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An Investigation of Truck Size and Weight Limits Technical Supplement Vol. 3

Truck and Rail Fuel Effects of Truck Size and Weight Limits

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July 1981
Final Report

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16. Abstract

This volume documents the analysis of the effects of truck size and weight limit changes on intercity freight unit vehicle truck and rail fuel intensiveness. It presents data and analytical methods to estimate probable changes in direct and indirect fuel consumption for new truck size and weight limits. These affects are examined in terms of changes in the competitive relationships between highway and rail services. The method for estimating fuel consumption includes linehaul and access fuel and makes allowance for the system fuel requirements of empty backhaul and circuity. The report covers single unit trucks, conventional tractor-semi-trailer, Western Doubles, Turnpike Doubles, and Triple Trailer combination rigs as well as the competitive carload boxcar and TOFC rail services. It also disaggregates truck service (i.e., van, reefer, household moving van, flat bed, tanker and dump), and the competitive rail services. National aggregate estimates, involving application of these unit vehicle averages to projections of truck activity disaggregated to comparable levels, are documented in Volume 7 of the Technical Supplement of the Secretary's Report to Congress.

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Truck-fuel consumption; Rail-fuel consumption; Truck weight limits; Truck and rail, indirect energy

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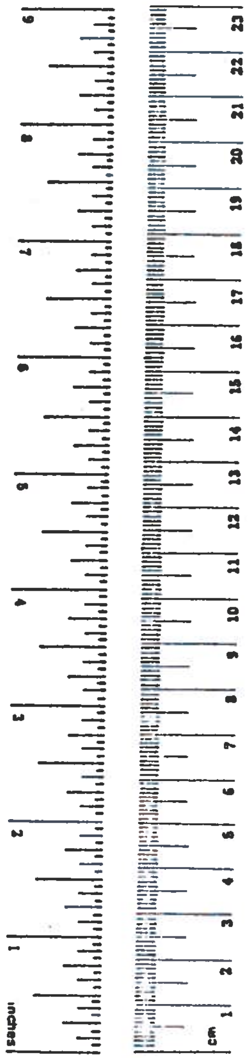
METRIC CONVERSION FACTORS

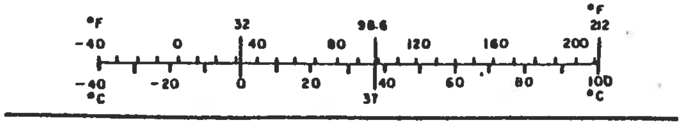
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

PREFACE

This is one of several technical reports prepared in support of the Secretary of Transportation's Report to Congress on the Truck Size and Weight (TS&W) Study mandated by Section 161 of the Surface Transportation Assistance Act of 1978. This Volume documents the results of one of many specific areas of investigation, the effects of truck size and weight limit changes on average truck fuel intensiveness and truck/rail fuel competitiveness.

The data and analytical methods required to estimate probable changes in direct and indirect fuel consumption for new truck size and weight (TS&W) limits are presented, as well as the average unit fuel consumption rates for truck and rail services under a range of TS&W limits, vehicle loading conditions, terrain, and carrier type operations. The highway direct fuel consumption rates were derived from an industry-developed and commercially available computer simulator. The rail direct fuel consumption rates were derived from limited reported testing of actual trains and of national average rates. The indirect energy estimates (Appendix D) are based on an energy input-output analysis. The results, which have been validated against fuel consumption rates in published sources, have been used for estimating aggregate fuel consumption for the truck traffic forecasts for specific TS&W limit scenarios.

This report covers single unit trucks, conventional tractor-semi-trailer, Western Doubles, Turnpike Doubles, Triple Trailer combination rigs, the competitive carload boxcar, and TOFC rail services. It also disaggregates truck service (i.e., van, reefer, household moving van, flat bed, tanker and dump) and the competitive rail services. Both truck and rail unit vehicle fuel consumption are given for typical average trips. Preliminary comparisons are also made for truck and rail average unit vehicle fuel consumption.

Volume 3 documents a comprehensive method for estimating direct fuel consumption. Indirect energy estimates used in the TS&W study are only partially covered in this report to give a perspective of the relative magnitudes of the direct and indirect energy components. The indirect energy estimated in the TS&W study are founded upon the results of a national energy input-output analysis performed by others and described in Appendix D of this report. The specific estimates used in the TS&W study for indirect energy associated with specific axle loads and gross vehicle weights for pavement and bridge structures are documented in Technical Supplement Volume 6 and in Appendix F of the main repor

The analysis and preparation of this report were the responsibility of the author under the overall technical direction of Domenic J. Maio, manager of the TSC participation in the DOT TS&W Study. The indirect energy analysis, documented in Appendix D, was developed by J.K. Pollard of TSC. The truck simulations were contributed by the Cummins Engine Company (at no cost to the Government) under the direction of Lloyd Florry and Larry Murphy of that firm. Interpretation of test results from the DOT/SAE Truck and Bus Fuel Economy Study was provided by Robert Mason of TSC. Selection of vehicle specifications for the simulations was performed by Russell Zub of TSC. Assistance in data analysis was provided by Patricia Kurkul and Wayne Stoddard of Raytheon Service Company.

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ACRONYMS

CIR	Circuity
FFC	Fixed Component of Fuel Consumption
LTL Service	Less-Than-Truckload Services
PU&D	Pick-Up-and-Delivery
TOFC	Trailer-On-Flat-Car
TL Service	Truck Load Service
VFC	Variable Component of Fuel Consumption

1. SUMMARY

Technical Supplement Volume 3, prepared in support of the Secretary of Transportation's Report to Congress, documents data and methods for calculating unit vehicle truck and rail average fuel consumption rates under a broad array of operating and market conditions. Fuel consumption effects, attributable to specific truck size and weight limits on a unit vehicle basis, are presented in this volume. National aggregate estimates involving application of these unit vehicle averages to projections of truck activity disaggregated to comparable levels are documented in Volume 7 of the Technical Supplement of the Secretary's Report to Congress. This volume deals primarily with "direct" petroleum fuel consumption by transport vehicles. It does provide, for perspective only, estimates of "indirect energy consumption (i.e., the energy input to construct, reconstruct, and maintain the physical plant, the energy input to the manufacture and maintenance of the vehicle, and the energy input for the production and distribution of the "direct" and "indirect" petroleum fuel used). Specific estimates of indirect energy related to axle loadings and gross weight for pavements and bridges are documented in Volume 6 of the Technical Supplement.

Volume 3 shows that larger and heavier trucks do offer fuel savings over existing size vehicles for certain truck movements; the magnitude of the savings varies widely among categories of freight markets and services. Savings are at their maximum only when trucks are fully loaded to the legal weight capacity. Partially loaded truck activity (greater than fully loaded activity) and empty mileage greatly reduce the magnitude of fuel savings. In most of the situations analyzed in this study, the savings resulting from larger and heavier trucks are less than those attributable to the adoption of fuel savings technology (e.g., more efficient diesel engines, radial tires, fan clutches, aerodynamic treatments, etc,) and adherence to the 55 mph speed limit.

The controversial issue of diversion of markets from the less energy-intensive rail services to the more energy-intensive highway services, is, in part, addressed in this volume. Fuel consumption comparisons of directly competitive truck and rail services reaffirm that most diversions, even to the larger and heavier trucks, will increase fuel consumption for the markets diverted. Rail TOFC and carload services are less fuel intensive under most operating situations and in most markets, except in certain instances identified in this volume. However, impacts on aggregate fuel consumption of specific changes in TS&W limits are functions of the relative magnitude of the traffic streams affected. The fuel consumption increase due to small diversions from rail may be more than compensated for by the fuel decrease due to the larger stream of truck traffic which may take advantage of the increased limits.

The results presented in this report, when compared to the field tests, are accurate, particularly for standard technology vehicles. Fuel estimates of vehicles incorporating fuel-saving technology based on the material in this report are more favorable than the field tests. The fuel-saver trucks simulated in the report represent vehicles with all available fuel saving technology, while the fuel-saver trucks in actual operations frequently are not equipped with all the available technology. The rail service fuel estimates for fuel-saver technology documented here tend to be understated because fuel inefficiencies in current rail operations are represented. With the exception of the fuel performance of the Milwaukee "Sprint" train demonstration, which has been used to suggest typical dedicated TOFC service in the forecast year (1985), all rail fuel performance data represents current rail operations. Much more in operational and technological improvements remains to be done in rail. The reader is, therefore, cautioned that ratios of truck fuel to rail fuel consumption are unfortunately biased in favor of the truck. This bias cannot be rectified without additional research into rail fuel conservation prospects for the near future.

The following observations, neither new nor surprising, are now supported by a comprehensive set of data developed and analyzed to serve the specific objectives of the DOT TS&W study.

Seven specific findings in this area of research are summarized below:

1. Increasing the gross weight of a typical tractor-semi-trailer combination from 73,280 pounds to 80,000 pounds offers a fuel savings of 7.7 percent for fully loaded trips. Increasing this arbitrary gross weight limit to the bridge formula limit (with current Federal axle limits) provides an additional 2.6 percent savings.
2. Substituting Turnpike Doubles of 120,000 pounds gross weight for the conventional semi-trailer of 80,000 pounds will reduce fuel consumption for a given flow of freight by a maximum of 13.6 percent. When hauling low density freight, the 103 ft Turnpike Doubles offer a maximum fuel savings of 31 percent, while the 65 ft Western Doubles offer an 11.8 percent fuel savings when both are compared to the 53 ft long tractor semi-trailer combinations. Movement of partial loads in Turnpike Doubles dramatically reduces their fuel savings.
3. Substituting a Western Double Combination for the conventional tractor-semi-trailer combination to transport a given flow of low dentisy LTL shipments saves 3.8 percent. If long multiple trailer combinations are acceptable in a route, then 95 ft long triple 27 ft trailer combinations provide a fuel savings of 12.5 percent over the conventional semi-trailer combination. This is 4 percentage points less fuel savings for low density freight than the Turnpike Double.
4. Implementing "fuel saver" technology on conventional tractor-semi-trailer combinations offers a 26.7 percent fuel savings for fully loaded trucks, when compared to

standard (i.e., pre '74) truck technology. The fleet mix of "fuel saver" and standard technology is estimated at 20 percent "fuel saver" in the base year (1977), rising to 70 percent in the forecast year (1985).

