.0	*	2,016.9
Chemicals, allied products	688.5	662.0	701.7	*	*	525.0	995.4
Clay, concrete, glass, stone	615.2	321.0	565.5	408.7	227.8	*	1,247.0
Coal, coke produced from coal	*	*	*	292.9	285.3	*	*
Crude oil, petroleum	770.7	*	789.2	*	*	427.1	1,011.6
Electrical machinery	805.9	*	829.2	939.5	*		1,208.2
Fabricated metal products	697.9	*	657.3	499.6	*	*	1,363.1
Food, kindred products, tobacco	558.0	472.3	931.5	*	*	619.0	927.8
Instruments, photo goods	1,093.7	*	985.2	*			*
Lumber, wood products, furniture	1,280.1	161.9	826.5	251.1	136.4	*	1,878.1
Metallic ores	483.9	96.1	*	197.8	165.1	*	189.0
Nonelectrical machinery	767.2	*	954.9	813.4		*	*
Nonmetallic minerals	666.6	189.0	*	175.8	127.4	500.3	145.9
Primary metal products	855.9	361.7	595.1	385.4	197.4		1,194.8
Pulp, paper, allied products	720.4	*	796.8	*	*	490.2	1,160.5
Rubber, plastic products	692.7	*	874.8	*	*	*	1,312.0
Textiles, apparel, leather	777.9	*	972.3				*
Transportation equipment	664.7	526.7	901.8	544.3	*	464.8	*
Waste, scrap materials	453.9	563.3	*	139.4	298.2	227.6	417.3
Average for all commodities	718.3	317.6	837.4	267.4	241.4	501.6	1,092.1

*Omitted due to erroneous data or because sample too small to be reliable; generally attributable to a small number of car types or commodities improperly coded.

@Includes TOFC/COFC.

#Includes auto rack, refrigerator, and stock cars.

Source: Special computer analyses of the Department of Transportation one-percent carload waybill sample, run by the Federal Railroad Administration.

TABLE B-4

AVERAGE LENGTH OF HAUL PER TON BY RAILROAD CAR TYPE AND COMMODITY: 1972
(miles)

CAR TYPE / COMMODITY	BOXCAR	COVERED HOPPER	FLAT CAR@	GONDOLA	OPEN-TOP HOPPER	TANK CAR	MISC. CARS#
Agricultural products	410.1	442.9	1,568.6	269.2	79.8	*	1,971.0
Chemicals, allied products	686.2	692.6	712.3	*	*	562.0	990.9
Clay, concrete, glass, stone	587.2	320.1	533.0	415.4	228.8	*	1,274.0
Coal, coke produced from coal	*	*	*	275.9	286.3	*	*
Crude oil, petroleum	767.7	*	886.5	*	*	450.1	1,032.5
Electrical machinery	844.2	*	878.3	1,079.2	*		1,328.4
Fabricated metal products	803.1	*	601.4	459.8	*	*	1,286.3
Food, kindred products, tobacco	582.8	501.6	941.1	*	*	636.0	980.3
Instruments, photo goods	1,287.3	*	1,025.5	*			*
Lumber, wood products, furniture	1,411.9	153.8	835.2	243.5	133.3	*	1,925.0
Metallic ores	391.6	103.2	*	173.2	161.6	*	179.8
Nonelectrical machinery	733.7	*	990.6	749.0		*	*
Nonmetallic minerals	584.4	196.6	*	176.2	127.8	505.6	139.0
Primary metal products	852.9	209.0	517.2	351.8	195.9		1,055.4
Pulp, paper, allied products	747.0	*	826.7	*	*	479.7	1,147.1
Rubber, plastic products	737.0	*	901.1	*	*	*	1,292.6
Textiles, apparel, leather	811.6	*	940.1				*
Transportation equipment	652.7	543.4	906.6	530.5	*	444.0	*
Waste, scrap materials	468.8	555.0	*	138.5	276.6	249.4	361.6
Average for all commodities	705.5	332.2	786.5	249.4	242.1	531.3	957.6

*Omitted due to erroneous data or because sample too small to be reliable; generally attributable to a small number of car types or commodities improperly coded.

@Includes TOFC/COFC.

#Includes auto rack, refrigerator, and stock cars.

Source: Special computer analyses of the Department of Transportation one-percent carload waybill sample, run by the Federal Railroad Administration.

TABLE B-5

PERCENT OF TONS MOVING ON EACH RAILROAD CAR TYPE BY COMMODITY: 1972

CAR TYPE COMMODITY	BOXCAR	COVERED HOPPER	FLAT CAR@	GONDOLA	OPEN-TOP HOPPER	TANK CARS	MISC. CARS#
Agricultural products	32.1	56.4	.8	2.2	3.9	.2	4.4
Chemicals, allied products	16.5	37.2	1.7	.1	.3	41.6	2.6
Clay, concrete, glass, stone	24.4	56.5	4.8	1.8	11.0		1.5
Coal, coke produced from coal	.3	0.2		5.4	94.1		
Crude oil, petroleum	4.2	0.5	0.9		0.5	93.0	0.9
Electrical machinery	69.2		25.6	2.6			2.6
Fabricated metal products	21.2		16.3	60.0			2.5
Food, kindred products, tobacco	30.9	27.6	3.5	.3	.1	10.3	27.3
Instruments, photo goods	80.0		20.0				
Lumber, wood products, furniture	25.3	40.9	14.2	15.2	1.7		2.8
Metallic ores	1.3	40.7		8.0	42.4		7.6
Nonelectrical machinery	26.6		66.7	6.7			
Nonmetallic minerals	3.6	25.4	.1	14.8	51.7	2.7	1.7
Primary metal products	18.0	4.0	16.5	54.1	5.2		2.2
Pulp, paper, allied products	93.9	0.5	1.9			1.0	2.7
Rubber, plastic products	88.6		8.6				2.9
Textiles, apparel, leather	76.9		23.1				
Transportation equipment	53.3	1.7	41.3	2.1	0.4	0.8	0.4
Waste, scrap materials	16.8	0.8	0.3	71.8	6.4	3.1	0.8
Average for all commodities							

@Includes TOFC/COFC.

#Includes auto rack, refrigerator, and stock cars.

Source: Special computer analyses of the Department of Transportation one-percent carload waybill sample, run by the Federal Railroad Administration.

traffic population that the sample represents (with noted exceptions). Other data needed to help compute rail transportation energy by commodity were obtained as follows:

> Average tare weight per car type was obtained from the ICC Bureau of Accounts publication, *Rail Carload Cost Scales for 1972*.
>
> The ratio of empty to loaded car-miles for each car type was obtained from special studies conducted by the ICC Bureau of Accounts, as reported in *Ratios of Empty to Loaded Freight Car-Miles by Type of Car and Performance Factors for Way, Through, and All Trains Combined*. Since cause-effect relationships cannot be developed for assigning different empty/loaded car-mile ratios to different commodities (with certain exceptions, such as unit trains), it is reasonable to assume that the average empty-return ratio for each car type represents a satisfactory measure of empty-car movements to be assigned to each commodity under the principle that empty car-miles are accrued on behalf of all commodities carried by that car type.
>
> The rail circuity factor for each car type was also obtained from *Rail Carload Cost Scales for 1972*. This factor was required to adjust the average haul measures reported in short-line miles in the waybill sample. Again, the sim-simplifying assumption was made that the factor for each car, averaged over all commodities, represented the best available measure of this information.

Table B-6 shows these results averaged for each car type.

Because of statistical variation, the ton-mile total computed in the TRANSEN calculations was found to be 13.3 percent lower than the published Association of American Railroads (AAR) totals. Ton-miles for each commodity were correspondingly increased to force a balance with the AAR's control total.

B.2.2 Energy Consumption

To convert rail traffic measures to energy consumption values requires measures of energy consumption (in Btus per ton-mile) by commodity and by car type. This information was obtained from an analysis of published and unpublished studies.

TABLE B-6

TARE WEIGHT, EMPTY/LOADED RATIO, AND CIRCUITY FACTOR VALUES FOR EACH CAR TYPE: 1972

CAR TYPE	TARE WEIGHT* (tons)	RATIO OF EMPTY TO LOADED FREIGHT CAR MILES@	CIRCUITY FACTOR#
Boxcar	30.5	.70	.16
Covered Hopper	30.0	1.02	.18
Flat Car@@	37.9	.67	.11
Gondola	29.5	.88	.16
Open Top Hopper	26.0	.91	.13
Tank Car	32.1	1.09	.18
Misc. Cars**	37.4	.88	.12

*Bureau of Accounts, Interstate Commerce Commission. Rail Carload Cost Scales - 1972. Washington, D.C.: October 1974, p. 154.

@Bureau of Accounts, Interstate Commerce Commission. Ratios of Empty to Loaded Freight Car-Miles by Type of Car and Performance Factors for Way, Through, and All Trains Combined. Washington, D.C.: December 1973, p. 6.

#Rail Carload Cost Scales - 1972, p. 148.

@@Includes auto rack, refrigerator, and stock cars.

** Includes TOFC/COFC.

The methodology for relating energy use to train performance was developed after review of existing literature and discussions with the Federal Railroad Administration, the Transportation Systems Center, and the Association of American Railroads. The basis for the calculations is the Davis formula :[1]

$$R = WN(1.3 + \frac{29}{W} + bV + \frac{CAV^2}{WN})$$

where R = resistance in pounds for a car or locomotive on tangent, level track in still air.

W = weight in tons per axle of car or locomotive.

N = number of axles.

b = coefficient of flange friction, swaying and concussion (.045 for freight cars, .03 for locomotives).

C = drag coefficient of air (.0017 for streamlined locomotives = .0025 for other locomotives, .0005 for freight cars).

A = cross sectional area of locomotives and cars (105-120 ft. for locomotives, 30-140 ft. for freight cars).

V = speed in MPH.

This formula was used to develop car resistance estimates using appropriate cross-sectional areas for each car type. A 10-mile-per-hour headwind was added to the base calculations. Corrections to the base were made for:

extra large cars and gaps;

box cars with open doors;

---

[1] Although the "modified" Davis formula is technically reported to be more correct--especially at speeds over 40 mph--the researcher's personal experience places greater reliability on the original formula.

extra curve resistance;

switching involved in train make-up; and

disparity of car types in trains, where applicable.

Using these estimates of energy consumption for each car type, estimates were made for each commodity group based on average load factors and assumptions regarding the average speed of the commodity/car type classification. The results, estimates of energy consumption in Btus per ton-mile, have been developed separately for loaded and empty movements for each car type and commodity classification. Tables B-7 and B-8 show these estimates.

Based on these values, total Btu consumption was computed in the TRANSEN model and was compared with rail freight fuel consumption reported by the ICC for freight, yard, switching, and work train services anq that portion of passenger service (distributed according to car-miles) attributed to freight.[1] The TRANSEN calculations were found to be 23 percent too low and were upvalued in a manner similar to the ton-mile estimates.

These estimates were used as the basis for determining the impacts of operating and technological changes which could conserve energy. For example, appropriate coefficients of drag were used for the aero-dynamic term of the modified Davis formula to compute the impact of streamlining locomotives and rail cars.

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[1] Transport Statistics in the United States, Year Ended December 31, 1972, Part I, Railroads, ICC Bureau of Accounts, Second Release, Washington, D.C., May 1974.

TABLE B-7

BTU PER TON MILE ESTIMATES

Loaded Movements

COMMODITY / CAR TYPE	Boxcar	Covered Hopper	Flat Car@	Gondola	Open-Top Hopper	Tank Car	Misc. Cars#
Agricultural products	335	235	725	290	380		715
Metallic ores	265	225		195	180		
Coal, coke produced from coal				195	210		
Crude oil, petroleum	440		725			275	415
Nonmetallic minerals	310	225		280	180	195	315
Food, kindred products, tobacco	420	310	750			266	410
Textiles, apparel, leather	775		725				
Lumber, wood products, furniture	475	300	600	340	360		380
Pulp, paper, allied products	395		700			270	410
Chemicals, allied products	390	240	725			257	380
Rubber, plastic products	875		730				610
Clay, concrete, glass, stone	350	225	600	295	225		380
Primary metal products	290	175	295	285	185		320
Fabricated metal products	820		725	370			530
Nonelectrical machinery	675		730	425			
Electrical machinery	1,050		750	340			725
Transportation equipment	650	480	846	400		570	
Instruments, photo goods	1,020		770				
Waste, scrap materials	420	300	725	300	190	252	400

@ Includes TOFC/COFC.

Includes auto rack, refrigerator, and stock cars.

TABLE B-8

BTU PER TON MILE ESTIMATES

Empty Movements

CAR TYPE COMMODITY	Boxcar	Covered Hopper	Flat Car@	Gondola	Open-Top Hopper	Tank Car	Misc. Cars#
Agricultural products	390	420	796	420	320		450
Metallic ores	390	420		420	320		
Coal, coke produced from coal				420	320		
Crude oil, petroleum	390		796			399	390
Nonmetallic minerals	390	420		420	320	399	390
Food, kindred products, tobacco	390	420	796			399	390
Textiles, apparel, leather	390		796				
Lumber, wood products, furniture	390	420	796	420	320		390
Pulp, paper, allied products	390		796			399	390
Chemicals, allied products	390	420	796			399	390
Rubber, plastic products	390		796				390
Clay, concrete, glass, stone	390	420	796	420	320		390
Primary metal products	390	420	796	420	320		390
Fabricated metal products	390		796	420			390
Nonelectrical machinery	390		796	420			
Electrical machinery	390		796	420			390
Transportation equipment	596	420	796	420		399	
Instruments, photo goods	390		796				
Waste, scrap materials	390	420	796	420	320	399	390

@ Includes TOFC/COFC.

Includes auto rack, refrigerator, and stock cars.

APPENDIX C

INLAND WATERWAY MOVEMENTS

C.1 METHODOLOGY

The inland waterways component of the TRANSEN model computes the Btus and Btus per ton and ton-mile for inland waterway movements for each of the 19 commodity groups. An inland waterway movement is assumed to consist of a tow boat and a flotilla of barges known as a "tow" (although tows are almost invariably "pushed"). Figure C-1 shows the conceptual framework for the inland waterway calculations and presents the computational sequence used.

A still-water speed, expressed in miles per hour, must consider tow and waterway characteristics. Since the characteristics significantly vary over different waterways, the U.S. inland waterway system is divided into six segments:

- Ohio River System;
- Upper Mississippi River System;
- Lower Mississippi River System;
- Gulf Intracoastal Waterway;
- Atlantic Intracoastal Waterway; and
- Pacific Coast Waterways.

The major waterways found in each system are shown in Table C-1.

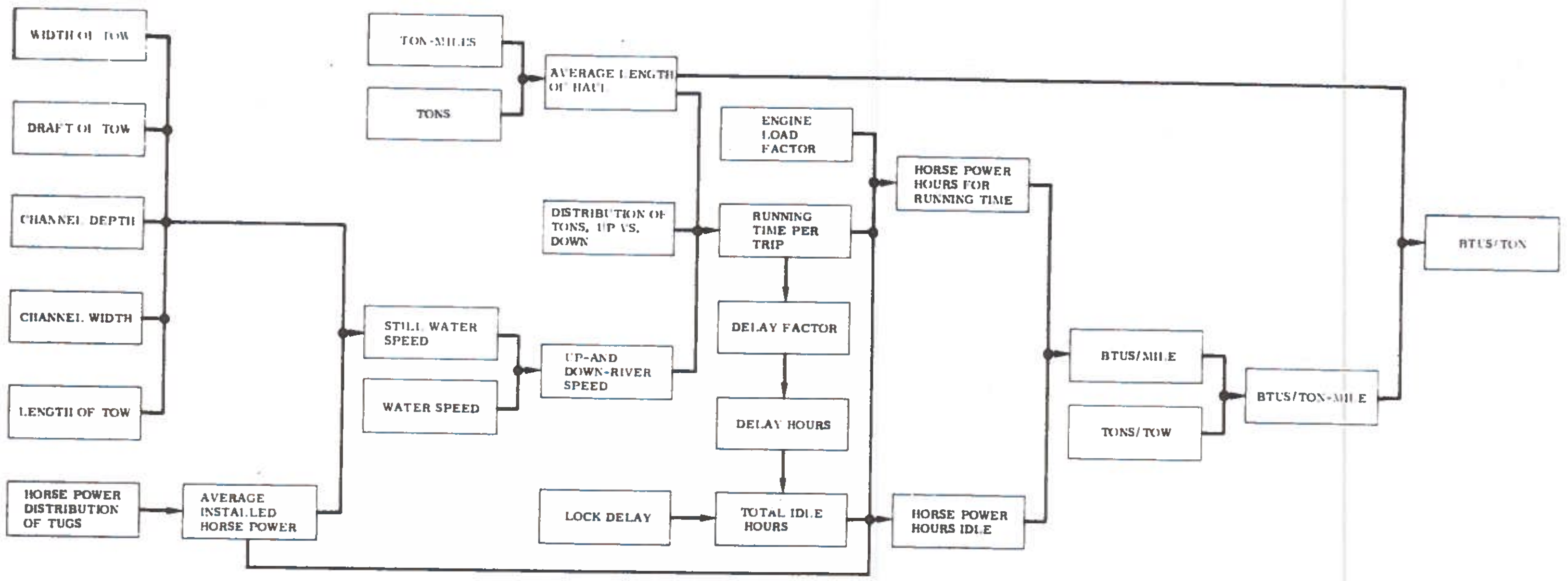

FIGURE C-1: CONCEPTUAL DESIGN OF THE INLAND WATERWAY COMPONENT OF THE TRANSEN MODEL

TABLE C-1
DESCRIPTION OF WATERWAY SYSTEMS

STUDY WATERWAY SYSTEM	MAJOR RIVERS & WATERWAYS & PROJECTS INCLUDED
1. Ohio & Antilles	Cumberland River
	Tennessee River
	Green & Barrem River
	Kentucky River
	Big Sandy River
	Kanawha River
	Monongahela River
	Allegheny River
	Little Kanawha River
	Ohio River System
2. Upper Mississippi and Illinois	Balck River
	St. Croix River
	Missouri River
	Illinois River
	Missipi River above mouth of Missouri
3. Lower Mississippi	Ouachita & Black Rivers
	Yazoo River
	Arkansas River and McClelland Canal
	White River
	Mississippi River below mouth of Missouri
4. Gulf Intracoastal Waterway	Appalachacola, Chatahoochie & Flint Rivers
	Black Warrior & Tombigbee Rivers
	Gulf Intracoastal (Consolidated report)
	Atchafalya Bayou
	Sabine-Neches
	GIWW Morgan City Route
	30 other waterways
5. Atlantic Intracoastal	New York Barge Canal System
	Atlantic Intracoastal, Norfolk to Key West
	Port of Boston
	Port of New York
	Delaware River
	Port of Baltimore
	Port of Norfolk
	45 other harbors and waterways
6. Pacific Coast Waterways	Columbia River System
	Ports of Los Angeles & Long Beach
	Ports of San Francisco & Stockton
	Port of Seattle
	40 other harbors and waterways

The Howe formula,[1] empirically modified to reasonably correlate to large tows, is used to compute the still water speed:

$$S_j = \frac{-1.14P_j + \left[(1.14P_j)^2 + 4Z\,(31.82P_j - .0039P_j^{1.75} + .38P_jD_j)\right]^{.5}}{2Z} \qquad \text{(C-1)}$$

$$\text{where } Z = .07125e^{1.46\left(\frac{1}{D_j - H_j}\right)} H_j^{\left(.6 + \frac{16.82}{W_j - B_j}\right)} L_j^{.38} B_j^{1.19} + 172.05$$

e = Natural log = 2.71828

S_j = Still-water speed in waterway, j (miles per hour)

P_j = Horsepower of tow boats used in waterway, j

D_j = Channel depth in waterway, j (feet)

H_j = Typical tow draft in waterway, j (feet)

W_j = Channel width in waterway, j (feet)

B_j = Typical tow width in waterway, j (feet)

L_j = Typical tow length in waterway, j (feet), including length of tug boat.

Actual tow speed is then computed for a typical tow going up- versus downstream. The water speed is added to the still-water speed for downstream trips and deducted for upstream trips. The adjustment of still-water speed in each waterway to reflect water speeds is necessary, because the energy intensity per hour of tugboat operations varies between up- and downstream operations.

A running time per trip expressed in hours is computed for each commodity group on each waterway for upstream and downstream movements.

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[1] "Process and Production Functions for Inland Waterway Transportation," Charles W. Howe, Paper No. 65 for Institute for Qualitative Research in Economics and Management, Purdue University, 1963.

The upstream and downstream formulas used for this computation are respectively:

$$UT_{ij} = \frac{H_{ij} U_{ij}}{A_j} \qquad \text{(C-2)}$$

$$DT_{ij} = \frac{H_{ij} (1 - U_{ij})}{E_j} \qquad \text{(C-3)}$$

where:

UT_{ij} = running time per trip, in hours, for commodity group, i, moving upstream on waterway, j

H_{ij} = average haul in miles for commodity group, i, on waterway, j

U_{ij} = percentage of total tons of commodity group, i, moving upstream on waterway, j

A_j = upstream tow boat speed (still water less current speed in miles per hour) on waterway, j

DT_{ij} = running time per trip, in hours, for commodity group, i, moving downstream on waterway, j

E_j = downstream tow-boat speed (still water plus current speed) on waterway, j.

In the coastal waterways, water speed is assumed to be zero, and $A_j = E_j = S_j$, where S_j is the still-water speed calculated in Equation C-1. Consequently, an upstream/downstream breakdown is not necessary.

The total horsepower-hour requirements corresponding to UT_{ij} and DT_{ij} are computed by multiplying each by the product of P_j (average installed horsepower of tow boats in waterway, j) and an engine-load factor that reflects the percent utilization of installed horsepower (effect of reducing throttle) while underway. This factor is assumed to be different for up- and downstream trips.

A total hours-per-trip delay due to weather, congestion, and other conditions is computed and added to a lock delay hour estimate. The lock delay hours per trip are estimated on the basis of the average number of locks per mile of waterway, j; average delay per lock in waterway, j; and average length of haul of commodity group, i, in waterway, j. Lockage and delay hours are each multiplied by P_j times an engine-load factor and added to obtain the horsepower hour requirement for total "idle" time per trip.

The total Btu consumption per trip for commodity group, i, moving in waterway, j, is estimated for the total horsepower hour requirements for the trip. This estimate, when divided by the product of length of haul and tons per tow of commodity group, i, in waterway, j, yields an estimate of Btus per actual ton-mile. Finally, Btus/ton are estimated by multiplying Btu/ton-mile with the actual length of haul.

C.2 DATA SOURCES

C.2.1 Base-Year Data

The primary source of data for the calculations of inland waterways fuel consumption is the U.S. Army Corps of Engineers.[1] Additional information was obtained through waterway simulation studies done for the Corps of Engineers by Pennsylvania State University.[2]

This subsection is divided into four parts. Each part describes the sources and methods used to derive the model input data. The four parts, including the input variables, are classified as follows:

1. Tonnage Measurements:

   total tons shipped in internal (domestic) traffic on U.S. waterways in 1972 by commodity;

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[1] U.S. Army Corps of Engineers, Waterborne Commerce of the United States - Calendar Year 1972, Vicksburg, Mississippi (hereafter called WCS). 1972 Annual Report to the Chief of Engineers on Civil Works Activities, Washington, D.C.

[2] Pennsylvania State University, Waterways System Simulation, U.S.A. Corps of Engineers, North Central Division, August 1971.
The Illinois Upper Mississippi River Ten Lock Subsystem, USCOE, Chicago, Illinois, October 1971.
Mississippi River 12 Foot Channel Study, USCOE, Chicago, Illinois, February 1972.

total tons by commodity and waterway; and

percent of tons moving upstream by commodity and waterway.

2. Average Haul:

average haul by commodity; and

average haul by commodity and waterway.

3. Tow Descriptors:

tow length in feet by waterway;

tow width in feet by waterway;

tow depth in feet by waterway;

median installed horsepower of towboats by waterway;

tons per tow; and

engine-load factors for upstream, downstream, lockage, and delays.

4. Waterway Descriptors:

channel depth by waterway;

channel width by waterway;

number of locks per mile by waterway;

current speed in miles per hour by waterway;

average delay per lock in hours by waterway; and

contingency delay factor (equal to .05 times running hours).

C.2.2 Tonnage Measurement

The calculation of fuel consumption for inland waterways requires traffic volume measures for the nation as a whole and for each waterway system. The ton and ton-mile measures by commodity group for the nation as a whole are found in the Waterborne Commerce, National Summaries[1] (see Table C-2).

Btus per ton-mile values vary on different waterways due to differences in the number of locks and dams and water current speed on each waterway. To account for these differences, data were obtained for the six different waterway systems for commodity tonnage, average length of haul, and the percent distribution of up- versus downstream traffic.[2]

In the Waterborn Commerce Statistics, tonnage data appear by commodity group for each waterway project that carries a significant amount of traffic. A project is a harbor, bay, port, canal, or stretch of river (called a "reach" of the waterway). All tons traversing the project are counted in project totals, irrespective of other project reaches over which the same shipment may have traveled. Consolidated tables of tonnages by commodity are also reported for aggregations of many projects, such as the Ohio River, Mississippi River, Gulf Intracoastal Waterway, Atlantic Intracoastal Waterway, and others. All double counting is eliminated in the consolidated tables. (A shipment which traversed the Mississippi River from Minneapolis to St. Louis and the Mississippi from St. Louis to Baton Rouge would be counted in the report for each of these projects but only once in the Mississippi consolidated report.) No consolidated reports are published for the six waterway systems defined for this study. Therefore, detailed project-by-project accounting of tons was made to arrive at "consolidated reports" for each of the study waterways.

Two methods of accounting were employed depending on the nature of the waterway and the organization of the reported data. The first method applied to the Ohio, the Upper and Lower Mississippi Rivers, and the Gulf Intracoastal Waterways. The second method was used for the Atlantic and Pacific totals. The existence of a consolidated report for the main stem of a waterway made the first accounting

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[1] WCS, op. cit., Part 5, pp 7-9, 126-8.

[2] WCS, op. cit., Parts 1, 2, and 4.

TABLE C-2

INTERNAL WATER TRAFFIC MEASURES -
U.S. SUMMARY 1972

COMMODITY	TONS (Thousands)	TON-MILES (Millions)
1. Agriculture	52,250	37,523
2. Metallic Ores	5,222	4,182
3. Coal and Coke	119,123	33,541
4. Petroleum	168,185	48,121
5. Non-Metallic Minerals	71,697	13,667
6. Food & Kindred Prod.	6,229	5,131
7. Textiles, Apparel & Leather	33	20
8. Lumber & Furniture	17,340	1,366
9. Pulp, Paper & Allied	2,518	623
10. Chemicals & Allied	32,979	21,542
11. Rubber & Plastics	8	4
12. Stone, Clay & Glass	6,296	2,204
13. Primary Metal Prod.	8,314	7,464
14. Fabricated Metal Prod.	350	294
15. Machinery ex. Elec.	266	112
16. Electrical Machinery	43	42
17. Transportation Equip.	20	4
18. Instruments & Misc. Mfg.	822	21
19. Waste & Scrap	12,764	1,567
Total	507,459	172,428

Source: Waterborne Commerce, National Summaries, Part 5, pp. 7-9 and 126-128.

method possible. For this method, the main stem totals were increased by the amount of traffic which traversed all ancillary waterways but which did not touch the main stem, and therefore were not counted in the main stem consolidated report. The second method was employed where no main stem consolidated report existed and where significant amounts of data were reported in the National Summary volume (Part 5, of the WCS) but not in the regional volumes (Parts 1, 2, 4 of the WCS), because it did not traverse a U.S.A. Corps of Engineers project. For this method, all tons listed as originating or terminating on the projects within the study waterway system were summed, and the total divided by two to arrive at the commodity totals for the waterway system. Thus, the greatest amount of traffic was captured, so that only traffic which both originated and terminated on non-Corps projects was left uncounted.