5. Ratios of highway to rail unit vehicle fuel consumption rates range from a high of 2.4:1 to a low of 1.0:1. The former is for truck load service, using fully loaded pre '74 technology semi-trailer combinations at 73,280 pounds gross weight. The latter is for truck load service using Turnpike Doubles and "fuel saver" technology loaded to 120,000 pounds gross combination weight. The former is relative to car load service, the latter is relative to TOFC "SPRINT" service. These ratios are for total trip fuel consumption, including access fuel, relative circuity, and empty mileage for each mode. For low density LTL service, the highway to rail fuel consumption ratio range drops to 1.3:1 to 0.8:1. The LTL competition is between the standard technology semi-trailer and the sprint TOFC services for the former, and between the fuel saver Western and Turnpike Doubles and the dedicated TOFC for the latter.

   From a fuel conservation perspective, this analysis indicates that modal shifts between high capacity, post'79 technology truck and rail TOFC services, projected for 1985, are a matter of indifference. However, shifts from carload service to either highway or TOFC services will increase fuel consumption.

6. Indirect energy, required in highway and rail freight transportation, is substantial, often approaching direct energy use in magnitude. While there is some uncertainty in the indirect energy estimates, the analysis shows an average of 1600 BTU/ton-mile required for highway freight and average of 515 BTU/ton-mile used for rail transportation. The highway indirect energy use represents an additional 70 percent of the direct use, while

rail indirect energy represents an additional 78 percent.

7. Based on the estimates of national total direct and indirect energy consumption given in Appendix D, trucking uses 3.5 times as much fuel as rail in direct consumption and 3.1 times as much indirect energy. The combined direct and indirect energy intensiveness of truck is 3.3 times as much as rail. Based on new technology and the Bridge Formula/20/34 weight limits, as shown in the text, at maximum load a 45 foot tractor-semi-trailer combination used 2.24 as much total energy as the standard boxcar, while the Turnpike Doubles used 2.22 as much. The 45 ft. tractor-semi trailer combination used 1.98 times as much total energy as TOFC; the Turnpike Doubles used 1.96 as much.

2. INTRODUCTION

2.1 PURPOSE

The primary objective of this research effort is to establish average unit vehicle fuel consumption values for various truck and rail service categories in sufficient detail and precision to be coupled with specific traffic flows developed by other tasks in the TS&W study. The analysis here is intended to allow prediction of aggregate fuel use changes for satisfying given freight demands under alternative sets of TS&W limits. The method used is oriented toward regulatory factors rather than vehicle technical differences. The number of vehicle technical differences has been simplified to allow differentiation of carrier operational characteristics.

Fuel consumed in intercity freight transportation consists of fuel used directly by the transportation vehicles and terminal equipment and a variety of energy sources in the manufacture and construction which is indirectly necessary to build and operate a transportation system. The direct fuel amounts to 50-75 percent of the total energy attributable to the transportation of freight. Direct fuel consists of 1) fuel consumed in the linehaul propulsion and environmental control of the transportation vehicle; 2) fuel used in collecting, consolidating, and distributing associated with the origin and destination activity; 3) fuel consumed in the moving of transportation vehicles within a transportation system to provide equipment, when and where needed, because of the imbalance of the transportation demand.

The indirect energy consumed in moving freight consists of 1) energy used to produce and distribute fuel; 2) energy embodied in fixed facilities; 3) energy used for heat, light and power at fixed facilities; 4) energy consumed in the production of vehicles from raw materials; 5) energy required in the maintenance and security of highways and railroads; and 6) energy consumed by supporting supplies and services.

This report documents the analyses of truck and rail average unit vehicle fuel consumption in providing intercity freight services. Unit vehicle fuel consumption averages are one-half of the data required for estimating the changes in aggregate fuel consumption for freight services resulting from changes in truck size and weight limits. Two equally important elements are needed to estimate aggregate fuel use (whether national, regional, industrial, or carrier sub-group): 1) the projected demand for transportation services disaggregated to levels sensitive to the key variables of this study (e.g., truck capacity and market served); and 2) the average fuel consumption rate per unit of equipment transporting the freight disaggregated to a comparable level. The former is the subject of Volume 4 in this series of technical supplements; the latter is discussed in this Volume.

The highway unit vehicle direct fuel consumption averages are based on truck simulations representing a broad array of operating conditions performed specifically for this study. These averages are far more precise than in prior analyses.[1] The rail direct fuel consumption values are less precise, however, than the highway, since they are based on reported national average rail fuel use and a few reported train operations. The indirect energy averages are based on national indirect energy input/output analysis.

2.2 SCOPE

This report provides 1) empirical equations for estimating highway and rail intercity freight direct fuel consumption; 2) a description of the method by which aggregate direct fuel consumption is estimated for the Truck Size and Weight (TS&W) limit scenarios;[2] 3) a summary of unit vehicle direct fuel consumption comparisons among trucks operating under various TS&W limits and

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[1] Appendix A of Reference 1 provided national aggregate fuel rates for rail and highway freight services.

[2] More detailed documentation of this process together with the resulting aggregate estimates is contained in Technical Supplement Volume 7.

between truck and rail freight services; and 4) a method for estimating indirect energy consumption based on national average truck and rail indirect energy use.

Unit vehicle fuel consumption rates are provided[3] for full trailer load (FTL) and carload (CL) size shipments and for less-than-trailer load (LTL) size shipments. Estimates of full door-to-door direct fuel consumption include linehaul, pickup and delivery functions, as well as allowances for empty backhaul and circuity.

Highway unit vehicle fuel consumption rates are given for several truck configurations: 1) single unit trucks, 2) conventional tractor/semi-trailer combinations, 3) Western Doubles, 4) Turnpike Doubles, and 5) triple 27-ft trailer combinations. Services and truck body types are differentiated as general service dry vans, refrigerator and insulated vans, household goods vans, auto transporters, tanks, flat/rack/log vehicles, and dumps. Carriers are differentiated as 1) regular route common carriers, 2) irregular route common and contract carriers, 3) private carriers, and 4) exempt carriers. This array of truck sizes, configurations, body types and services has been designed to represent the truck type likely to be in operation in the forseeable future. They are intended to bracket the full range of operating characteristics of many other types of trucks (e.g. truck and full trailer combinations) used to haul freight.

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[3] Simulations conducted by the Cummins Engine Co., Inc., Columbus, IN are the primary source for the truck fuel consumption. The rail fuel consumption is based on earlier rail test data conducted by DOT (Reference 2), results from the DOT/DOE Intermodal Demonstration "Sprint" program, and on reported national average rail fuel consumption (Reference 3).

[4] The "Sprint" program was established to develop and demonstrate improved rail intermodal service. From June, 1978, through May, 1980, the Milwaukee Road operated the "Sprint" demonstration between Chicago and the Twin Cities (Minneapolis/St. Paul). The demonstration involved four dedicated intermodal trains each way each weekday in the corridor (Reference 4).

Route differentiation includes level, hilly, and mountainous terrain, and the road classifications of interstate/primary, secondary and urban limited access. Allowances are made for both routing through terminals and direct shipper to receiver movement.

Rail unit vehicle fuel consumption rates are given for 1) dedicated TOFC service, representative of current average run-through trains; 2) a special rail TOFC service, based on results from the "Sprint" demonstration program;[4] and 3) conventional rail carload service representing current mixed consist trains. Fuel consumption rates for the rail competitors to the identified truck services include TOFC general service dry vans; TOFC reefer and insulated vans; and carload services for general service box, reefer, tanks, gondola, hopper, and auto carrier.

In estimating aggregate direct fuel consumption, the weighted average fuel consumption per vehicle mile presented in this report is multiplied by the corresponding vehicle miles traveled (VMT), projected in Volume 7 of the Technical Supplement. Average unit ve cle fuel consumption relationships are given as a function of payload weight and trip distance. The aggregate fuel consumption estimates are based on VMT projections developed for a status quo base case and for several alternative TS&W limit scenarios. The truck activity is disaggregated by 1) state, 2) interstate/primary and secondary roads, 3) level, hilly, mountainous terrain, 4) vehicle weight, and 5) gasoline and diesel powered.

2.3 APPROACH

This section describes the method for estimating direct fuel consumption changes attributable to alternative TS&W limits at two levels, the vehicle trip level and the national aggregate level. The final equations, tables of variable inputs, and instructions for application are provided in Appendix A of this volume. The method for estimating indirect energy consumption is given in Appendix D.

An "engineering" approach is taken in estimating annual national aggregate fuel consumption for each of the truck types affected and their related transportation activity.[5] The method analytically combines the unit vehicle fuel performance of each truck configuration with its associated annual miles traveled. For each truck configuration, the unit vehicle fuel consumption is constructed from system average door-to-door functional shipping elements and from the system fuel requirements to support the activity. Fuel subtotals for all truck activities are summed to estimate total direct fuel use for a status quo base case and for each of several size and weight limit alternatives.[6] This technique allows an examination of truck size and weight limit changes in terms of the marginal change in productivity and fuel consumption attributable to each set of limits. In summary, for each truck type configuration analyzed:

$$\text{Unit Vehicle Fuel Performance} \times \text{Transportation Activity} = \text{Aggregate Transportation Activity Direct Fuel Use.}$$

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[5] Rail fuel consumption in moving intercity freight is also estimated, but it is based on a much smaller information source than is truck fuel use. Where modal comparisons of fuel use are shown, they are intended as approximations because of the disparity in the data sources and the inherent differences in services between modes.

[6] Total energy use (as opposed to total direct fuel use) includes the indirect energy input to the system which should be considered when comparing different modes of transportation. This is particularly important when major new facilities or reconstruction and maintenance of existing facilities are required. See Section 4.4.3 and Appendix D.

2.3.1 Unit Vehicle Fuel Consumption

Unit vehicle fuel use is given by empirical equations[7] that contain coefficients developed from a combination of computer simulations, reported field testing and fuel accounting costs, and simple analyses developed where necessary. Vehicle fuel performance units are expressed in gallons per vehicle mile for each vehicle classification. The classifications are by axle configuration and by gross vehicle weight. In the aggregate calculation, the unit fuel performance numerical values are weighted averages of the unit vehicle consumption rates for the various truck groupings adjusted from the base year to forecast the 1985 fleet mix, reflecting an estimated percentage use of new technology vehicles.

The fuel consumption rates for each of the truck types and for each gross vehicle weight limit are built from the fuel use of each functional element (line-haul, pickup and delivery, and terminal). Line-haul fuel consumption, in almost all activities, is much greater than the consumption in the other functions. Line-haul fuel consumption is also the function most affected by changes in size and weight limits and is, therefore, developed in greater detail. Appendix A shows the development of the equations and the coefficients as well as instruction for the use of the equations.

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[7] Typical vehicle fuel performance, represented by average fuel consumption rates for each of the dominant vehicle types, is the basis for estimating fuel consumption in this study. Even though the number of choices is great, particularly in trucking, between vehicle manufacturers and truck types, engine types, power trains, optional equipment, etc., there are "typical" types of equipment which dominate each classification of use and service. Fuel consumption within the classification appears close enough to allow the use of unit average values. In Appendix C, results of fuel measurements made in field tests and service operations are compared to fuel estimates made with the method developed for this study and documented in this report.