Table C-3 shows the resulting values for tons by commodity group and waterway. The tons shipped by waterway were used by the model only as weighting factors to average out the effects of different waterways on the average energy intensiveness by commodity. The total energy consumption was obtained by use of the national summary data which are more reliable and complete. Also, the energy intensiveness calculations were determined in part from waterway and commodity movement characteristics. As a consequence, statistical errors in waterway tonnage inputs to the model show up only in the weighting by waterway of energy intensity for the separate commodities, not in the overall average energy intensity calculations. Consistency between the waterway specific commodity ton-mile data and the national summary data is maintained by adjusting average haul assumptions.

Average haul per ton is calculated as the ratio of ton-miles to tons. For lack of better information, this ratio is also assumed as the average haul per shipment. Although traffic measured in tons over the several waterways will total more than national tons shipped, the ton-mile measure of the same traffic will sum exactly to the national total. Shipments may traverse more than one waterway and thus be included in tonnage counts for each waterway. However, the length of haul on each waterway is less than the total shipment length of haul, and therefore the total ton-miles by waterway are equal to the national total. For example, if a shipment of 1,000 tons moves 500 miles downstream on the Ohio to the Mississippi and then 500 miles further downstream on the Mississippi to its destination, the ton statistics would indicate that 1,000 tons were moved on both the Ohio and the Mississippi. The national summary would count the 1,000 tons only once. If the separate waterway tonnages were summed, it would show that 2,000 tons had been shipped on U.S. waterways when, in fact, only 1,000 tons had been shipped. However, this same shipment, when measured in

TABLE C-3

TONS SHIPPED BY COMMODITY AND WATERWAY (BOTH DIRECTIONS)
(Thousands)

COMMODITY	OHIO	UP. MISS.	L. MISS.	GIWW	ATLANTIC	PACIFIC
1. Agriculture	3,164	23,613	33,180	13,951	310	1,579
2. Metallic Ores	1,748	133	3,096	248	147	0
3. Coal and Coke	92,689	13,976	23,038	9,031	5,214	0
4. Petroleum	29,383	12,185	58,819	60,066	36,279	7,284
5. Non-Metallic Minerals	24,150	10,284	15,252	10,045	11,590	4,584
6. Food & Kindred Prod.	621	2,494	5,197	518	317	465
7. Textiles, Apparel & Leather	4	5	26	4	0	0
8. Lumber & Furniture	49	96	837	178	1,164	15,016
9. Pulp, Paper & Allied	220	71	627	77	192	1,435
10. Chemicals & Allied	11,675	5,869	20,350	14,240	1,485	463
11. Rubber & Plastics	0	0	8	0	0	0
12. Stone, Clay & Glass	1,976	2,348	3,525	794	415	75
13. Primary Metal Prod.	4,888	1,906	5,335	2,386	209	12
14. Fabricated Metal Prod.	136	68	220	118	41	13
15. Machinery ex. Elec.	136	22	84	59	18	5
16. Electrical Machinery	36	0	40	34	2	0
17. Transportation Equip.	0	2	8	6	2	6
18. Instruments & Misc. Mfg.	0	0	100	718	2	2
19. Waste & Scrap	957	3,743	1,028	825	5,183	1,028
Total	171,832	76,815	170,770	113,298	62,570	31,967

Source: Waterborne Commerce Statistics, Parts 1, 2, and 4.

ton-miles, generated 500,000 ton miles on the Ohio, 500,000 ton-miles on the Mississippi, and 1,000,000 ton-miles for the total waterway system. Since the sum of ton-miles by waterways equals the national total, the average haul assumptions by waterway and commodity can therefore be used to bring consistency to the model inputs.

To complete the characterization of commodity tons by waterway, upstream tonnage movements were separated from downstream tonnage movements, because energy intensiveness differs by direction as well as by waterway. To determine the proportion of tons moving upstream, the published consolidated reports for the main stem traffic (as found in WCS Part 2) were examined for the Ohio and the Upper and Lower Mississippi Rivers. Downstream tonnage was calculated as total tonnage minus upstream tonnage. The other waterways were assumed to have zero current, and therefore the traffic was arbitrarily split 50 percent in each direction for model input convenience. This assumption has no effect on the average energy intensiveness for commodities traversing these waterways. Waterway directional proportions are listed in Table C-4.

C.2.3 Average Haul Ton

The average length of haul per ton was found by dividing the reported ton-miles by the reported tons from the national summary data[1] (see Table C-5).

The average haul for each commodity for each waterway cannot be computed directly from published data. Therefore an indirect method was devised:

> average haul was estimated by waterway, irrespective of commodity;
>
> average haul by waterway was distributed among commodities according to the variation around the mean found in the national average hauls by commodity (Table C-5); and
>
> commodity average haul by waterway was scaled so that when multiplied by tons by each respective waterway (Table C-3), the result is the national total ton-miles (Table C-2).

The results of this calculation are found in Table C-6.

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[1] WCS, Part 5, op. cit.

TABLE C-4

PROPORTION OF TONS MOVING UPSTREAM BY COMMODITY AND WATERWAY

COMMODITY	OHIO	UP. MISS.	L. MISS.	GIWW[1]	ATLANTIC[1]	PACIFIC[1]
1. Agriculture	.94	.00	.07	N/A	N/A	N/A
2. Metallic Ores	.95	1.00	.59			
3. Coal and Coke	.55	.93	.41			
4. Petroleum	.82	.80	.79			
5. Non-Metallic Minerals	.99	.83	.61			
6. Food & Kindred Prod.	.80	.45	.29			
7. Textiles, Apparel & Leather	1.00	1.00	.92			
8. Lumber & Furniture	1.00	.91	.27			
9. Pulp, Paper & Allied	1.00	1.00	.29			
10. Chemicals & Allied	.18	.94	.79			
11. Rubber & Plastics	.69	.00	.38			
12. Stone, Clay & Glass	N/A[2]	.62	.27			
13. Primary Metal Prod.	.41	.35	.43			
14. Fabricated Metal Prod.	.29	.40	.38			
15. Machinery ex. Elec.	.39	.86	.67			
16. Electrical Machinery	.12	.22	.72			
17. Transportation Equip.	.83	1.00	.43			
18. Instruments & Misc. Mfg.	N/A[2]	N/A[2]	.18			
19. Waste & Scrap	.89	.50	.42			

[1] No significant water current. Direction is immaterial.

[2] Near zero traffic of these commodities on these waterways.

Source: Waterborne Commerce Statistics, Part 2.

TABLE C-5

WEIGHTED AVERAGE HAUL PER TON FOR WATER MOVEMENTS BY COMMODITY

COMMODITY	AVERAGE HAUL[1] (Miles)
1. Agriculture	718
2. Metallic Ores	801
3. Coal and Coke	282
4. Petroleum	286
5. Non-Metallic Minerals	181
6. Food & Kindred Prod.	824
7. Textiles, Apparel & Leather	606
8. Lumber & Furniture	79[2]
9. Pulp, Paper & Allied	247
10. Chemicals & Allied	653
11. Rubber & Plastics	500
12. Stone, Clay & Glass	350
13. Primary Metal Prod.	898
14. Fabricated Metal Prod.	840
15. Machinery ex. Elec.	421
16. Electrical Machinery	977
17. Transportation Equip.	223
18. Instruments & Misc. Mfg.	26[2]
19. Waste & Scrap	123[2]

[1] See discussion on derivation.

[2] Based on derivations described. Probable errors in ton-mile and ton source statistics.

Source: Calculated from ton and ton-mile statistics as reported by W.C.S., Part 5.

TABLE C-6

AVERAGE HAUL BY COMMODITY AND WATERWAY
(Miles)

COMMODITY	OHIO	UP. MISS.	L. MISS.	GIWW	ATLANTIC	PACIFIC
1. Agriculture	334	309	764	261	78	84
2. Metallic Ores	480	443	1,026	374	112	-
3. Coal and Coke	201	187	460	157	47	-
4. Petroleum	208	192	473	161	49	51
5. Non-Metallic Minerals	170	157	389	133	40	42
6. Food & Kindred Prod.	350	324	750	273	82	87
7. Textiles, Apparel & Leather	290	267	660	226	-	-
8. Lumber & Furniture	216	203	498	171	51	55
9. Pulp, Paper & Allied	285	262	650	222	68	71
10. Chemicals & Allied	287	265	654	224	68	71
11. Rubber & Plastics	-	-	500	-	-	-
12. Stone, Clay & Glass	171	158	389	133	40	42
13. Primary Metal Prod.	359	332	820	280	84	90
14. Fabricated Metal Prod.	364	336	831	284	86	91
15. Machinery ex. Elec.	281	260	641	219	66	69
16. Electrical Machinery	272	-	621	212	64	-
17. Transportation Equip.	-	162	399	136	41	43
18. Instruments & Misc. Mfg.	-	-	61	21[1]	7[1]	7[1]
19. Waste & Scrap	176	164	403	137	41[1]	43[1]

Source: See text discussion

[1] Probable error in some statistics.

C.2.4 Tow Descriptors

The modified Howe formula, which was used to calculate water speed, requires the input of several descriptive variables. Average draft and installed horsepower are derived from published statistics. The remaining variables (i.e., tow length, tow beam, engine load factors, and tons per tow) are assumed values based on discussions with industry and Corps of Engineers analysts. Tons per tow were calculated based upon length, beam, and draft.

Installed Horsepower. The size of the towboat was represented by the horsepower. Statistics on towboat horsepower were provided by the U.S. Corps of Engineers by waterway for the Mississippi River-Gulf Intracoastal system. However, it was necessary to assume values for the Atlantic and Pacific Coasts due to lack of data. The values given for the Ohio, Upper and Lower Mississippi, and Gulf are median values, since averages did not adequately represent the importance of the larger boats. Table C-7 lists the estimated average towboat installed horsepower by waterway.

To compute horsepower hours, the installed horsepower was modified by an engine load factor to reflect operating conditions and optimum running loads. These load factors were assigned after discussions with various barge operators. Table C-8 lists the engine-load factor for upstream and downstream for both contingency delays (assumed at 5 percent of running time) and lock delays by waterway. A constant figure of 1,600 Btus per horsepower hour was assumed as the energy consumption rate for towboat diesel engines, which is equal to a specific fuel consumption rate of .35 lbs. per horsepower hour.

Length and Width of the Tow. Tow sizes for each waterway were estimated on the basis of what the average horsepower boat would typically handle on each waterway. Although tows of 40 barges or more are not uncommon on the Lower Mississippi, the typical tow sizes were estimated as:

Lower Mississippi - 15 barges;

Ohio and Upper Mississippi - 9 barges;

Atlantic - 2 barges; and

Gulf and Pacific Coasts - 4 barges.

TABLE C-7

MEDIAN INSTALLED HORSEPOWER OF TOWBOATS BY WATERWAY

WATERWAY	HORSEPOWER
Ohio	3,650
Upper Mississippi	3,700
Lower Mississippi	4,900
Gulf Intracoastal	3,150
Atlantic Coastal W.W.	1,200
Pacific Coastal W.W.	2,400

Source: U.S.A. Corps of Engineers table reproduced in Battelle, Hazardous Substances Study, U.S. Department of Transportation, 1974.

TABLE C-8

ENGINE LOAD FACTORS BY OPERATION CONDITION AND WATERWAY

WATERWAY	UPSTREAM	DOWNSTREAM	CONTINGENCY DELAY	LOCK DELAY
Ohio	1.0	0.8	0.5	0.1
Upper Mississippi	1.0	0.8	0.5	0.1
Lower Mississippi	1.0	0.8	0.5	0.1
Gulf Intracoastal	0.9	0.9	0.5	0.1
Atlantic Coast W.W.	0.9	0.9	0.5	0.1
Pacific Coast W.W.	0.9	0.9	0.5	0.1

Source: Interviews with barge operators.

to calculate the flotilla size in feet, we assumed a 195 foot by 35 foot barge (200 feet by 42 feet on the Pacific) and a 140 foot by 35 foot towboat. Table C-9 lists the length and width of average tows by waterway.

Draft and Tons Per Tow. Statistics on numbers of trips by drafts were available in the WCS Parts 1, 2, and 4 for all waterway projects. However, not all waterway projects, especially the coastal projects, listed drafts below 18 feet. Where the data were listed down to the 6 foot draft, the trip data were compiled for each region to obtain an indicator of the average draft for the waterway region under study. Table C-10 details the number of trips by draft and waterways. The values for 3 feet and greater are used as weights to compute the average loaded drafts listed in Table C-11. The loaded draft is an estimate of the deepest point of the tow. When calculating the tons of cargo per tow, an average draft for all barges empty and loaded is calculated to account for empty movements.

Given the tow size in number of barges and the average draft, it is possible to compute the tons of cargo transported per tow. The assumed barge is 190 feet by 35 feet, which when loaded to 9 feet of draft carries 1500 tons. When empty, the same barge draws 2 feet of draft. Consequently, each foot of draft is equivalent to about 214 tons of cargo (for "box" shaped barges. Barges with "rake" bows are slightly different.) Therefore, the tons per tow equals approximately the draft less two, multiplied by 214, and further multiplied by the number of barges. The results of this computation are given in Table C-12.

Except for certain dedicated tows, the typical river tow will have some empty barges mixed in among loaded barges. Average draft among barges drawing 3 feet or more is used for computing water speed. The average draft of all barges, empty and loaded, to compute the tons carried per tow. Thus, the presence of empty barge movements is accounted for, which eliminates the need to find or assume an average empty backhaul ratio.

Waterway Descriptors. The modified Howe formula used to calculate speed, and subsequently hours underway, requires the input of waterway channel widths and depths. Other variables which affect hours underway and engine hours include, for each waterway, lockage time, numbers of locks, and the current speed.

Width and Depth. The underkeel clearance can have a significant impact on operating speeds. The depths chosen were approximate

TABLE C-9

TOW WIDTH AND LENGTH BY WATERWAY

WATERWAY	LENGTH	WIDTH	NO. OF BARGES LENGTH X WIDTH
Ohio	725	105	3 x 3
Upper Mississippi	725	105	3 x 3
Lower Mississippi	1,115	105	5 x 3
Gulf Intracoastal	530	70	2 x 2
Atlantic Coastal W.W.	530	35	2 x 1
Pacific Coastal W.W.	540	84	2 x 2

Source: Estimated.

TABLE C-10

NUMBER OF TRIPS BY DRAFTS AND WATERWAYS

WATERWAY	DRAFT IN FEET												
	13	12	11	10	9	8	7	6	5	4	3	2	1
Ohio			296	8389	155358	25954	22198	13482	3582	915	1782	190416	11636
Upper Mississippi				2102	53775	12549	7251	8063	5972	3243	2894	60054	10512
Lower Mississippi		515	1123	6377	86134	15647	25007	6143	3721	5054	2932	96810	582
Gulf Intracoastal	200	2018	3860	19224	67149	25036	12090	21950	13904	2881	5452	88390	15457
Atlantic Coast W. W.	1541	1891	1307	7249	7171	3390	2034	864	716	725	6239	16607	12
Pacific Coast W. W.	293	1708	2152	2412	2036	4169	7581	283	210	306	1436	9242	2

Source: WCS, Parts 1, 2, & 4, Trip Data.

TABLE C-11

AVERAGE DRAFT BY WATERWAY

WATERWAY	LOADED DRAFT	EMPTY & LOADED DRAFT
Ohio	8.4	5.4
Upper Mississippi	7.9	5.3
Lower Mississippi	8.1	5.7
Gulf Intracoastal	7.9	5.7
Atlantic Coastal W.W.	8.0	6.0
Pacific Coastal W.W.	8.2	6.4

Source: Calculated from Table C-10.

TABLE C-12

ESTIMATED TONS PER TOW BY WATERWAY

WATERWAY	NET TONS PER TOW
Ohio	10,414
Upper Mississippi	10,221
Lower Mississippi	18,321
Gulf Intracoastal	4,886
Altantic Coastal W.W.	2,571
Pacific Coastal W.W.	7,168

Source: Estimated.

estimates of average pool depths. (Ohio River depths will change in future years due to a new systems of locks.) The estimated channel depths are given in Table C-13. Project depths listed in statistical sources refer only to minimum clearances.

Waterway channel widths, as expressed by project widths, are sufficiently large so that they do not affect the Howe formula results as much as depths. The project widths of various reaches of the waterway were weighted by their importance in terms of annual tonnage to arrive at an average waterway channel width. The figures used for this calculation are taken from the American Waterways Operators, Big Load Afloat.[1] The average channel widths found are listed in Table C-14.

Current Velocity. The velocity of current in a river channel is dependent upon the cross-sectional area of a point on the river and the volume of water per unit of time passing that point. On the Ohio, velocities were found to vary from 1.5 to 6.2 miles per hour.[2] The speeds calculated for each reach (segment), weighted by the length of the reach, were used to calculate an average current speed. The Upper Mississippi was estimated to average the same speed as the Ohio, and the Lower Mississippi to be .5 miles per hour faster. These estimates were made after discussion with barge operators familiar with conditions on these waterways. The Coastal waterways have a zero current speed. Table C-15 gives the current velocities used in the study.

Number of Locks per Mile by Waterway. The number of locks within each waterway was divided by the length of that segment and then divided by the tons of traffic on that segment to calculate the average "locks per mile." This figure is then multiplied by the average haul by commodities to determine the average number of locks traversed by a typical tow. This is further multiplied by the delay time in hours to determine the total lock delay attributable to each commodity and each waterway. Table C-16 shows the numbers of locks per mile by waterways.

Lock Delay Time. Though lock delay varies considerably from lock to lock, the model detail makes it necessary to assume a common delay time for all locks within a waterway. The delay times used in this study are not observed delays, but rather calculated delays based on waterway simulation studies done at Penn State University[3] and the Chicago District

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[1] Washington, D.C., 1973, pages 121 to 149.

[2] Pennsylvania Transportation and Traffic Safety Center, Waterway Systems Simulation Vol. IV, Penn. State University, University Park, Pennsylvania, 1971, p. 63-4

[3] Ibid. p. 38-39 (Calibration Run (Ohio R))

TABLE C-13

AVERAGE PROJECT DEPTH BY WATERWAY

WATERWAY	DEPTH (Feet)
Ohio	20
Upper Mississippi	15
Lower Mississippi	30
Gulf Intracoastal	12
Atlantic Coastal W.W.	18
Pacific Coastal W.W.	18

Source: Contact with Corps of Engineers district offices.

TABLE C-14

AVERAGE CHANNEL WIDTH BY WATERWAY

WATERWAY	WIDTH (Feet)
Ohio	400
Upper Mississippi	460
Lower Mississippi	1,300
Gulf Intracoastal	170
Atlantic Coastal W.W.	960
Pacific Coastal W.W.	1,300

Source: American Waterways Operators, <u>Big Load Afloat</u>, Washington, D. C., 1973.

TABLE C-15

CURRENT VELOCITY BY WATERWAY

WATERWAY	VELOCITY (MPH)
Ohio	3.5
Upper Mississippi	3.5
Lower Mississippi	4.0
Gulf Intracoastal	0
Atlantic Coastal W.W.	0
Pacific Coastal W.W.	0

Source: Estimated.

TABLE C-16

AVERAGE LOCKS PER MILE BY WATERWAY

WATERWAY	AVERAGE LOCKS PER MILE
Ohio	.0426
Upper Mississippi	.0295
Lower Mississippi	.0026
Gulf Intracoastal	.0055
Atlantic Coastal W.W.	.0000
Pacific Coastal W.W.	.0108

Source: Calculated from Corps of Engineers data: Annual Report, Chief of Engineers, Washington, D.C., 1973.

Office of the COE.[1] The delays found in the calibration run for 1970 data were increased in the same proportion that tonnage increased from 1970 to 1972. This calculation was made for the Ohio and the Upper Mississippi. The values for the remaining waterways were based upon judgment as to their similarities to the calculated delays. An estimated lockage time of one hour was added to the delay time to arrive at total lockage time. Table C-17 lists the lock delays used in the model.

Scenario Data

The model inputs for traffic volume, tow characteristics, and lock characteristics, vary with each scenario. The depth of the Ohio River is also projected to change because the of fewer high-lift locks which will be in place by 1980.

Traffic Volume. Using the percentage rates of increase by commodity developed for the national projections (see Section 4), both the national total ton traffic and the waterway specific ton traffic were extended to 1980 and 1985. This approach implies an unchanging average haul per ton and an unchanging share of the total traffic. All 1980 and 1985 scenarios use the ton values listed in Tables C-18 and C-19.

Tow Characteristics. Changes in tow sizes and power are assumed to occur on the first three waterways. The coastal waterways' tows are assumed to remain the same. On the Ohio and the Upper Mississippi waterways, the tow is projected to increase from 9 to 11 barges from 1972 to 1980 and to 12 barges by 1985.[2] On the Lower Mississippi, the base-year 15 barge average tow is projected to increase to 18 in 1980 and to 20 in 1985. As a result of these changes, the tons carried per tow are projected to increase. The changes in the four tow parameters are outlined in Table C-20.

Lock Characteristics. The only change under the government influence scenario is a 1985 change in lock delays, because of the replacement of locks and dam 26 at Alton, Illinois, and replacement of industrial lock on the Gulf Intracoastal waterway. These changes are not anticipated in the industrial change scenario, and lock delays

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[1] Figures obtained by telephone.

[2] The Ill-Upper Miss 10 Lock Subsystem, U.S.A. Corps of Engineers, 1971, P. D-1 (Upper Miss).

TABLE C-17

ESTIMATED DELAYS AT LOCKS BY WATERWAY

WATERWAY	DELAY AT LOCKS (Hours)
Ohio	1.44
Upper Mississippi	1.99
Lower Mississippi	1.00
Gulf Intracoastal	1.25
Atlantic Coastal W.W.	--
Pacific Coastal W.W.	1.00

TABLE C-18

PROJECTED 1980 INLAND WATERWAY TRAFFIC IN TONS
(Thousands)

COMMODITY	U.S. TOTAL[1]	WATERWAY					
		OHIO	UP. MISS.	L. MISS.	GIWW	ATLANTIC	PACIFIC
1. Agriculture	71,687	4,341	32,397	45,523	19,141	425	2,166
2. Metallic Ores	11,243	3,763	286	6,666	534	316	0
3. Coal and Coke	164,032	127,633	19,245	31,723	12,436	7,180	0
4. Petroleum	241,345	42,165	30,544	84,405	86,195	52,060	10,453
5. Non-Metallic Minerals	124,609	41,973	17,874	26,508	17,458	20,143	7,967
6. Food & Kindred Prod.	7,755	773	3,105	6,470	645	395	579
7. Textiles, Apparel & Leather	45	5	7	35	5	0	0
8. Lumber & Furniture	20,340	57	113	982	209	1,365	17,614
9. Pulp, Paper & Allied	4,515	394	127	1,124	138	344	2,573
10. Chemicals & Allied	56,922	20,151	10,130	35,124	24,578	2,563	799
11. Rubber & Plastics	13	0	0	13	0	0	0
12. Stone, Clay & Glass	8,537	2,679	3,184	5,259	1,077	563	102
13. Primary Metal Prod.	13,918	8,183	3,191	8,964	3,994	350	20
14. Fabricated Metal Prod.	522	203	101	328	176	61	19
15. Machinery ex. Elec.	443	226	37	140	98	30	8
16. Electrical Machinery	67	56	0	63	53	3	0
17. Transportation Equip.	34	0	3	14	10	3	10
18. Instruments & Misc. Mfg.	1,281	0	0	156	1,119	3	3
19. Waste & Scrap	18,980	1,423	5,566	1,529	1,227	7,707	1,529
Total	746,288	254,025	124,910	255,026	169,093	93,511	43,842

Source: TMM&Co. estimate (see Chapter IV).

(1) Totals do not add across due to duplicate reporting of tons on more than one waterway.

TABLE C-19

PROJECTED 1985 INLAND WATERWAY TRAFFIC IN TONS
(Thousands)

COMMODITY	U.S. TOTAL(1)	WATERWAY					
		OHIO	UP. MISS.	L. MISS.	GIWW	ATLANTIC	PACIFIC
1. Agriculture	80,003	4,845	36,155	50,804	21,361	474	2,417
2. Metallic Ores	14,279	4,779	363	8,466	678	401	0
3. Coal and Coke	182,568	142,055	21,420	35,308	13,841	7,991	0
4. Petroleum	287,925	50,303	36,439	100,695	102,831	62,108	12,470
5. Non-Metallic Minerals	155,387	52,340	22,289	33,055	21,770	25,118	9,935
6. Food & Kindred Prod.	8,701	867	3,484	7,259	724	443	650
7. Textiles, Apparel & Leather	51	6	8	39	6	0	0
8. Lumber & Furniture	22,984	64	128	1,110	236	1,542	19,904
9. Pulp, Paper & Allied	5,558	485	156	1,384	170	423	3,167
10. Chemicals & Allied	70,754	25,048	12,592	43,659	30,550	3,186	993
11. Rubber & Plastics	16	0	0	16	0	0	0
12. Stone, Clay & Glass	9,818	3,081	3,662	6,048	1,239	647	117
13. Primary Metal Prod.	16,869	9,918	3,867	10,864	4,814	424	24
14. Fabricated Metal Prod.	611	238	118	384	206	71	22
15. Machinery ex. Elec.	544	278	45	172	120	37	10
16. Electrical Machinery	82	68	0	77	65	4	0
17. Transportation Equip.	39	0	3	16	11	3	11
18. Instruments & Misc. Mfg.	1,577	0	0	192	1,376	4	4
19. Waste & Scrap	21,846	1,638	6,406	1,760	1,412	8,871	1,760
Total	879,612	296,022	147,135	301,308	201,410	111,747	51,484

Source: PMM&Co. estimate (see Chapter IV).

(1) Totals do not add across due to duplicate reporting of tons on more than one waterway.

TABLE C-20

PROJECTED 1980 AND 1985 TOW CHARACTERISTICS

1980

WATERWAY	INSTALLED HORSEPOWER	TOW LENGTH	TOW WIDTH	TONS CARRIED PER TOW
1. Ohio	4,500	920	105	12,729
2. Upper Miss.	4,500	920	105	12,493
3. Lower Miss.	6,000	1,310	105	21,986

1985

WATERWAY	HORSEPOWER	TOW LENGTH	TOW WIDTH	TONS CARRIED PER TON
1. Ohio	5,000	920	105	13,886
2. Upper Miss.	5,000	920	105	13,629
3. Lower Miss.	6,400	1,115	140	24,429

Source: PMM&Co. estimate.

are projected to increase due to increased traffic. Table C-21 gives the lock delays assumed by waterway and scenario.

Pool depth and numbers of locks per mile change only on the Ohio River due to new lock construction now taking place and to be in place before 1980. Though the number of locks remain the same, one new lock will replace an old lock, which will raise the pool level in 1985. On the Ohio, pool depth is assumed to be 22 feet in 1980 and 23 feet in 1985. Locks per mile will decrease from .0426 in 1972, to .0354 in 1980 and 1985.