The line-haul fuel consumption rates are calculated from fuel consumption equations which were, in turn, derived from a truck fuel performance computer simulation conducted by the Cummins Engine Company.[8] The simulation results were used to generate fuel consumption equations, in which fuel consumption is expressed as gallons per payload ton-mile. Linear equations were found to represent the simulation results adequately.[9,10]

The basic expression used in estimating unit vehicle fuel consumption is linear, giving average line-haul fuel consumption rates (gallons per vehicle-mile) with payload weight in tons as the independent variable. Fixed and variable coefficients (FFC, VFC) derived from the Cummins Vehicle Mission Simulation are used for each type of vehicle and for each service and operating environment. To determine door-to-door fuel consumption, the equation is expanded by adding terms to include: 1) line-haul distance, and 2) pickup and delivery and terminal area fuel. Pickup and delivery and terminal fuel are calculated as a single element and referred to as "access" in this study.

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[8] Most major equipment manufacturers have computer simulations for evaluating equipment. The Cummins Engine Co., Inc., Columbus, IN, has developed a vehicle mission simulation (VMS) which includes 320,000 miles of truck routes throughout the world. This model can simulate approximately 60 vehicle configurations, approximately 1000 truck engines, and a wide variety of transmissions, axles, wheels, driving conditions, etc.

[9] Linearity of fuel consumption, as a function of vehicle weight as shown by the simulation, is quite close for level and hilly terrain. The mountainous routes' fuel consumption are slightly curvilinear; however, fuel use in mountainous travel is subject to a wide range because of differences in terrain, vehicles, and driving. Because only a very small percent of VMTs are on mountainous routes, the linear form is used for all terrain (Reference 5).

[10] Results of fuel prediction methods from other sources and a comparison of results estimated by the method given in this report and of field tests are given in Appendix C.

Transportation systems usually have operational inefficiencies which add fuel requirements to line-haul and access and which must be allocated to the shipments transported. The most common of these inefficiencies are movements of empty transportation equipment within the system to meet traffic demand, flow imbalances, and circuitous routing of shipments and equipment resulting from the carriers' route structure, operating practices, and regulatory restrictions.

Total trip fuel for the equipment types and conditions specified is given by the following equation:

$$\text{Total Trip Fuel (Gallons) Average} =$$

$$[(FFC)(EBH) + (VFC)\ (P)]\ (D)\ (CIR) + AF + REFF + INTER$$

where: FFC is the fixed fuel coefficient.
EBH is the empty back-haul coefficient.
VFC is the variable fuel coefficient.
P is the payload in tons.
D is the distance in miles.
CIR is the circuity coefficients (if actual miles are unknown).
AF is the access fuel required for either TL or LTL size shipments.
REFF is the additional fuel required by refrigerated service
INTER is the fuel required in processing at intermediate terminals (rail only).

Appendix A provides coefficients for estimating truck and rail services unit vehicle fuel consumption for each of several equipment/service types, operations, and operating environments.

2.3.2 Aggregate Fuel Consumption

The primary objective of this area of research, as stated earlier, is to develop the data for estimating changes in national and regional total fuel consumption attributable to specific changes in truck size and weight limits. Therefore, the unit vehicle fuel consumption values calculated for typical vehicles operated in specific market environments must be aggregated to broader groupings of truck activity before application to VMT projections of said activity.

Truck activity is defined in the forecast year status quo base case and in the alternative TS&W limit scenarios in terms of VMT by truck axle configuration and gross weight group for each state and highway class. For purposes of calculating aggregate fuel consumption the VMT was further disaggregated into gasoline and diesel powered units and into movements of LTL and TL sized shipments. These truck activity projections have been developed from several data sources using a very large and complex series of algorithms and computer programs which are fully described in Technical Supplement Volumes 4 and 5.

In general, a three step procedure was followed to develop fleet average fuel consumption rates per vehicle mile for application to the projected truck activity. First, an average fuel coefficient for each truck configuration was calculated, weighted by the body type distribution of each axle configuration group. In the second step, a fleet average fuel consumption, based on an estimated mix of fuel saver and standard technology, is developed for both the base year and the forecast year. The third step involved application of a weighted average terrain factor for each state. The three-step procedure is described in more detail in Appendix B.

2.3.3 Indirect Energy and Total Energy Requirements

Indirect energy estimates are based on an additional percentage of energy consumed, per ton-mile of the direct energy. The indirect energy estimates are given separately for rail and for highway. Because of the difficulty in separating specific energy costs for specific services and activities of transportation, indirect energy is not disaggregated to any level below the national average for each mode.

Total energy is the sum of direct fuel and indirect energy.

Total Energy = Direct Energy + Indirect Energy

where units are BTU.

Direct fuel estimates are given in Appendix A.

Indirect energy estimates are given in Appendix D.

2.4 DEFINITIONS

Terms used in this report have specific meanings which should be understood when interpreting results.

2.4.1 Technology Level

2.4.1.1 Highway

Standard Technology - Vehicles sold until 1974 that do not contain any of the fuel saving technology and devices which have become available since then. The base year fleet is presumed to be dominated by this type of equipment.

Fuel-Saver Technology - The best fuel saving technology available in 1979. Recent truck sales statistics indicate that few vehicles are equipped with all the fuel-saving options offered, but the forecast year fleet is projected to be dominated by this type of equipment.

2.4.1.2 Rail

Standard Technology - Average technology and performance used in box car and dedicated TOFC service in the base year.

Special Technology - For TOFC, a representation of dedicated, run-through, high-speed TOFC train competitive with truck services as demonstrated by the "Sprint Train" operation on the Milwaukee Road is the model for this service. Dedicated TOFC service in the forecast year is projected to be more like this.

2.4.2 Vehicles

A conventional semi-trailer - A tractor-semi-trailer combination truck in which the prime mover is a three-axle cab over engine pulling a 40-45 ft semi-trailer with tandem axles. The overall length is limited to 65 ft, and the axle configuration is noted as a 3S2.

A Western Double - A tractor-semi-trailer and full trailer combination in which the prime mover is a two-axle cab over engine tractor pulling two 27-ft trailers with single axles. The overall length of a Western Double is 65 ft, and the axle configuration can be noted as 2S1-2.

A Turnpike Double - A tractor-semi-trailer and full trailer combination in which the prime mover is a three-axle tractor, pulling two 40-45 ft trailers all with tandem axles. The overall length of a Turnpike Double varies between 102-108 ft depending on the type of tractor used (cab over vs. cab behind), and the axle configuration can be noted as 3S2-4 or 3S2-3.

A Triple 27 - A tractor-semi-trailer and full trailer combination in which the prime mover is a two or three-axle cab over engine tractor pulling three 27-ft trailers all with single axles. The overall length of Triples is 95 ft, and the axle configuration can be noted as 2S1-2-2 or 3S1-2-2.

Trailer-container on flat car (TOFC/COFC) trains - An interaction between truck and rail modes in which the services of both modes are used in the transport operation. For this study, all TOFC/COFC operations are represented by estimating attributes of 40 ft trailers on flat cars.

2.4.3 Terrain

2.4.3.1 Highway

Level

Hilly

Mountainous

2.4.3.2 Rail

Rail carload service fuel consumption is based on the national average fuel consumption rate.

Rail TOFC fuel consumption is based on tests conducted on mid-western routes and is representative of level and rolling terrain.

2.4.4 Truck Size and Weight Limits

In the tabulations and graphs of this report, TS&W limits are referred to by A, B, C, D, E, for simplicity. All axle and gross weight limit alternatives considered in the study scenarios are represented by these five sets of limits.

A - 73/18/32 Limit, where

73 is a vehicle maximum weight limit of 73,280 lb.
18 is a single axle weight limit of 18,000 lb.
32 is a double axle weight limit of 32,000 lb.

B - 80/20/34, Limit, where

80 is a vehicle maximum weight limit of 80,000 lb.
20 is a single axle weight limit of 20,000 lb.
34 is a double axle weight limit of 32,000 lb.

C - Bridge/18/32 Limit, where

"Bridge" is the maximum vehicle weight determined by the Bridge Formula "A".
18 is a single axle weight limit of 18,000 lb.
32 is a double axle weight limit of 32,000 lb.

D - Bridge/20/34 Limit, where

"Bridge" is the maximum vehicle weight determined by the Bridge Formula "B".
20 is a single axle weight limit of 20,000 lb.
34 is a double axle weight limit of 34,000 lb.

E - Bridge/22.4/36 Limit, where

"Bridge" is the maximum vehicle weight determined by the Bridge Formula "C".

22.4 is a single axle weight limit of 22,400 lb.

36 is a double axle weight limit of 36,000 lb.

2.4.5 Line-Haul Speed

All trucking operations, unless noted, are made with a 55 mph speed limit. All rail operations are at current average speeds for each service.

2.5 LIMITATIONS

Estimating future fuel consumption both for individual vehicle units and for aggregate transportation demand is not exact. Errors are introduced in the form of input data deficiencies, using average unit performance values, and in forecasts of future economic activity

With these deficiencies, results from this analytical approach are better suited to estimating changes in fuel consumption resulting from specific changes in fleet operating characteristics and levels of demand, than to estimating absolute fuel use. However, adequacy of the absolute estimates for the purposes of this study are demonstrated in the Appendix of Technical Supplement Volume 7.

3. EFFECTS OF TS&W LIMITS ON TRUCK FUEL CONSUMPTION

3.1 INTRODUCTION

Changing Truck Size and Weight (TS&W) limits affects unit vehicle fuel consumption in several ways, depending on the truck loading condition[11] and the type of truck. Results of the parametric analysis conducted in this chapter are summarized by the following observations.

1. Increasing Gross Weight limits allow trucks designed and loaded to higher weights to achieve a lower average gallon per ton-mile fuel consumption rate. Thus payloads with higher densities move at a lower gallon per ton-mile fuel consumption rate.
2. Increasing Gross Weight limits have no effect on fuel consumption for partially loaded trucks, unless the higher weight limits encourage a proliferation of heavier tare weight trucks. If so, fuel consumption may be increased for partial truck load movements.
3. Increasing vehicle length (e.g., larger semi-trailers or permitting multiple trailer combinations) will not improve fuel consumption for high density payloads unless the gross weight limit is also increased.
4. Increasing vehicle length (e.g., larger semi-trailers or permitting multiple trailer combinations) without increased gross weight limits will improve unit vehicle fuel efficiency for only low density payloads.

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[11] Payload sizes can be: 1) partial, 2) filled to volume capacity but below weight limit, and 3) filled to weight limit.

This chapter examines fuel relationships to shows the effects of changes in TS&W limits on unit vehicle fuel consumption. In most cases typical trip fuel consumption[12] is given for the various truck types.[13] Fuel rates are described as a function of vehicle type, gross weight and payload density. Fuel use comparisons are made between trucks of different weight limits, and between single and double trailer combinations for different vehicle loading conditions. The latter comparison shows the effect of length and weight limit changes together on fuel consumption. Also shown is fuel consumption as affected by technology, terrain, and speed limits.

3.2 MAXIMUM WEIGHT LIMIT PAYLOADS

Unit vehicle fuel consumption rates for fuel-saver technology truck types hauling maximum weight payloads at various gross weight limits are shown in Table 3-1. This table gives the fuel consumption values used for calculating typical unit vehicle reductions in fuel consumption resulting from increasing weight and size (to allow multiple trailers) limits.

Table 3-2 gives the reduction in unit vehicle fuel consumption gained from increasing size limits. This table shows that

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[12] Linehaul rates demonstrate only the effects of vehicle characteristics on fuel consumption. Linehaul comparisons are limited to where services of the vehicles are directly substitutable, and there is no difference in either service or system support requirements. Typical trip fuel use comparisons better illustrate system fuel impacts which include the varying amount of inefficiencies of both the different vehicles and operating practices of the different carrier types.

[13] Truck types and configurations investigated in this study are listed in Table A-1, along with 1) gross vehicle weights for the principal TS&W limits, 2) corresponding maximum payloads, 3) payload weights when the truck is filled to its volumetric capacity with shipments having a stowed density of 12 lb/cu. ft., and 4) average loads.

TABLE 3-1. UNIT VEHICLE TRIP FUEL CONSUMPTION FOR VARIOUS TRUCK TYPES AND CONFIGURATIONS AT DIFFERENT WEIGHT LIMITS (GAL/PAYLOAD TON-MILE)*

Vehicle	73/18/32	80/20/34	Br./18/32	Br./20/34	Br./22.4/36
Vans	"A"	"B"	"C"	"D"	"E"
Single Unit+	0.01619	0.01494	0.01389	-	-
1-45	0.00924	0.00852	0.00912	0.00852	0.00828
2-27	0.01040	0.00923	0.00923	0.00923	0.00914
2-45	-	-	0.00875	0.00827	0.00790
3-27	-	-	0.00817	0.00799	0.00782
Reefers					
1-45	0.00980	0.00898	0.00967	0.00898	0.00871
2-45	-	-	0.00964	0.00914	0.00859
Moving Vans					
1-45	0.00921	0.00822	0.00909	0.00822	0.00791
2-45	-	-	0.00854	0.00819	0.00768
Tanks					
1-45	0.01188	0.01136	0.01176	0.01136	0.01099
2-45	-	-	0.00994	0.00951	0.00912
Flats					
1-45	0.00914	0.00848	0.00903	0.00848	0.00825
2-45	-	-	0.00804	0.00770	0.00773
Dumps					
1-45	0.01078	0.01054	0.01078	0.01054	0.00985
2-45	-	-	0.01023	0.00978	0.00912

*Includes pickup and delivery, empty mileage factor, 400-miles trip, level terrain, 55 mph speed limit. Fuel-saver technology vehicles (see Table A-3). Maximum payload weights (see Tables A-1, A-2).

-Configuration not practical for weight limit.

+Single Unit Vans

Wt. Limit.	Maximum Payload (Tons)
73/18/32	10.6
80/20/34	11.6
Br./18/32	12.6

TABLE 3-2. IMPACT ON TS&W LIMIT CHANGES ON VAN FUEL CONSUMPTION

	Percent Fuel Intensiveness Improvement*	
	Vans	Flats
Change in Weight Limit		
Conventional Semi-Trailer (1-45)		
73/18/32 to 80/20/34	7.8%	7.2%
80/20/34 to Br./22.4/36	2.8	2.7
Turnpike Doubles (2-45)		
Br./18/32 to Br./20/34	5.5	4.2
Br./20/34 to Br./22.4/36	4.5	4.8
Change in Length 1-45 to 2-45		
73/18/32 to Br./18/32	1.6	12.0
80/20/34 to Br./20/34	2.9	9.2
Br./20/34 to Br./22.4/36	4.6	11.1

---

*Based on values and conditions given in Table 3-1.

in increasing the limit from 18/32/73 to 20/34/78, semi-trailer vans and flats will consume 7.8 percent and 7.2 percent less fuel respectively. Other comparisons are readily seen.

This table also shows that, for van trucks going from conventional semi to turnpike doubles at the same weight limit, there is a gain of from 1.6 percent to 4.6 percent fuel efficiency.

Use of turnpike doubles in van operations offers a small gain in efficiency for carrying maximum weight payloads. For example, shown below are vehicle and payload weights and unit fuel consumption for 1-45 and 2-45 van rigs at the 80/20/34 and Br./20/34 weight limits.

	MGVW* (lb)	Δ MGVW	Payload (Tons)	Δ Payload	Fuel Consumpt. (gal/ton-mile)	ΔFC
1-45	78,000	48.5%	25.05	40.3%	.00852	-2.9%
2-45	115,800		35.15		.00827	

*Actual maximum gross combination weight, calculated with Bridge Formula B, see Technical Supplement Volume 1.

Increasing the length limit to allow double 45 ft trailers permits an increase in payload wieght of 40.3 percent with a corresponding increase in fuel efficiency of 2.9 percent.

Flat body double trailer trucks show a fuel efficiency gain of from 9.2 percent to 12.0 percent. The larger fuel savings gain derives from lower empty weights, which allow a larger proportion of payload if the weight limit increases.

In actual operations, comparative fuel intensiveness depends on other factors. One such consideration is the restriction of turnpike doubles in shipper-to-receiver service. In situations where turnpike doubles are not run from the shipper to receiver but are assembled and broken down at twin-trailer terminals on the highways at the outskirts of urban areas, additional fuel will be consumed in making two pickup and delivery runs. To show this effect, Table 3-3 gives total trip fuel consumption for conventional semi and turnpike doubles van combinations where the fuel intensiveness is given for each at the various weight limits. The percentage difference between the single and double trailer operations is also given. This table shows that if turnpike doubles are not allowed in PU&D operations, then the fuel efficiency of this combination in linehaul is not sufficient to overcome the additional PU&D fuel consumption, unless the doubles combination has an equal or higher axle load limit than the conventional semi-trailer combination. In other words, if turnpike doubles are permitted on the interstate system only, they require axle limits at least as high as the present Federal standards if they are to provide significant fuel savings. Lower axle limits will make turnpike doubles more fuel-intensive on a total trip basis than are conventional semi-trailer combinations under current limits.

3.3 PARTIAL LOADS

3.3.1 Volume Limited Loads

Use of both turnpike doubles and Western Doubles combinations will offer fuel advantages over single trailer combinations carrying low density payloads, if the payloads are sufficiently large in volume to fill, or nearly fill, available cargo space. Linehaul fuel consumption, as a function of loaded density, is shown in Figure 3-1 for single 45 ft, double 27 ft, triple 27 ft, and double 45 ft combinations. The weight limits for each truck type are indicated. The breakpoints on the curves are at the critical

TABLE 3-3. COMPARISON OF CONVENTIONAL SEMIS AND TURNPIKE DOUBLES SHOWING EFFECT OF SINGLE AND DOUBLE TRAILER PU&D OPERATION ON TOTAL TRIP* FUEL

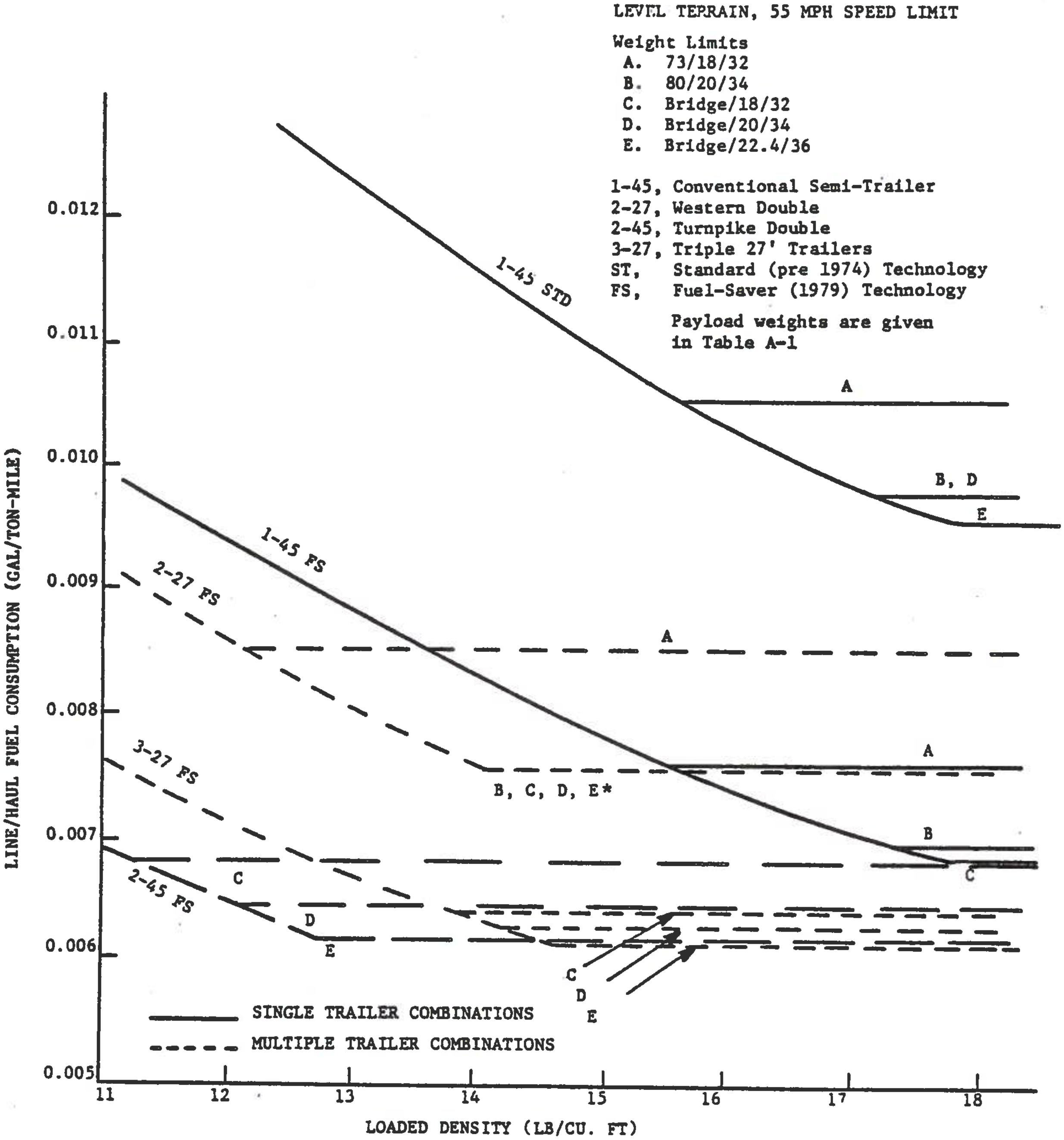
PU&D CONFIGURATION	WT.** LIMIT	TURNPIKE DOUBLE FUEL CONSUMPTION (GAL/TON-MILE)	TRIP FUEL PERCENT CHANGE FROM 1-45 To 2-45	
			1-45@ LIM. A+	1-45@ LIM. B+
SINGLE TRAILER PU&D				
	C	0.00875	-5.3%	+2.7%
	D	0.00827	-10.5%	-2.9%***
	E	0.00790	-14.5%	-7.3%
DOUBLE TRAILER PU&D				
	C	0.00814	-11.9%	-4.5%
	D	0.00770	-16.7%	-9.6%***
	E	0.00736	-20.3%	-13.6%

*Trip - 400 miles includes pickup and delivery, terminal, and highway access fuel, level terrain, 55 mph speed limit.