TABLE C-21

LOCK DELAY ASSUMPTIONS IN 1980 AND 1985

WATERWAY	LOCK DELAYS (Hours)		
	1980 INDUSTRY CHANGE	1985 INDUSTRY CHANGE	GOVERNMENT
1. Ohio	1.05	1.05	1.05
2. Upper Mississippi	4.00	5.00	1.50
3. Lower Mississippi	1.10	1.12	1.12
4. Gulf Intracoastal	1.50	1.60	1.05
5. Atlantic Waterways	-	-	-
6. Pacific Waterways	1.10	1.12	1.12

Source: PMM&Co. estimate.

APPENDIX D

COASTAL SHIPPING

D.1 METHODOLOGY

This component of the TRANSEN model computes energy intensity values for coastal movements of domestic deep-sea ships and barges in oceangoing tug-barge configurations (not included in the inland waterways component of the model).

Because modal share values for barges and coastal ships vary by commodity, this component of the model computes energy intensity values for both shipping modes. Figure D-1 shows the logic of the calculations. The lower part of the figure presents the procedure used for ships, and the upper part presents the procedure for barges. Except for differences in data inputs, the procedures are similar. First, total Btu's required per trip for ships are estimated. Btu's per ton and ton-mile and total Btu's for the year's shipping volume are then estimated.

Running hours per trip are computed by:

$$SH_i = \frac{2CTM_i}{CTN_i SS_i} \qquad \text{(D-1)}$$

where:

SH_i = Total steaming hours per trip for commodity group, i

CTM_i = Total ton-miles of commodity group, i, in coastal shipping

CTN_i = Total tons of commodity group, i, in coastal shipping

SS_i = Speed (miles per hour) for a typical size ship used in shipping commodity group, i.

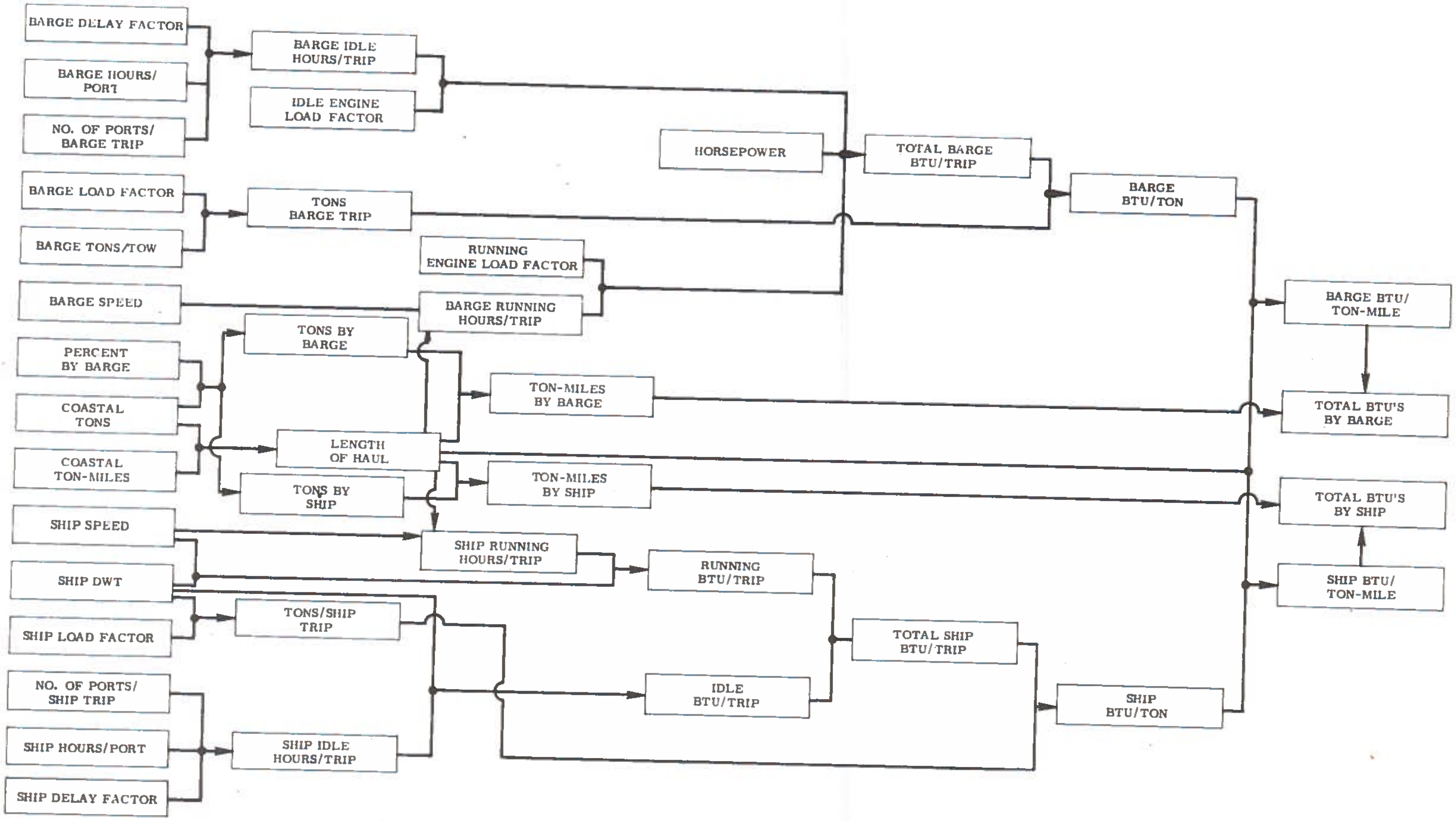

FIGURE D-1: CONCEPTUAL DESIGN OF THE COASTAL SHIPPING COMPONENT OF THE TRANSEN MODEL

To compute the total Btu requirements that correspond to SH , the following formula is used:[1]

$$RF_i = (62.257SS_i + .0086SD_i - 904)SH_i \qquad (D-2)$$

where:

RF_i = Fuel consumption (light distillate or bunker C fuel oil) for running hours per trip (expressed in U.S. gallons) in carrying commodity group, i

SD_i = Typical size ship (deadweight tons) used in coastal shipping of commodity group, i.

Equation D-2 is a good representation of fuel consumption for ships between 17,500 and 45,000 dead weight tons (DWT). The number of ports called per trip, hours spent at each port, and a delay factor are used to compute total idle hours per trip. The fuel consumption for idle hours is then computed by:

$$IF_i = .0014SD_i \ (IH_i) \qquad (D-3)$$

where:

IF_i = Fuel consumption for idle hours per trip (expressed in U.S. gallons) for commodity group, i

IH_i = total idle hours per trip for commodity group, i.

RF_i and IF_i values are then converted to Btu's per trip, ton, and ton-mile and total Btu's for the yearly volume of commodity group, i. The same procedure is used to compute EI values for coastal shipping by barge.

D.2 DATA SOURCES

D.2.1 Base-Year Data

An accurate analysis of coastal shipping is extremely difficult, because of the lack of summary data on ships engaged in coastal trade

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[1] P. Chudleigh, "Economic Potential of Specialized World Shipping Services," Journal of Transport Economics and Policy, Vol. IX, No. 3, September 1975.

and the intermingling of international with domestic cargoes on many ships. The methods and assumptions for coastal movements use readily available data to (1) give a general indication of how this mode relates to other modes and (2) permit analysis of the effects of changes in speed and ship size on energy consumption.

The base-year input variables used in the coastal shipping component of the TRANSEN model fall into three categories:

commodity data:

ton-miles by commodity in coastal shipping;

tons by commodity group in coastal shipping; and

proportion of coastal shipping volume by commodity group shipped by barge.

ship data:

speed for a typical size ship used to ship each commodity;

size of a typical ship used to ship each commodity;

number of ports per trip for a typical ship used to ship each commodity;

ship capacity utilization factor;

ship delay factor due to weather;

ship port time; and

size of typical tow used to ship each commodity.

tow data

speed of a typical tow used in coastal shipping by barge for speed commodity;

horsepower of a typical tow used in coastal shipping by barge for each commodity;

engine load factor of a typical tow during idle time; and

Btu's per horsepower hour of tow boats.

These data items are discussed below.

D.2.1.1 Tons and Ton-Miles

U.S. Department of the Army, Corp of Engineers, publishes annual waterway traffic statistics in tons and ton-miles. Table D-1 presents all coastwise and lakewise traffic statistics by commodity for 1972. The figures combine all tonnage for both barges and ships.

D.2.1.2 Proportion of Traffic by Barge

The Corps of Engineers also provides data at commodity group detail for tons shipped by barge in coastwise and lakewise shipping. Barge tons are then expressed as a percent of the total tons shown in Table D-1. Table D-2 presents the proportion of tons shipped by barge.

D.2.1.3 Ship Speed and Size

For each commodity group, a typical ship type (i.e., dry bulk, break bulk, and tanker) is assumed. Tankers and dry-bulk ships are assumed to have an average speed of 15 knots. The speed assumed for break-bulk ships is 17 knots. The size assumed for a break-bulk vessel is 12,500 dead weight tons. The assumed capacity for dry-bulk vessels is 17,500 DWT and 25,000 DWT for tankers. Table D-3 presents the assumed ship types, speeds, and ship capacities by commodity groups.

D.2.1.4 Number of Ports per Trip

Dry-bulk vessels are typically used in dedicated service to carry raw materials and intermediate goods to processing centers. Therefore, it is assumed that two ports would be called per trip; one to load and the other to unload. Tankers typically call one to three ports to unload and one port to load. Thus, the total number of ports for tankers is assumed to be three ports. Break-bulk ships are assumed to call four ports per trip.

D.2.1.5 Ship Capacity Utilization Factor

The ship capacity utilization factor gives an estimated proportion of the ship's DWT capacity typically utilized per trip. Although a majority of tanker trips and dedicated dry-bulk vessel trips are loaded to full capacity, the same is not true for break-bulk vessels. However, in some instances, departures with a load less than the full capacity are justified because of trade-off between port costs and marginal revenues due to added load per trip. Because of inadequate data, the average utilization factor estimated for all ships is .80 (i.e., when a ship is loaded, 80 percent of its DWT capacity is being utilized).

D.2.1.6 Delay and Port Time

A delay factor of 10 percent of the total trip hours is assumed. The delay factor accounts for delays due to weather conditions, port congestion, and other factors which cause a deviation from ship speed at sea and/or port time. Port time is assumed to be 24-hours per call.

D.2.1.7 Tow Size and Speed

Dedicated, oceangoing tug-barges of 10,000 DWT are becoming the standard vessel for coastal shipping of crude oil and related products. Howser type tows (tug pulling) with one to two barges per tow are the common practice for oceangoing tows. Such tows can run at an average speed of 12 knots. Because of hull streamlining differences, dry cargo barges are smaller and slower compared to tank barges. It is assumed that 15,000 DWT is the average capacity of tank barges (when used for commodity groups other than petroleum). The average capacity per tow for dry cargoes is assumed to be 10,000 DWT with a speed of 11.6 miles per hour. It is further estimated that a 5,000 horsepower towboat is used for tank barges, and a 4,000-horsepower towboat is used for dry-cargo barges.

D.2.1.8 Engine Load Factors and Btu per Horsepower Hour

Towboats are assumed to have 100 percent engine load factor while at sea. During idle time, the parasitic-load requirements for accessories is estimated to run the engine at 10 percent of rated power. Specific fuel consumption of a diesel engine is assumed to be .36 lbs. per horsepower hour, which translates to approximately 6,900 Btu's of diesel fuel per horsepower hour.

D.2.2 Scenario Data

The variables which change by scenario are traffic volumes, ship sizes and speeds, and port delay times. Average length of haul, proportion of traffic carried by seagoing barges, the size and speed of those barges, and the number of ports of call are all constant.

TABLE D-1

COASTWISE AND LAKEWISE TRAFFIC, 1972

COMMODITY	TONS (Thousands)	TON-MILES (Millions)
1. Agriculture	4,115	4,521
2. Metallic Ores	69,527	51,636
3. Coal and Coke	28,859	8,032
4. Petroleum	199,294	281,382
5. Non-Metallic Minerals	50,143	21,889
6. Food & Kindred Prod.	2,268	10,744
7. Textiles, Apparel & Leather	189	400
8. Lumber & Furniture	3,470	5,488
9. Pulp, Paper & Allied	966	834
10. Chemicals & Allied	11,265	24,024
11. Rubber & Plastics	100	168
12. Stone, Clay & Glass	8,359	2,927
13. Primary Metal Prod.	2,359	4,232
14. Fabricated Metal Prod.	782	1,369
15. Machinery ex. Elec.	344	636
16. Electrical Machinery	153	306
17. Transportation Equip.	714	819
18. Instruments & Misc. Mfg.	403	605
19. Waste & Scrap	422	261
Total	383,732	420,273

Source: U.S. Army Corps of Engineers, Waterborne Commerce of the U.S., Calendar Year 1972, Part 5: National Summaries, pp. 7-9 and 126-128.

TABLE D-2

PROPORTION OF TOTAL COASTWISE AND LAKEWISE TONS SHIPPED BY BARGE, 1972

COMMODITY	PROPORTION
1. Agriculture	.38
2. Metallic Ores	.00
3. Coal and Coke	.45
4. Petroleum	.12
5. Non-Metallic Minerals	.60
6. Food & Kindred Prod.	.05
7. Textiles, Apparel & Leather	.01
8. Lumber & Furniture	.30
9. Pulp, Paper & Allied	.03
10. Chemicals & Allied	.11
11. Rubber & Plastics	.02
12. Stone, Clay & Glass	.72
13. Primary Metal Prod.	.17
14. Fabricated Metal Prod.	.26
15. Machinery ex. Elec.	.22
16. Electrical Machinery	.08
17. Transportation Equip.	.14
18. Instruments & Misc. Mfg.	.00
19. Waste & Scrap	.52

Source: Adapted from U.S. Army Corps. of Engineers, Waterborne Commerce of the U.S., Calendar Year 1972, Part 5: National Summaries, pp. 30-32.

TABLE D-3

SHIP TYPES, SPEEDS, AND CAPABILITIES

COMMODITY	SHIP TYPE	SPEED (MPH)	SIZE (DWT)
1. Agriculture	Dry Bulk	17.40	17,500
2. Metallic Ores	Dry Bulk	17.40	17,500
3. Coal and Coke	Dry Bulk	17.40	17,500
4. Petroleum	Tanker	17.40	25,000
5. Non-Metallic Minerals	Dry Bulk	17.40	17,500
6. Food & Kindred Prod.	Break Bulk	19.72	12,500
7. Textiles, Apparel & Leather	Break Bulk	19.72	12,500
8. Lumber & Furniture	Dry Bulk	17.40	17,500
9. Pulp, Paper & Allied	Break Bulk	19.72	12,500
10. Chemicals & Allied	Break Bulk	19.72	12,500
11. Rubber & Plastics	Break Bulk	19.72	12,500
12. Stone, Clay & Glass	Dry Bulk	17.40	17,500
13. Primary Metal Prod.	Break Bulk	19.72	12,500
14. Fabricated Metal Prod.	Break Bulk	19.72	12,500
15. Machinery ex. Elec.	Break Bulk	19.72	12,500
16. Electrical Machinery	Break Bulk	19.72	12,500
17. Transportation Equip.	Break Bulk	19.72	12,500
18. Instruments & Misc. Mfg.	Break Bulk	19.72	12,500
19. Waste & Scrap	Dry Bulk	17.40	17,500

Source: Battelle estimates.

D.2.2.1 Traffic Data for 1980

Traffic projections for 1980 and 1985 are the same for both the base case and the industry change scenarios, that is, no shift in modal shares to or away from coastal shipping. Tons and ton-miles are presented in Table D-4 for 1980 and in Table D-5 for 1985 (see Chapter IV for projection bases).

D.2.2.2 Port Time

Due to improvements in materials handling and port capacity, port times are estimated to decrease from 24 hours for both ship and barge to 20 hours in 1980 and 18 hours in 1985.

D.2.2.3 Ship Speed and Size Changes

Table D-6 shows the estimates for ship speed and size in 1980 and 1985. The speed and size changes are arbitrary increases made in the absence of adequate historical data to test their effect on energy intensiveness.

TABLE D-4

PROJECTED TRAFFIC MEASURES FOR COASTAL SHIPPING, 1980

COMMODITY	TONS (Thousands)	TON-MILES (Millions)
1. Agriculture	5,646	6,213
2. Metallic Ores	149,692	111,178
3. Coal and Coke	38,584	11,063
4. Petroleum	285,987	403,744
5. Non-Metallic Minerals	87,149	38,041
6. Food & Kindred Prod.	6,559	13,376
7. Textiles, Apparel & Leather	257	544
8. Lumber & Furniture	4,070	6,443
9. Pulp, Paper & Allied	1,732	1,498
10. Chemicals & Allied	19,443	41,455
11. Rubber & Plastics	158	265
12. Stone, Clay & Glass	11,294	3,971
13. Primary Metal Prod.	3,949	7,083
14. Fabricated Metal Prod.	1,167	2,045
15. Machinery ex. Elec.	573	1,057
16. Electrical Machinery	239	479
17. Transportation Equip.	1,205	1,382
18. Instruments & Misc. Mfg.	628	942
19. Waste & Scrap	628	389
Total	618,960	651,168

Source: PMM&Co. estimates.

TABLE D-5

PROJECTED TRAFFIC MEASURES FOR COASTAL SHIPPING, 1985

COMMODITY	TONS (Thousands)	TON-MILES (Millions)
1. Agriculture	6,301	6,934
2. Metallic Ores	190,103	141,196
3. Coal and Coke	42,945	12,313
4. Petroleum	341,182	481,667
5. Non-Metallic Minerals	108,674	47,437
6. Food & Kindred Prod.	7,359	15,008
7. Textiles, Apparel & Leather	289	613
8. Lumber & Furniture	4,599	7,281
9. Pulp, Paper & Allied	2,132	1,844
10. Chemicals & Allied	24,168	51,528
11. Rubber & Plastics	191	322
12. Stone, Clay & Glass	12,988	4,566
13. Primary Metal Prod.	4,786	8,584
14. Fabricated Metal Prod.	1,366	2,394
15. Machinery ex. Elec.	703	1,298
16. Electrical Machinery	292	585
17. Transportation Equip.	1,373	1,574
18. Instruments & Misc. Mfg.	773	1,159
19. Waste & Scrap	722	447
Total	750,946	786,750

Source: PMM&Co. estimates.

TABLE D-6

SHIP SPEED AND SIZE ESTIMATES
(Industry Change Scenario)

COMMODITY	SHIP TYPE	1980	1985	1980	1985
1. Agriculture	Dry Bulk	18.0	18.2	18,000	18,500
2. Metallic Ores	Dry Bulk	18.0	18.2	18,000	18,500
3. Coal and Coke	Dry Bulk	18.0	18.2	19,000	20,000
4. Petroleum	Tanker	18.0	18.2	30,000	35,000
5. Non-Metallic Minerals	Dry Bulk	18.0	18.2	18,000	18,500
6. Food & Kindred Prod.	Break Bulk	20.7	20.9	14,000	15,000
7. Textiles, Apparel & Leather	Break Bulk	20.7	20.9	14,000	15,000
8. Lumber & Furniture	Dry Bulk	18.0	18.2	18,000	18,500
9. Pulp, Paper & Allied	Break Bulk	20.7	20.9	14,000	15,000
10. Chemicals & Allied	Break Bulk	20.7	20.9	14,000	15,000
11. Rubber & Plastics	Break Bulk	20.7	20.9	14,000	15,000
12. Stone, Clay & Glass	Dry Bulk	18.0	18.2	18,000	18,500
13. Primary Metal Prod.	Break Bulk	20.7	20.9	14,000	15,000
14. Fabricated Metal Prod.	Break Bulk	20.7	20.9	14,000	15,000
15. Machinery ex. Elec.	Break Bulk	20.7	20.9	14,000	15,000
16. Electrical Machinery	Break Bulk	20.7	20.9	14,000	15,000
17. Transportation Equip.	Break Bulk	20.7	20.9	14,000	15,000
18. Instruments & Misc. Mfg.	Break Bulk	20.7	20.9	14,000	15,000
19. Waste & Scrap	Dry Bulk	18.0	18.2	18,000	18,500

Source: PMM&Co. estimates.

APPENDIX E

PIPELINES

The methodology used to compute pipeline energy intensity is based on calculations for eight product types and 22 pipeline sizes. Because many conditions which influence the design of a pipeline can only be inferred from national data, the computation of average energy intensity required certain assumptions. Because of the lack of data on pipeline operations, it was necessary to assume flow rates (velocity) for various pipeline sizes. The velocity profiles were based on best interview consensus with pipeline experts, and cannot be statistically verified or quantified. Velocity profiles of 1 mph for crude and 1.5 mph for products were assumed for a 2" inside diameter line, and 5 mph and 6.5 mph respectively were assumed for a 48" line. The velocity assumption of intermediate lines were based on linear interpretations between the two, as plotted in **Figures 2-2 and 2-3 in the study report.**

E.1 METHODOLOGY

The methodology used in the TRANSEN model to compute pipeline energy intensity accounts for pipeline size, flow rate, specific gravity of the product, and an empirical friction factor for each product. Figure E-1 diagrams the algorithm logic described in this section.

The methodology employed avoids any explicit or implicit assumption on pump-station spacing by calculating ton-miles and horsepower requirements per mile of pipe.

Barrel-miles per mile of pipe per hour are equal to the flow rate in barrels per hour (since the "miles" in the numerator cancel the "miles" in the denominator).[1]

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[1] The conventional way of computing barrel-miles in pipelines is to count the number of barrels which arrive during a period of time at a terminal and multiply that times the length of the pipe. In an hour, the number of barrels to arrive at the terminal is equal to the flow rate. The barrel-miles delivered equals the flow rate times the miles of pipe between the origin and the terminal. The barrel-miles per mile is found by dividing by the same number of miles, which leaves the flow rate.

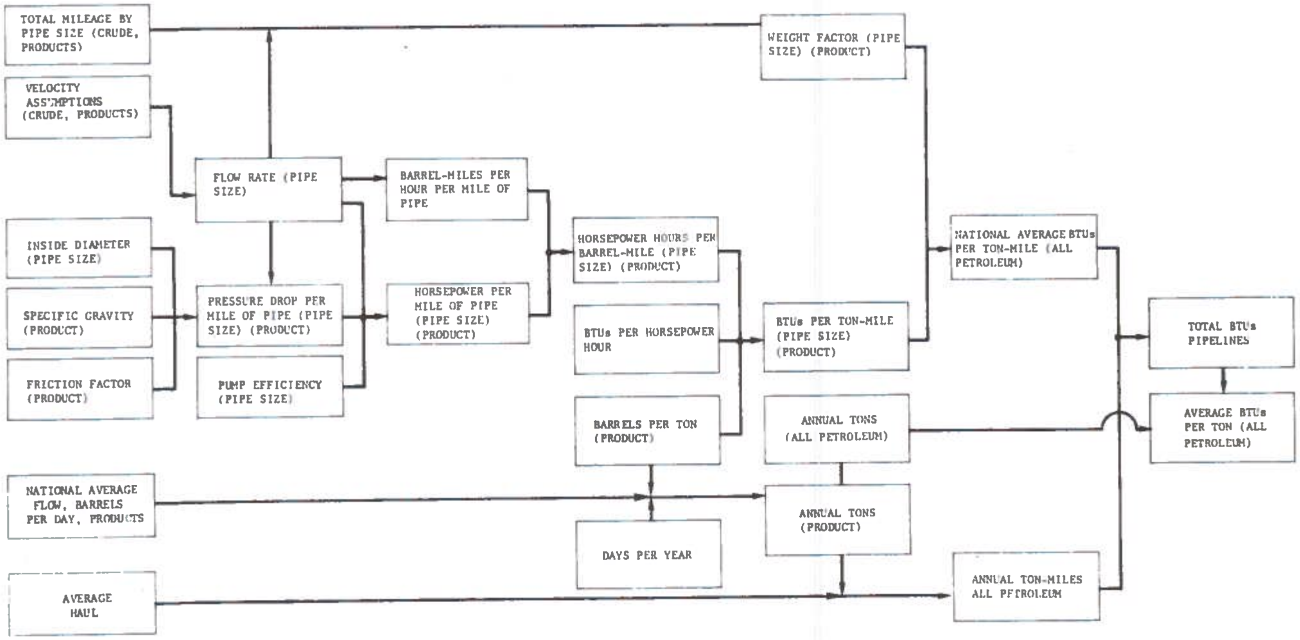

FIGURE E-1: CONCEPTUAL DESIGN OF THE PIPELINE COMPONENT OF THE TRANSEN MODEL

The horsepower requirement at a pumping station is computed by the formula:

$$H_{ij} = \frac{B_i P_{ij}}{2450 E_i} \qquad \text{(E-1)}$$

where:

H_{ij} = brake horsepower requirement at the pumping station for pipeline size, i, for product type, j

B_i = flow rate in barrels per hour for pipeline size, i

P_{ij} = pump pressure differential (output pressure minus input pressure) in pounds per square inch (psi) for pipeline size, i, for product type, j

E_i = pump efficiency (HP delivered/HP consumed), a dimensionless number between 0 and 1

The pump pressure differential, P, is constrained by the maximum allowable pressure, and depends on the total friction loss between pumping stations. This loss depends on the product characteristics and the velocity in the pipe, which in turn depends upon the total horsepower of all pumping stations on the pipeline. When pumping stations are closer together, they may still have the same, maximum pump differential pressure because the velocity of the fluid will be increased (thereby increasing the rate of pressure drop per mile, resulting in the same input pressure to the next pump).

For this analysis, pressure-drop per mile of pipe is used to replace pump-pressure differential in Equation E-1. With the velocity assumed, it is possible to calculate the pressure-drop per mile which is consistent with that velocity for each product and pipeline using the following formula:[1]

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[1] Theodore Baumeister, ed. (Lionel S. Marks ed. [late]), Standard Handbook for Mechanical Engineers, Seventh Edition, McGraw-Hill, N.Y., 1967 p. 11-183, 4. (cited formula in psi/1000 ft. was multiplied by 5.28)

$$q_{ij} = \frac{12355.2\ B_i^{1.852}\ S_j}{C_j^{1.852} d_i^{4.870}} \qquad \text{(E-2)}$$

where:

q_{ij} = pressure drop (psi/mile) for pipeline size, i, for product type, j

B_i = flow rate in barrels per hour for pipeline size, i

S_j = specific gravity for product type, j

C_j = friction factor for product type, j

d_i = inside pipe diameter in inches for pipeline size, i

Energy use is related to the required horsepower multiplied by time. Horsepower hours per barrel-mile are found by dividing per mile horsepower requirement by the flow rate. The horsepower hours times Btus per horsepower hour equals the Btus per barrel-mile for each product for each pipeline size. Using the number of barrels per ton for each product, this figure was transformed to Btus per ton-mile.[1]

To complete the analysis, an overall weighted average Btu per ton-mile figure was calculated by weighting the product values according to the proportion of each to the total flow and the pipelines' size values according to the total mileage for each pipeline size. Product proportions and pipeline mileages are available from the Bureau of Mines.[2] Multiplying average Btus per ton-mile for products and crude by the average length of haul for each and by the total ton-miles yields Btus per ton and the total Btu consumption of pipelines.

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[1] See discussion on specific gravity and ton conversion for barrel-per-ton calculation.

[2] B.O.M., Mineral Industry Surveys, Petroleum Statement Annual 1972, December 1973, p. 31.