**Weight Limits
A. 73/18/32
B. 80/20/34
C. Bridge/18/32
D. Bridge/20/34
E. Bridge/22.4/36

***Indicates equal axle load comparisons.

+Fuel Consumption for 1-45 Conventional semi-trailer is 0.00924 Gal per ton-mile at weight Limit A and is 0.00852 Gal per ton-mile at weight Limit B for the trip specified.



*Tractor capacity limits MGVW and loaded density.

FIGURE 3-1. UNIT VEHICLE LINEHAUL FUEL CONSUMPTION PER TON-MILE AS A FUNCTION OF LOADED DENSITY densities for the different weight limits (where the weight of the payload increases the vehicle gross weight to the maximum at that particular weight limit).

Table 3-4 shows the unit vehicle fuel percentage saved in the line-haul operations of multiple trailer combinations over the single 45 ft conventional semi-trailer van. As indicated in this Table, and in Figure 3-1, Western Doubles (2-27) combinations save 8 percent when operated at the 18/32/73K limit at densities of 12.1 lb/cu ft or less. At this limit, the 2-27 uses more fuel for payloads with densities of 13.6 or greater. If the weight limit is increased to 20/34/80K, the 8 percent savings can be extended to a density of 14 lb/cu ft. At densities above 15.6 lb/cu ft, the 2-27 ft combination uses more fuel when filled to its weight limit because of its greater tare weight and lower payload weight than with the 1-45 ft combination.

In a similar way, it can be shown that the triple 27 ft trailer trucks, when operated at the 20/34/Bridge Formula limit, offer 24 percent line-haul fuel savings over single trailer rigs at densities of 14.6 lb/cu ft or less. Above that density, the triple trailer fuel savings advantage is progressively reduced until a minimum saving of 9 percent is reached at 17.6 lb/cu ft density.

Turnpike Doubles combinations provide a maximum saving of 31 percent at densities below 11.2 lb/cu ft (20/34/Bridge formula limit). These double-45 ft combination line-haul fuel savings are reduced as densities increase to the point where the turnpike doubles offer 7 percent fuel savings at the 20/34/Bridge formula limit.

A special category of volume limited loadings, comprising a significant share of the regular route carrier market is the less-than-truckload (LTL) traffic. This market is predominately low density with an average on-board loaded density of 12 lb/cu ft. In Table 3-5, the total trip fuel use on a ton-mile basis

TABLE 3-4. LINEHAUL PERCENT FUEL SAVING OF MULTIPLE-TRAILER CONFIGURATIONS OVER CONVENTIONAL SEMI-TRAILER COMBINATIONS*,**

Loaded Density (lb/cu ft)	Western Double 2-27		Western Triples 3-27			Turnpike Doubles 2-45		
	A	BCDE***	C	D	E	C	D	E
12	8%	8%	24%	24%	24%	28%	31%	31%
13	3	8	24	24	24	23	27	30
14	-3	8	24	24	24	18	22	26
15	-9	3	18	20	21	13	18	21
16	-15	-2	13	15	16	8	13	16
17	-22	-8	9	10	12	3	8	12
18	-23	-9	8	9	11	2	7	16

*These values are independent of the single trailer weight limits because the single trailer design density is greater than that of the multiple trailers.

**Level terrain, 55 mph speed limit, fuel-saver technology vehicles.

Note: Weight Limits

A. 73/18/32
B. 80/20/34
C. Bridge/18/32
D. Bridge/20/34
E. Bridge/22.4/36

***Western doubles combinations, with weight limits B, C, D, E, are limited to MGVW of 80,000 lb. because of the capacity limit of double axle tractors.

TABLE 3-5. FUEL CONSUMPTION FOR TYPICAL TRIPS FOR CONVENTIONAL SEMI-TRAILER AND MULTIPLE-TRAILER COMBINATIONS FOR LESS-THAN-TRUCKLOAD SHIPMENTS*

Configuration	Payload (Tons)**	Fuel Consumption (Gal/Payload Ton-Mile)	
		Standard	Fuel-Saver
1-45	17.45	0.02375	0.01984
2-27	20.80	0.02223	0.01908
2-45	34.90	0.01881	0.01657
3-27	31.21	0.01982	0.01737

*Level terrain, 55-mph speed limit, typical trip conditions.

**Calculated on the basis of an average on-board density of 12.0 lb/cu.ft.

is shown for the various axle configurations. This table shows that when the single 45 ft combination is compared to the double 27 ft trailer combination, the twin 27 ft combination carries 19.2 percent more payload but offers only a 3.8 percent fuel saving. The triple 27 ft combination carries 78.8 percent more payload but offers a 12.4 percent fuel saving. The double 45 ft combination carriers 100 percent more payload (2 trailers), producing a 16.5 percent fuel saving.

3.3.2 Less-than-Volume Limited Loads

When trucks are not loaded either to their payload weight or to their volume limit, each loading condition should be evaluated separately for fuel use comparisons. In Figure A-3,* fuel consumption is shown as a function of payload weight for conventional semi-trailer and turnpike doubles combinations in both standard and fuel-saver types. This figure shows that, on an equal payload weight basis (up to the capacity of the conventional semi which is not likely in operation), when the same level of technology is used, single 45 ft rigs will consume 20-25 percent less fuel than double 45 ft combinations for the standard technology trucks and 30-35 percent less fuel for the fuel saver trucks. Stated another way, the single 45 ft trailer combination will consume less fuel than will the turnpike double combination on a gallon per ton-mile basis, as long as the double combination fails to carry a load 25-30 percent greater than the single trailer combination.

If the double trailer combination is used to combine two average conventional semi-trailer loads, then the trip fuel saving by the turnpike double is in the range of 25-30 percent.

3.4 OTHER FACTORS AFFECTING FUEL CONSUMPTION

Many factors interact to establish fuel consumption. In some cases they interact directly with the TS&W limits. In addition, some of these factors, such as technology and speed limits

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*Appendix A.

are discretionary and can be used to reduce fuel consumption. Other factors, not directly controllable but affecting fuel consumption are terrain, traffic density, and type of roadway.

In Appendix A, the method to calculate fuel consumption includes the effects of these factors: 1) the fuel savings resulting from the adoption of fuel-saving technology, and 2) the adherence to the 55 mph speed limit. The effect of terrain on fuel-saving is described. Roadway classification and traffic effects are also covered in Appendix A where fuel consumption coefficients permit their estimation.

A comparison of unit vehicle fuel savings achieved by technology improvements, speed limits, and various TS&W limit changes is given in Table 3-6. This table shows that fuel-saving technology offers a substantial reduction in fuel. It also shows that adhering to the 55 mph speed limit also provides a significant but smaller fuel saving. In the remainder of this section, the effects on fuel consumption of technology, terrain, and adherence to the 55 mph speed limit are discussed.

3.4.1 Technology

The best possible 1979 fuel-saver technology shown earlier is compared to 1974 vehicles in Figure 3-2 as a separate item. The gains from technology are impressive when compared with changes in TS&W limits. An important factor is that technological fuel-saving improvements occur for all operations. As shown in Section 3.3, the TS&W limit increases can create conditions where more fuel is required when trucks are not operated at or near their maximum capacity.

Actual improvements in unit vehicle line-haul fuel consumption ranged from 21.6 percent to 28.1 percent.

TABLE 3-6. SUMMARY OF UNIT VEHICLE FUEL SAVINGS

Fuel Saving Method	Fuel Saving (percent)
Technological (1974 to 1979)	21-28
Speed Limit (65 mph reduced to 55 mph)	10
TS&W Limit Changes	
Loaded to Maximum Weight	
Conventional semi-trailer (1-45 ft)	
73/18/32 to 80/20/34	7.8
80/20/34 to Bridge/22.4/36	2.8
Turnpike doubles (2-45 ft)	
Br./18/32 to Br./20/34	5.5
Br./20/34 to Br./22.4/36	4.5
Change in Length	
Conventional semi-trailer to turnpike doubles	
73/18/32 to Br./18/32	1.6
80/20/34 to Br./20/34	2.9
Br./20/34 to Br./22.4/36	4.6
Loaded to Volume Capacity with 12 lb/cu.ft. payload	
Change in length to allow multiple trailers	
1-45 to 2-27	8
1-45 to 3-27	24
1-45 to 2-45	31

Note: Based on typical trip operations, level terrain, 55 mph speed limit.