E.2 DATA SOURCES

E.2.1 Base-Year Data

Data requirements for the pipeline algorithm are:

- barrels per day for products and crude;
- barrels per ton for products and crude;
- average length of haul for products and crude;
- miles of pipeline for products and crude by pipeline size;
- inside diameter by pipeline size;
- friction factors for products and crude;
- energy conversion efficiency (power source); and
- pump efficiency.

Sources for each of the data requirements are discussed below.

E.2.1.1 Barrels Per Day

Statistics for pertroleum transportation are reported in barrels per period of time, either annual or daily. This analysis is based on statistics for the daily movements of petroleum by transportation mode, published by the U.S. Bureau of Mines[1] (see Table E-1). These values were converted to barrels per hour for use in the analysis.

E.2.1.2 Barrels Per Ton

Converting barrels of petroleum to tons requires the assumption of a given weight per barrel. No true average figure has been determined for number of barrels per ton. This study uses representative 1972 values published by the American Petroleum

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[1] U.S. Department of the Interior, Bureau of Mines, Mineral Industry Surveys, Petroleum Statement Annual 1972, December 1973.

TABLE E-1

DAILY MOVEMENTS OF PRODUCTS BY REGULATED PIPELINES
(1972)

PRODUCT DESCRIPTION	BARRELS PER DAY
Crude Oil	8,966,000
Motor Gasoline	4,471,770
Aviation Gasoline	11,005
Naphtha Type Jet Fuel	50,422
Kerosene Type Jet Fuel	575,540
Kerosene	130,134
Distillate Fuel Oil	1,799,447
Natural Gas Liquids	1,093,633
Total	**17,097,951**

Source: U.S. Department of the Interior, Bureau of Mines, Mineral Industry Surveys, Petroleum Statement Annual 1972, December 1973, p.31.

Institute.[1] These values are shown in Table E-2. Specific gravity was calculated for each barrel per ton value by dividing barrels per ton into 5.71 barrels of water per ton. The resulting specific gravity figures were used in Equation E-2. The barrel-per-ton values were also used to convert barrels to tons. Ton values appear in Table E-3.

E.2.1.3 Average Length of Haul

Average length of haul was estimated for this analysis to permit conversion of tons to ton-miles. Alternately, ICC estimates of total ton-miles moving in pipelines could have been used.[2] The ICC estimates are based on common carrier reported barrel-miles expanded to cover all movements in pipelines and converted to ton-miles.[3] However, the study team chose not to use the ICC ton-mile estimates, because:

> The factors to convert barrels to tons used by the ICC differ from those used in this study.
>
> The figures on which the ICC total ton-miles are based are not strictly comparable to the Bureau of Mines total barrels, because the ICC approach does not use data published by the Bureau of Mines in developing their ton-mile estimate for all pipelines.[4]

Therefore, the study team chose to compute ton-miles from an estimate of average length of haul. Haul was estimated as the ratio of published ICC common carrier barrel-miles to originated barrels based on the assumption that the ratio for regulated moves is comparable to that for the entire industry. Average haul per ton values for crude and product lines thus computed were 422 and 403 miles,

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[1] American Petroleum Institute, Petroleum Facts and Figures, 1971 Annual, Washington, D.C.

[2] ICC, Transport Statistics in the United States, Part 6, 1972, Washington, D.C., Table 4.

[3] Regulated pipelines represent 75 percent of total mileage and 85 to 88 percent of national throughput.

[4] This is probably because they are required to produce this estimate before BOM statistics become available.

TABLE E-2

BARRELS PER METRIC TON AND SPECIFIC GRAVITY
(Representative Values)

PRODUCT DESCRIPTION	NUMBER OF BARRELS PER TON	SPECIFIC GRAVITY
Crude Oil	6.71	.851
Motor Gasoline	7.72	.740
Aviation Gasoline	7.85	.727
Naphtha Type Jet Fuel	7.72	.740
Kerosene Type Jet Fuel	7.05	.810
Kerosene	7.05	.810
Distillate Fuel Oil	6.58	.868
Natural Gas Liquids	10.53	.542

Source: American Petroleum Institute, Petroleum Facts and Figures 1971 Annual, Washington, D.C., p. 588.

TABLE E-3

ANNUAL TONS AND TON-MILES OF CRUDE OIL
AND PETROLEUM PRODUCTS SHIPPED BY REGULATED PIPELINE
(1972)

PRODUCT DESCRIPTION	TONS (Thousands)	TON-MILES (Millions)
Crude Oil	489,055	206,381
Petroleum Products:	389,645	157,027
Motor Gasoline	212,004	
Aviation Gasoline	513	
Naphtha Type Jet Fuel	2,390	
Kerosene Type Jet Fuel	29,879	
Kerosene	6,756	
Distillate Fuel Oil	100,091	
Natural Gas Liquids	38,012	
TOTAL	878,700	363,408

Source: Calculated from Bureau of Mines (op. cit.) data on Barrels per day using 366 days and barrels per ton from American Petroleum Institute (op. cit.). Ton-miles calculated by extending tons with average haul calculated from ICC data (op. cit.).

respectively. These values were used to convert ton estimates to the ton-mile estimates shown in Table E-3.

E.2.1.4 Pipeline Miles and Diameters

For this analysis, the pipeline mileages used are represented in Table E-4. These values represent those reported as of January 1, 1971. Pipeline mileage reports are published triannually by the U.S. Bureau of Mines. These figures are as close to the 1972 base-year actual mileages as can be found from published sources.

Included in Table E-4 are the inside diameters assumed in this study for each pipeline size. Pipeline sizes are quoted in terms of a nominal diameter. For pipes with 12-inch, or less nominal diameter, the nominal size is close to the inside diameter but will differ depending on the thickness of the pipe wall. For pipe sizes greater than 12-inches, the nominal diameter is equal to the outside diameter of the pipe. The representative inside diameter values selected for this analysis were taken from an American Petroleum Institute report[1] and discussions with industry engineers.

E.2.1.5 Friction Factors

The friction factors listed in Table E-5 are empirical values determined for each product. They were obtained from the Standard Handbook for Mechanical Engineers.[2]

E.2.1.6 Energy Conversion Efficiency

One horsepower hour equals 2,547 Btus, which is a defined physical relationship relating output horsepower to output Btus of useful work. A variety of conversion systems exist in pipeline transport, each of which has an overall thermal efficiency (ratio of output energy to input energy).

Conversion systems and power sources are found in Table E-6 for pipelines. The actual efficiency of each will vary depending on the

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[1] Petroleum Extension Service, Oil Pipeline Construction and Maintenance, Texas Education Agency and American Petroleum Institute, April 1973.

[2] Baumeister, op. cit.

TABLE E-4

CRUDE AND PRODUCT PIPELINE MILEAGES

NOMINAL PIPELINE DIAMETER (Inches)	INSIDE DIAMETER*	MILES OF CRUDE PIPELINES	MILES OF PRODUCT PIPELINES
2	2.067	0	0
3	3.068	479	702
4	4.026	3,090	2,771
6	6.065	9,435	16,732
8	7.981	19,269	25,634
10	10.020	11,867	9,785
12	12.000	10,106	8,732
14	13.250	571	2,441
16	15.250	5,630	1,603
18	17.250	2,002	919
20	19.250	5,040	907
22	21.250	2,664	9
24	23.250	1,504	131
26	25.250	1,039	217
28	27.250	0	177
30	29.250	938	300
32	31.376	0	288
34	33.376	792	0
36	35.376	2	1,058
40	39.250	634	0
42	41.000	4	0
48	47.000	0	0
TOTAL		75,066	72,406

1) Includes a small amount of 2 1/2-inch pipe.
2) Includes a small amount of 5-inch pipe.
3) Includes a small amount of 7-inch pipe.
4) Includes a small amount of 9-inch pipe.
5) Includes a small amount of 11-inch pipe.
6) Includes a small amount of 35-inch pipe.
7) Alyeska Pipeline.

Source: U.S. Department of the Interior, Bureau of Mines, Mineral Industry Surveys: Crude Oil and Product Pipelines, December 1971, p. 2.

*Representative values

TABLE E-5

FRICTION FACTORS FOR PETROLEUM PRODUCTS
(Dimensionless)

PRODUCT DESCRIPTION	FRICTION FACTOR
Crude Oil	130
Motor Gasoline	150
Aviation Gasoline	150
Naphtha Type Jet Fuel	160
Kerosene Type Jet Fuel	160
Kerosene	134
Distillate Fuel Oil	130
Natural Gas Liquids	136

Source: Op. cit., Theodore Baumeister, ed.

TABLE E-6

TYPES OF PUMPING STATIONS IN PIPELINE TRANSPORT

STATION TYPE	SOURCE OF ENERGY
Electric Motor	Coal, Oil, Hydropower, Nuclear, Other
Gas Turbine	Natural Gas
Liquid Fuel Turbine	Light Fuel Oil, LPG (from the pipeline)
Diesel Engine	Light Fuel Oil

condition of the system and the distance from the source of power. Net-delivered Btu efficiency is typically considered only for electricity (power plant plus transmission losses) and natural gas (shrinkage due to use of gas for running compressors). Actually, any chemical fuel involves production, refining, and transport losses. Strict comparability between energy conversion systems must account for total losses from production, transportation, and conversion of a natural resource into useful work.

This study makes no attempt to account for this loss. Most modes are primarily users of petroleum and therefore the overhead of production and refining losses are identical. In pipelines a significant proportion of power is derived from electrricity and from natural gas. A lesser proportion comes from petroleum products.[1]

Strict comparability, however, must be considered beyond the scope of the study. Therefore, electricity will include power-plant and transmission losses. Other systems will include only the engine losses. Delivered electric power as a percent of input fuel at the power plant has been identified by the Edison Electric Institute[2] to be 30 percent. Members of the study team familiar with the problems of electric utilities thought this figure to be a high average. The 30 percent efficiency probably assumes a steam plant operating at full capacity. Older turbine peaking units operate at about 26 percent efficiency and steam plants will drop off considerably in overall efficiency at less than full capacity, possibly as low as 24 percent. Gas and liquid fuel turbines vary widely in energy conversion efficiency depending upon their age and consequently, their internal operating temperatures. Older engines have fans from less-advanced metals and cannot operate at higher internal temperatures of newer engines; therefore, older engines have a lower operating efficiency. The newest turbines operate at 37 percent efficiency, while the oldest (usually minimally adapted aircraft turbines) operate at 26 percent. With turbine engines, an overhaul can usually mean an increase in power and efficiency over original design capacity due to replacement of blades and fans with more advanced metals that permit higher operating temperatures. Turbine technology is advancing, so that further improvements in power and efficiency may be expected

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[1] No statistics are available from which an estimate of the relative proportions can be made.

[2] Telephone conversation.

in the future. The largest diesel engines are about 37 percent efficient while the smaller engines are approximately 34 percent efficient.

The efficiency figures discussed vary from 24 to 37 percent. For the purposes of this study, an overall efficiency level of 30 percent was chosen for pipeline energy conversion. This requires an average of 8,490 Btus per engine output horsepower hour.

E.2.1.7 Pump efficiency

Pump efficiency was assumed to be .75 for the smaller pipeline sizes and .8 for pipelines of 16-inch diameter and greater. These values were chosen based on estimates of industry engineers and are typical of standard practice in engineering design when specific data are not available.

E.2.2 Scenario Data

The weighted average Btu/per ton mile consumption made use of the product of flow rate times miles of pipe for each pipeline diameter divided by the sum of all such products for all pipeline sizes. This yields a proportion of total annual ton-miles shipped in each pipeline size given the fundamental velocity assumptions. The 1972 and base case proportions are compared to the industry case proportions in Table E-7. The only change from base case proportions was a shift in the distribution of barrel-miles by pipeline size toward larger pipelines. It was assumed that 50 percent of the increase in average daily barrel-miles from 1972 would move through pipelines 26-inches in diameter and greater. The Alaska pipeline mileage was added to the crude pipeline mileage for 1980 with a flow rate assumed at the implied velocity of 1.54 miles per hour, to be consistent with the overall assumptions. Otherwise, the additional barrel-miles in large pipes (26 inches and greater) and small pipes were apportioned according to the distribution of barrel-miles found for 1972.[1] The average haul was assumed constant from 1972 through 1980 and 1985. The average flow rates in barrels per day are given in Table E-8.

---

[1] The 1972 barrel-mile distribution was found by multiplying the flow rate for each pipeline by the mileage for that pipeline.

TABLE E-7

PROPORTION OF DELIVERED TON-MILES BY PIPELINE SIZE AND SCENARIO FOR PRODUCTS AND CRUDE

PIPE SIZE INCHES	CRUDE		PRODUCTS	
	1972, 1980/5 BASE CASE	1980/5 INDUSTRY CHANGE	1972, 1980/5 BASE CASE	1980/5 INDUSTRY CHANGE
2	-	-	-	-
3	.0002	.0001	.0004	.0002
4	.0017	.0012	.0029	.0016
6	.0147	.0099	.0480	.0257
8	.0627	.0431	.1492	.0823
10	.0664	.0413	.0987	.0585
12	.0927	.0616	.1394	.0702
14	.0066	.0046	.0499	.0308
16	.0939	.0641	.0463	.0340
18	.0459	.0314	.0362	.0299
20	.1588	.1084	.0469	.0370
22	.1039	.0682	.0006	.0003
24	.0722	.0483	.0105	.1100
26	.0615	.0402	.0214	.0459
28	-	-	.0210	.1490
30	.0008	.0682	.0423	.0780
32	-	-	.0480	.0780
34	.0973	.0636	-	.0732
36	.0003	.0004	.2381	.0555
40	.1193	.0787	-	.0085
42	.0008	.1313	-	-
48	-	.1354	-	-

TABLE E-8
PROJECTED DAILY MOVEMENTS OF PETROLEUM BY PIPELINE

PRODUCT DESCRIPTION	BARRELS PER DAY	
	1980	1985
Crude Oil	12,866,210	15,349,389
Motor Gasoline	6,416,990	7,655,469
Aviation Gasoline	15,792	18,767
Naptha Type Jet Fuel	72,356	86,321
Kerosene Type Jet Fuel	825,900	985,299
Kerosene	186,742	222,783
Distillate Fuel Oil	2,582,206	3,080,572
Natural Gas Liquids	1,569,363	1,872,250
Total	24,535,559	29,270,850

Source: Developed based on 1972 data and growth factors as explained in Chapter IV, Section 1.

The distribution of barrel-miles among pipeline sizes was assumed to remain constant from 1980 to 1985. Consequently, there was no change in average energy consumption per ton-mile for crude or products during that period.

APPENDIX F

AIR CARGO MOVEMENTS

F.1 METHODOLOGY

The air cargo sector of the TRANSEN model estimates the fuel consumption for air freight movements in both passenger and all-cargo aircraft.

The model prepares two estimates of energy consumption by passenger aircraft, based on two different hypotheses:

> The energy consumed by cargo moving in passenger aircraft is the incremental energy used. The aircraft would fly to transport the passengers even without the cargo, and thus the energy consumed by the cargo is the extra or incremental energy used to transport the additional cargo load.
>
> The energy consumed by cargo moving in passenger aircraft is the fully allocated share of the total energy consumed by the aircraft--energy consumed is proportionally allocated to passenger and freight movements.

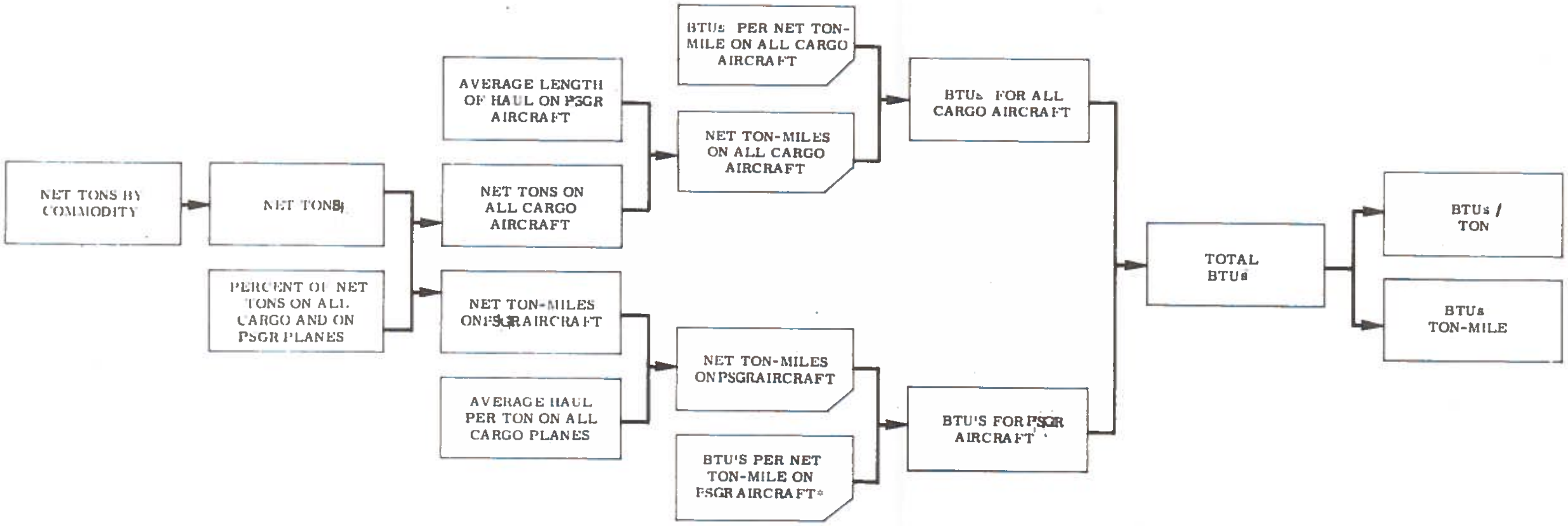
Although the TRANSEN model starts with air cargo data broken down by commodity groups, the energy consumption outputs appear in the form of aggregate average Btus because of the paucity of data which exists on air cargo movements by commodity.

Figure F-1 shows the process of calculating air cargo energy consumption in detail. Net air cargo tons are allocated to all cargo aircraft and passenger aircraft and converted to net ton-miles by the appropriate average length of haul measure:

$$M_i = TP_iH_i \qquad \text{(F-1)}$$

Where:

i = aircraft type (all cargo or passenger)
M_i = ton-miles for aircraft type, i
T = total air cargo net tons
P_i = proportion of air cargo tons moving on aircraft type, i
H_i = average length of haul for aircraft type, i



NOTE: Passenger aircraft BTU /ton-time values will be input for both marginal and full energy consumption.

FIGURE F-1: CONCEPTUAL DESIGN OF THE AIR FREIGHT TRANSPORTATION COMPONENT OF THE TRANSEN MODEL

Ton-miles for each type of movement are converted to energy consumption through multiplication by the appropriate Btu/net ton-mile value. For passenger aircraft, two estimates of fuel consumption are used: incremental and fully allocated fuel consumption:

$$A_i = M_i E_i \qquad \text{(F-2)}$$

Where:

A_i = Btus for aircraft type, i
E_i = Btus/net ton-mile for aircraft type, i

Finally, Btus are summed and divided by net tons and net ton-miles to obtain weighted average energy consumption:

$$B = \sum_{i=1}^{2} A_i \qquad \text{(F-3)}$$

$$C = B/T \qquad \text{(F-4)}$$

$$D = B/(M_1 + M_2) \qquad \text{(F-5)}$$

Where:

B = total Btus
C = Btus/net ton
D = Btus/net ton-mile

F.2 DATA SOURCES

Air cargo data can be divided into three categories: tonnage, traffic parameters, and energy consumption. Each category is discussed below.

F.2.1 Tonnage by Commodity

Accurate breakdowns of air freight data by commodity are difficult to find. A literature search and discussions with the Civil Aeronautics Board yield three sources of air cargo commodity estimates:

> The CAB estimated 1972 traffic volumes by commodity for a domestic air freight rate investigation. The estimates were based on an 11-month, 10-percent airbill sample, disaggregated for major commodities shipped. Thirty-nine percent of the sampled traffic was classified as general commodity traffic (not identifiable).

> The 1972 Census of Transportation published percentages of commodity shipments for most of the commodity groups in this study, allocated by mode.[1] Their information is based on data from a survey of shippers.[2] The major limitation of these air cargo data is that they appear in percentage form. Since air cargo shipments form such a small proportion of total shipments for many commodity groups, rounding of air cargo percentages for publication is likely to result in major distortions of the air data or even elimination of the data from the report if the size of the air cargo total is small relative to the commodity total.
>
> Jack Faucett Associates, Inc., allocated freight data by commodity and by mode as part of a study of historical and projected freight transportation data for the DOT, as mentioned earlier.[3] The study broke down air cargo data into commodity groups according to input-output model assumptions.

For this study, the information in the Jack Faucett report was selected as the most comprehensive source of air freight data by commodity. The 1970 data in this study have been adjusted to 1972 values according to growth rates estimated as part of the study. The results have been compared to those calculated in the other sources mentioned above, and the totals have been adjusted to agree with published overall air cargo totals. Table F-1 shows the distribution of air cargo tons and net ton-miles by commodity.

F.2.2 Traffic Parameters

Traffic parameters serve two functions in these calculations: some are basic inputs into the TRANSEN model and others serve as a basis from which to compute the energy consumption values input into the

---

[1] Air Transport 1975, Air Transport Association of America (New York, 1975) p.4.

[2] Shipper Groups, Commodity Transportation Survey, 1972 Census of Transportation (June 1975).

[3] Jack Faucett Associates, Inc. Transportation Projections: 1970-1980, March 1973.

TABLE F-1

DOMESTIC AIR CARGO TONS AND TON-MILES BY COMMODITY: 1972*

COMMODITY	TONS (thousands)	TON-MILES (millions)
Agricultural products	159	150
Chemicals, allied products	132	66
Clay, concrete, glass, stone	21	13
Coal, coke produced from coal	-	-
Crude oil, petroleum	-	-
Electrical machinery	422	315
Fabricated metal products	137	67
Food, kindred products, tobacco	29	24
Instruments, photo goods	78	69
Lumber, wood products, furniture	10	6
Metallic ores	-	-
Nonelectrical machinery	210	121
Nonmetallic minerals	-	-
Primary metal products	58	34
Pulp, paper, allied products	25	7
Rubber, plastic products	108	45
Textiles, apparel, leather	105	70
Transportation equipment	128	55
Waste, scrap materials	-	-
Subtotal	1,622	1,042
Other	819	469
Total	2,441	1,511

*The numbers of tons and ton-miles in this table were prorated from statistics in Air Transport 1975: An Anniversary Approaches by the Air Transport Association of America. The proportion of tons and ton-miles for each commodity was derived from Transportation Projections: 1970-1980 by Jack Faucett Associates, Inc., March 1973.

model. The following air traffic parameters were required for this analysis:

percent of air cargo moving on all cargo and on passenger/aircraft;

average length of haul for all cargo and for passenger/aircraft;

cargo-load factor for all cargo and for passenger/aircraft; and

passenger-load factor for passenger/aircraft.

These data were obtained from the CAB Handbook of Airline Statistics[1] and are shown in Table F-2.

F.2.3 Energy Consumption

Inputs to the TRANSEN model are energy consumption values, in terms of Btus per ton-mile for all cargo and for passenger/plane movements. The energy consumed by all cargo plane movements was computed from fuel consumption and ton-mile measures reported for domestic all cargo flights as reported in the CAB Handbook of Airline Statistics. The energy consumption values for cargo moving in passenger/aircraft have been taken from data developed in a study conducted at the Transportation Systems Center.[2] This study examined the fuel consumed by the narrow-body, four-engine and wide-body, three- and four-engine aircrafts, including sensitivity to passenger and cargo load factors and flight length. The energy consumption values were in the study developed from information in manufacturers' technical performance manuals and were used in a manual simulation of representative operations to compute energy consumed. Exhibit F-1 shows the study assumptions relevant to the energy consumption values developed. The values selected for use in the TRANSEN model were based on assumptions of

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[1] Civil Aeronautics Board, Handbook of Airline Statistics, 1973 Edition (Washington, D.C.: CAB), 1974.

[2] Domenic J. Maio and Michael Mui, An Analysis of Air System Fuel Consumption, for Combination Passenger/Cargo Service (Cambridge, Massachusetts: Transportation Systems Center) 1974.

TABLE F-2

1972 AIR CARGO TRAFFIC PARAMETERS

TRAFFIC PARAMETER	All Cargo Aircraft Movements	Passenger Aircraft Movements
Percent of Domestic Freight Revenue Ton Miles[1,2]	51%	49%
Average Length of Haul (Miles)[2,3]	1,131	420
Cargo-Load Factor[3]	.57	.28*
Revenue Passenger-Load Factor	-	.52

Source:

(1) 1972 CAB data.
(2) Used to derive percentage of tons on each aircraft type.
(3) CAB <u>Handbook of Airline Statistics</u>, 1973 Edition, (Washington, D.C.: CAB) 1973.

* Estimated from data on passenger load factor and total available ton-miles.

EXHIBIT F-1

ASSUMPTIONS USED IN DEVELOPING MEASURES OF AIR CARGO ENERGY CONSUMPTION IN PASSENGER/CARGO AIRCRAFT

1. All aircraft are operated under the same flight profile, described as follows: the aircraft take off from sea level, then climb to cruise level of 33,000 feet. The cruise speed is maintained at Mach.82. At the end of the cruise, the plane descends under the long-range descent plan and lands. Taxi time for take-off and landing is 8 minutes and 5 minutes, respectively.

2. All flights are operated under ideal weather conditions: standard day without any temperature deviation and zero headwind or tailwind.

3. Lower hold baggage space of 5-cubic feet is assigned to each enplaned passenger. The remaining space is then allocated for cargo use. This assumes that maximum cubic space is utilized for maximum payload.

4. Full compliment of cargo containers (LD3) is carried on the lower hold of the wide bodied aircraft. A full container is assigned for baggage purpose even if it is not filled completely.

5. An average density of 10 pounds per cubic foot is assigned to the DC-8 and 707.

6. The wide body aircraft are assigned maximum payload weight since cubic capacity is not a problem, particularly with the variety of baggage and cargo storage options provided by the manufacturers. If these wide-body aircraft are considered truly combination aircraft and only half the seating capability is needed, then main deck systems for baggage and cargo appear desirable options for new equipment.

7. The maximum gross weight constraints are given consideration to ensure that all aircraft operate within design take-off and landing weight limits.

8. The combined weight of each passenger and baggage is 200 pounds, a CAB standard practice.

9. Narrow-body freighters are operated at 65 percent load factor, equivalent to carrying 52,000 pounds of cargo per flight and have an average fuel productivity of six ton-miles per gallon at this load factor.

SOURCE: Measures of Air Cargo Energy System Fuel Consumption for Combination Passenger/Cargo Service, Domenic J. Maio and Michael Mui (Cambridge, Massachusetts: Transportation Systems Center) 1974, pages 29-31.

average 25 percent cargo-load factor, 50 percent passenger-load factor, 500-nautical-mile stage length, and an aircraft mix based on the existing aircraft fleet as of December 31, 1972, as reported by FAA.[1] Table F-3 shows the data input into the TRANSEN model for all cargo and passenger/plane energy consumption.

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[1] Federal Aviation Administration, 1972 Statistical Handbook of Aviation, (Washington, D.C.: FAA), 1973

APPENDIX G

REPORT OF INVENTIONS

This report is a compilation of data concerning current and future energy impacts in freight transportation. No inventions, innovations, discoveries, or otherwise patentable material were used in this report.

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