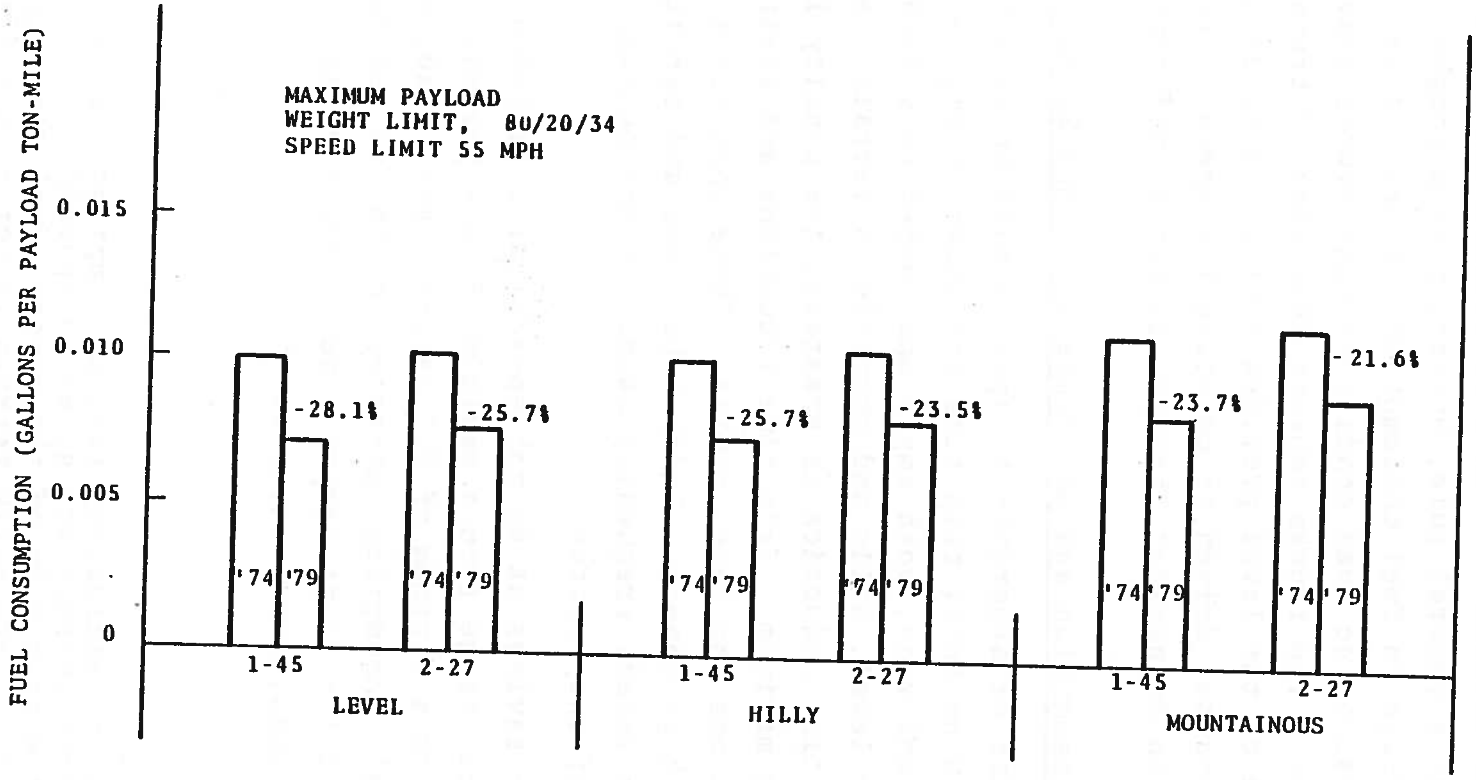

FIGURE 3-2. LINE-HAUL FUEL CONSUMPTION FOR STANDARD (1974) AND FUEL SAVER (1979) TECHNOLOGY WITH CONVENTIONAL SEMI-TRAILER (1-45) AND WESTERN DOUBLES (2-27) COMBINATION VAN TRUCKS

3.4.2 Terrain

Effects of terrain[14,15] on fuel consumption are shown in Figure 3-3. As a general rule, operating in a rougher terrain causes an increase in fuel consumption. An exception occurs under light load or no load conditions with trucks traveling up and down grades. The trucks consume less than if traveling an equal distance on the level provided that 1) on up-grades, the vehicles are not driven to maintain the speed averaged on the level, and 2) on downgrades, braking is not significant.

3.4.3 Fuel Consumption and Adherence to 55-MPH Speed Limit

The effects of adherence to speed limits on line-haul fuel consumption and on total trip time are shown in Figure 3-4 for conventional semi vans, both empty and loaded to a 20/34/80 weight limit, and for level, hilly and mountainous terrain. As shown, when the trip time reduction is greatest, the penalty in fuel consumption is maximum. Trip time reductions are greatest with empty combinations and level routes. These conditions permit the attainment of high speeds. Under other load and terrain conditions, maximum speeds frequently cannot be met because of the power limits of the tractor.

Trip time savings at 65 mph speed limit, as compared to 55 mph speed limit, range from a maximum of 13.4 percent (empty load, flat terrain) to a minimum of 2.7 percent (max, load, mountain terrain). Fuel consumption increases for the 65 mph range from a maximum of 22.1 percent (empty load, level terrain) to 1.7 percent (maximum load, mountainous terrain).

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[14] Coefficients for estimating fuel consumption for level, hilly, and mountainous terrain are given in Appendix A.

[15] Throughout the main body of the report, fuel comparisons are for level terrain. Since hilly terrain is not much different from level, and mountainous terrain effects a low percentage of the total vehicle-miles, the level terrain fuel use rates can be approximated for national average rates. For fuel aggregation estimates, however, truck traffic is disaggregated by terrain type for each state.

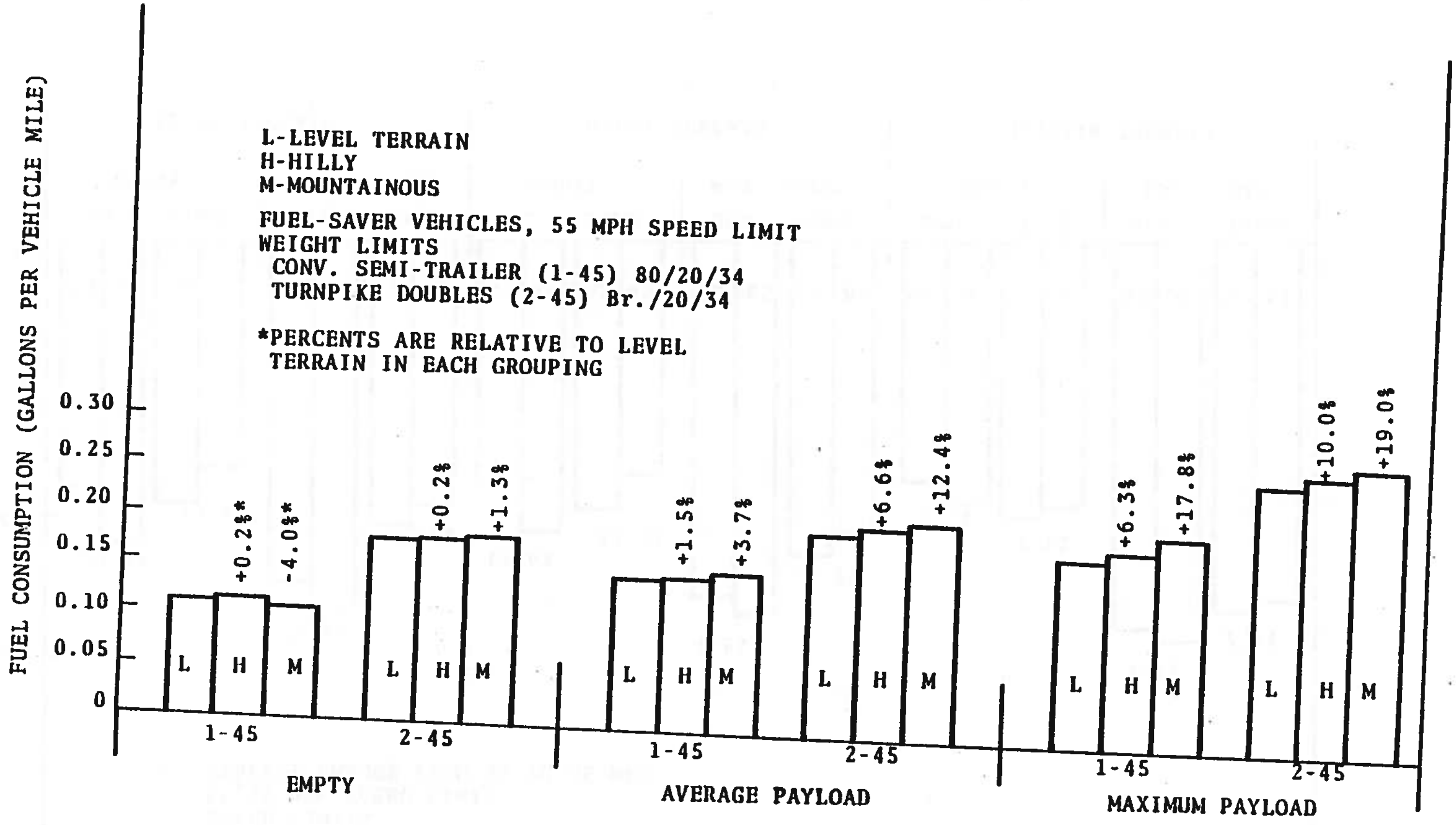

FIGURE 3-3. TERRAIN EFFECTS ON LINE-HAUL FUEL CONSUMPTION OF CONVENTIONAL SEMI-TRAILER AND TURNPIKE DOUBLE VAN COMBINATIONS

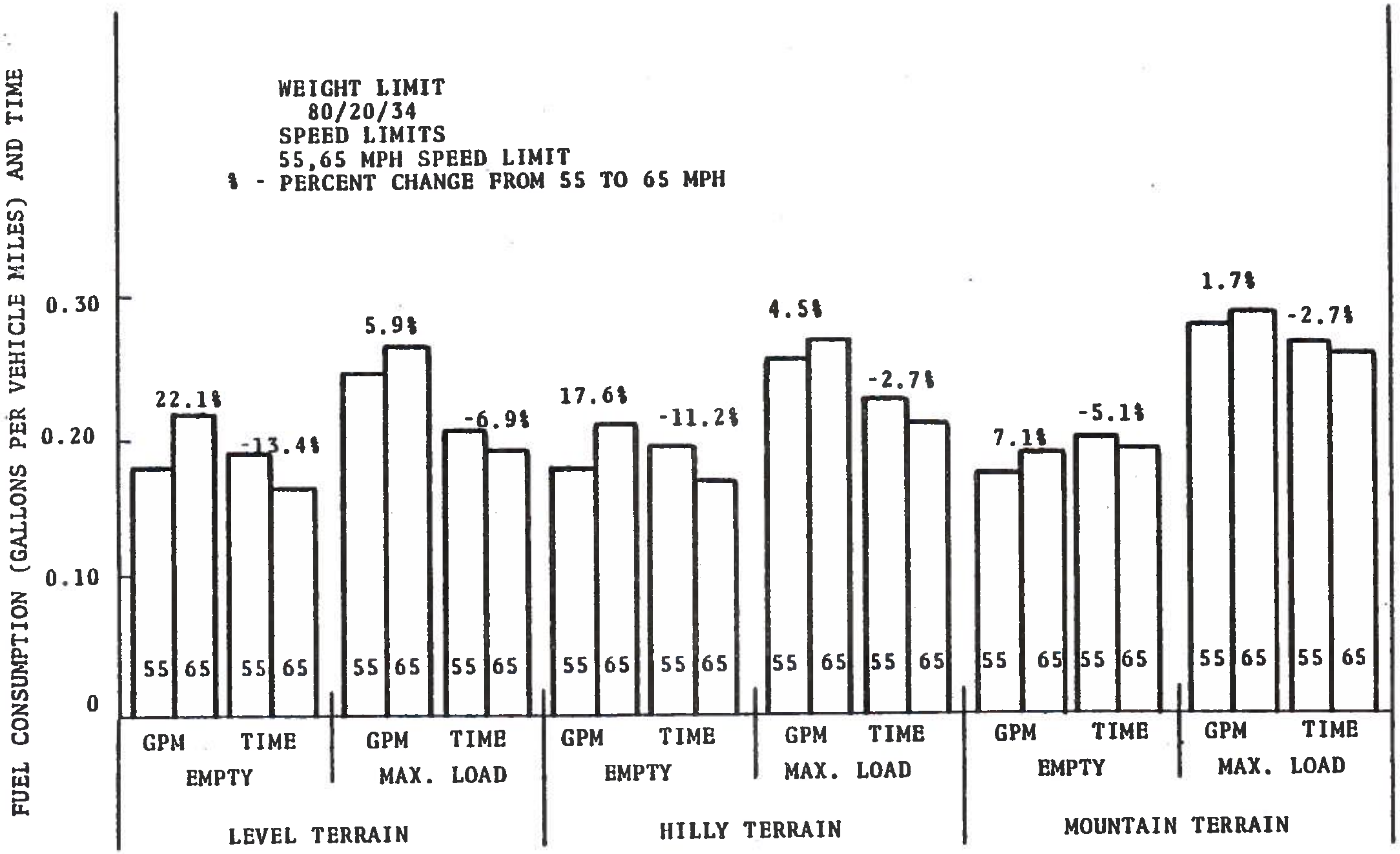

FIGURE 3-4 SPEED LIMIT EFFECTS ON FUEL AND LINEHAUL TIME FOR CONVENTIONAL

4. EFFECTS OF TRUCK SIZE AND WEIGHT LIMITS ON THE FUEL CONSUMPTION OF COMPETITIVE TRUCK AND RAIL SERVICES

4.1 INTRODUCTION

Changing the existing TS&W limits can affect the aggregate fuel consumption of competing truck and rail services. Rail freight transportation, in most cases, is less fuel intensive than are the competitive highway services. New truck size and weight limits could permit lower transportation prices and could cause shippers to perceive an economic advantage in shifting from rail to trucking. More fuel, therefore, would be consumed to transport traffic shifted from rail to highway.

The principal exception to rail's fuel advantage is rail TOFC service. The current TOFC fuel intensiveness differs only slightly from highway.[16]

Based on current technology and operations, trucking consumes slightly less fuel than does dedicated TOFC with conventional equipment under any of the following conditions: 1) the use of fuel-saver technology, turnpike doubles, 2) routing traverses mountainous terrain where trucking has a relative grade and curvature advantage, and rail has an inherent gross weight to payload weight disadvantage, 3) exceptionally large circuity exists in the rail network for the specific market, and 4) PU&D routing causes large access and/or egress penalties for TOFC. For conditions other than those stated above, TOFC is less fuel intensive than trucking.

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[16] Improvements in rail TOFC operating practices and equipment could substantially improve TOFC's current fuel intensiveness and restore the historic rail/truck relationship. This study, however, represents truck and rail technology and operations only as they exist today, with the exception that improvements which exist only in limited areas (i.e., Sprint train demonstration) are used to represent the near future.

Rail carload service is in almost all cases, less fuel intensive than trucking service. For rail to be more fuel intensive, either the payload must be very light (under approximately 25 tons when compared to the most efficient trucks - see Section 4.2), or the circuity must be high (over 100 percent extra miles when carrying maximum weight loads) (See Section 4.4).

In this chapter, the competing highway and rail services are compared on both an ideal (line-haul only) and typical trip (including systems inefficiencies) operation for each of several TS&W limits.[17]

In Section 4.2, highway truckload and rail carload services are compared. In Section 4.3 highway truckload and LTL services are compared with the competitive TOFC services.[18]

4.2 RAIL CARLOAD AND HIGHWAY SERVICES FUEL USE COMPARISON

Rail box cars carrying maximum weight and average weight payloads are compared to typical highway truckload operations at the various truck weight limits in Figure 4-1 and in Tables 4-1 and 4-2. General service box cars and trailers are used here for illustrating relationships. Similar relationships exist for the other services (i.e., gondolos, flat cars, etc. and the corresponding truck types). Data for estimating the fuel consumption relationships of the full array of body types/services is contained in Appendix A. Highway trucks used here for illustration are conventional semi-trailers and turnpike doubles.

Even at low payload weights (approximately 10-25 tons) rail box cars consume less fuel than all highway services except conventional semi-trailer combinations with fuel saver technology (Figure 4-1). At these low payload weights, TOFC service also

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[17] Aggregate fuel estimates combining these unit vehicle averages with truck and rail traffic activity is covered in Technical Supplement Volume 7.

[18] Energy comparisons between transportation modes are far from exact. When comparisons are made, the service or activity for each mode should be on as equal a basis as possible, consistant with the operational characteristics of each mode.

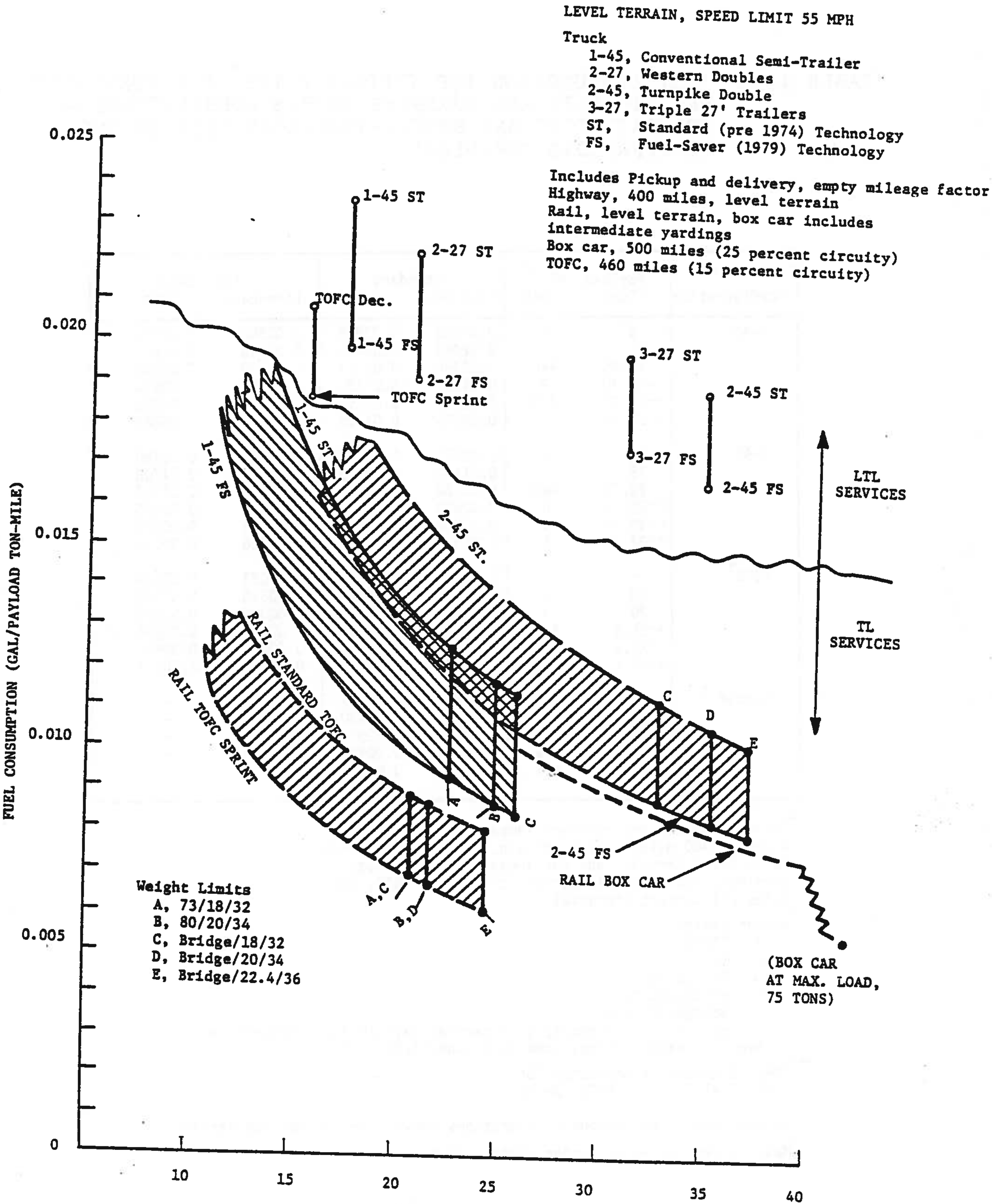

FIGURE 4-1. TRIP FUEL CONSUMPTION OF HIGHWAY VAN TRUCKS AND COMPETITIVE RAIL: TL AND LTL SERVICES

TABLE 4-1. FUEL CONSUMPTION FOR TYPICAL TRIPS[*] FOR CONVENTIONAL SEMI-TRAILER AND TURNPIKE DOUBLE COMBINATIONS AND FOR RAIL TOFC AND BOXCAR-TRUCKLOAD SIZE SHIPMENTS (GAL/PAYLOAD TON-MILE)

Configuration	Payload (Tons)	WT.[**] Limit	Standard		Fuel Saver	
			Line-Haul	Trip	Line-Haul	Trip
1-45	5	-	0.03822	0.03822	0.02852	0.02852
	10	-	0.02046	0.02495	0.01506	0.01894
	15.85	Ave.	0.01390	0.01724	0.01009	0.01258
	††22.70	A	0.01052	0.01250	0.00753	0.00924
	††25.05	B,D	0.00979	0.01158	0.00697	0.00852
	††25.95	E	0.00954	0.01128	0.00679	0.00828
2-45	10	-	0.02371	0.03068	0.01845	0.02480
	15	-	0.01664	0.02129	0.01286	0.01708
	22.70	Ave.	0.01184	0.01491	0.00908	0.01187
	††32.74	C	0.00898	0.01111	0.00682	0.00875
	††35.15	D	0.00853	0.01052	0.00646	0.00827
	††37.25	E	0.00819	0.01006	0.00620	0.00790
TOFC[***]	5	-	0.1397	0.02764	0.01033	0.02174
	10	-	0.00825	0.01528	0.00610	0.01195
	20	-	0.00539	0.00909	0.00398	0.00705
	††21.8	A,C,	0.00515	0.00858	0.00381	0.00664
	††22.3	B,D	0.00509	0.00845	0.00377	0.00654
	††24.6	E	0.00486	0.00794	0.00359	0.00613
Boxcar[†]	10	-	0.00872	0.02187	-	-
	20	-	0.00545	0.01230	-	-
	30	-	0.00436	0.00911	-	-
	48	Ave.	0.00354	0.00671	-	-
	75	Max.	0.00305	0.00528	-	-

[*] Includes pickup and delivery, empty mileage factor
Highway, 400 miles, level terrain, 55 mph speed limit
Rail, level terrain, box car includes intermediate yardings, 500 miles (25 percent circuity), TOFC, 460 miles (15 percent circuity)

[**] Weight Limits
A. 73/18/32
B. 80/20/34
C. Bridge-18/32
D. Bridge/20/34
E. Bridge/22.4/36
\- no limit, inlcuded to show partial payload fuel consumption
Ave. estimated average load at Bridge/18/32 Limit

[***] TOFC "Standard" = dedicated TOFC
TOFC "Fuel Saver" = TOFC Sprint

[†] No fuel saving technology or operations shown here for box car service.

[††] Maximum payload weight under stated limit

TABLE 4-2. RATIOS OF ESTIMATED FUEL CONSUMED, HIGHWAY, TRUCK LOAD SERVICE TO RAIL BOXCAR

Weight[1] Limit	Rail Boxcar	LINEHAUL				TRIP[4]			
		1-45[3]		2-45		1-45		2-45	
		ST	FS	ST	FS	ST	FS	ST	FS
A	Ave. Load[2]	2.97	2.13	-	-	1.86	1.38	-	-
	Max. Load	3.45	2.47	-	-	2.37	1.75	-	-
B	Ave. Load	2.77	1.97	-	-	1.73	1.27	-	-
	Max. Load	3.21	2.29	-	-	2.19	1.61	-	-
C	Ave. Load	2.69	1.92	2.54	1.93	1.68	1.23	1.66	1.30
	Max. Load	3.13	2.23	2.94	2.24	2.14	1.57	2.10	1.66
D	Ave. Load	-	-	2.41	1.82	-	-	1.57	1.23
	Max. Load	-	-	2.80	2.12	-	-	1.99	1.57
E	Ave. Load	-	-	2.31	1.75	-	-	1.50	1.18
	Max. Load	-	-	2.68	2.03	-	-	1.91	1.50

[1] Weight Limits
A. 73/18/32
B. 80/20/34
C. Bridge/18/32
D. Bridge/20/34
E. Bridge/22.4/36

[2] Rail Boxcar
Ave. Load, 48 tons
Max. Load, 75 tons

[3] Truck
1-45, Conventional semi-Trailer
2-45, Turnpike Double
ST, Standard (pre 1974) Technology
FS, Fuel-Saver (1979) Technology

[4] Includes pickup and delivery, empty mileage factor
Highway, 400 miles. level terrain, maximum payload, 55 mph Speed Limit
Rail, level, terrain, box car includes intermediate yardings;
500 miles (25 percent circuity)
TOFC, 460 miles (15 percent circuity)

consumes less fuel than standard box cars. At higher payload weights, rail box car is considerably less fuel intensive than are all highway and TOFC services.[19]

Rail carload and highway fuel consumption comparisons for the specific TS&W limits for highway trucking are shown in Table 4-2. Ratios of truck to box car fuel consumption are shown to be relatively insensitive to truck size or weight limits.

4.2.1 Existing TS&W Limits

Line-haul Only

A conventional semi-trailer, with standard technology and a maximum load (at 80,000 MGVW), uses approximately 2.97 times as much fuel as the standard box car when the box car is carrying an average load (48 tons). It uses 3.45 times as much fuel when the box car is loaded to its weight limit.

Trip Requirements

When compared on a shipper to receiver basis, the standard technology conventional semi-trailer at the 18/32/73,280 lb. limit uses 2.37 times the fuel of the standard box car when the box car is loaded to its weight limit, and 2.19 times the fuel at the 20/34/80,000 lb. limit. The corresponding figures for fuel-saver trucks are 1.86 and 1.73 times as much fuel as the standard box car at its load limit.

4.2.2 Increasing TS&W Limits to Allow Turnpike Doubles

Line-Haul Only

The standard technology Turnpike Doubles consume 2.94 as much fuel as the standard box car when carrying maximum payloads at the 18/32/Bridge limit. Value at the 20/34/Bridge limit drops to 2.80.

When fuel saver Turnpike Doubles are used, the ratio of fuel compared to a box car maximum load is 2.24 at the 18/32/Bridge

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[19] See Section 4.4 for qualifications.

limit and drops to 2.12 at the 20/34/Bridge limit.

Trip Requirements

Typical trip fuel consumption comparisons show that standard technology turnpike doubles have the following ratios of fuel consumption compared to the standard box car when the box cars are carrying maximum payloads:

	Weight Limits	Truck to Rail Carload Fuel Consumption Ratio
C.	18/32/Bridge	2.10
D.	20/34/Bridge	1.99
E.	22.4/36 Bridge	1.91

Fuel-saver turnpike doubles have the following ratios.

	Weight Limit	Truck to Rail Carload Fuel Consumption Ratio
C.	18/32/Bridge	1.66
D.	20/34/Bridge	1.57
E.	22.4/36/Bridge	1.50

When box cars are loaded to their average weight and payload and turnpike doubles are loaded to their weight limits, the following ratios of fuel use are produced by fuel-saver trucks.

	Weight Limit	Truck to Rail Carload Fuel Consumption Ratio
C.	18/32/Bridge	1.30
D.	20/34/Bridge	1.23
E.	22.4/36/Bridge	1.18

For average operational conditions, when truck and rail carload fuel consumption are compared, trucking consumes more fuel than rail, regardless of weight limit or configuration. Only under extreme situations of rail circuity or lightly loaded rail cars, will rail approach or surpass truck fuel intensiveness. These conditions are described in Section 4.4.

4.3 TOFC AND HIGHWAY SERVICES FUEL USE COMPARISON

4.3.1 Truckload Shipments

Ratios of truck fuel to TOFC fuel are considerably smaller than for truck to carload. The relationships do not change drastically if conventional semi-trailer rigs or if turnpike doubles are compared to TOFC 40-ft trailers. The effect of shifting from standard technology to fuel-saver technology is slightly less than the substitution of turnpike doubles for conventional service.

Fuel use ratios are shown in Table 4-3 for both line-haul and typical trip operations and for the various truck weight limits.[20] The ratios range from 2.04 for line-haul for the 1-45 ft standard technology combination compared to a dedicated TOFC, to a value of 0.98 comparing the trip fuel for a fuel-saver 2-45 ft combination to a dedicated TOFC service.

4.3.1.1 Existing TS&W Limits

Line-Haul Only

When a standard technology conventional semi-trailer is compared to dedicated TOFC services for line-haul only, the truck uses 2.04 times the fuel as the dedicated TOFC.

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[20] The truck to TOFC fuel comparisons shown in this chapter are, for the most part, based on a rail circuity of 15 percent greater than trucking, (based on a national rail short-line circuity value). However, dedicated TOFC service, as it currently exists between major city pair combinations, according to mileage figures in the Official Railway Guide-North America Freight Edition (Reference 6), are very close to Interstate Highway Distances given by Rand McNally (Reference 7). In some instances the rail distance is less. Therefore, for most major city-pair routes, this report understates the truck/rail fuel ratios by an estimated 5-10 percent unless stated to the contrary. In Table 4-5, which gives truck to rail fuel ratios fo LTL Services and is the most favorable for trucking energy intensiveness fuel ratios shows both 15 percent additional rail circuity and equal circuity (See Section 4.4.1).

TABLE 4-3. RATIOS OF ESTIMATED FUEL CONSUMED HIGHWAY TO TOFC, TRUCK LOAD SERVICE

		LINE-HAUL				TOTAL TRIP**			
		1-45		2-45		1-45		2-45	
Wt. Limit	TOFC	ST	FS	ST	FS	ST	FS	ST	FS
A/A,C*	ST***	2.04	1.46	-	-	1.46	1.08	-	-
	FS	-	1.98	-	-	-	1.39	-	-
B/B,D	ST	1.92	1.37	-	-	1.37	1.01	-	-
	FS	-	1.85	-	-	-	1.30	-	-
C/A,C	ST	-	-	1.74	1.32	-	-	1.30	1.02
	FS	-	-	-	1.79	-	-	-	1.32
D/B,D	ST	-	-	1.68	1.27	-	-	1.24	0.98
	FS	-	-	-	1.71	-	-	-	1.26
E/E	ST	-	-	1.84	1.28	-	-	1.27	0.99
	FS	-	-	-	1.73	-	-	-	1.29

*Indicates weight limit used for both highway and TOFC
For example, A/A,C is:

$$\frac{\text{Highway Fuel Consumption at Weight Limit "A"}}{\text{TOFC Fuel Consumption at Weight Limits "A" or "C"}}$$

where:

A. 73/18/32
B. 80/20/34
C. Bridge/18/32
D. Bridge/20/34
E. Bridge/22.4/36

**Includes pickup and delivery, empty mileage factor
Highway, 400 miles, level terrain, maximum loads
Rail, 460 miles (15 percent circuity), level terrain, maximum loads, 55 mph speed limit

***ST, Standard (pre 1974) Technology
FS, Fuel-Saver Technology

Trip Requirements

Compared on a shipper-to-receiver basis, the greater inherent system inefficiencies of rail penalize the relative fuel advantage of TOFC and reduce the ratio of truck trip fuel to rail trip fuel to 1.46.

4.3.1.2 Increasing TS&W Limits to Allow Turnpike Doubles

Line-Haul Only

Substitution of Turnpike Doubles for conventional combinations operating at a 20/34K Bridge formula weight limit reduces the fuel ratio of truck to dedicated TOFC from 1.92 to 1.68, when standard technology vehicles are used.

When fuel saving technology 2-45 ft trucks are used, the fuel ratio of truck to dedicated TOFC is reduced to approximately 1.27 percent.

If improved efficiency TOFC is used, as represented by the "Sprint" results, the ratio of line-haul Turnpike Doubles to special TOFC fuel consumption is increased again to 1.71.

Trip Requirements

As indicated before, the rail systems inefficiencies reduce the fuel advantage of TOFC when compared on a door-to-door basis. When standard technology Turnpike Doubles, at the 18/32/Bridge Formula limit, compete with standard TOFC, the trucks consume 1.30 times as much fuel as the TOFC.

When fuel saver technology trucks are in competition with standard dedicated TOFC the turnpike doubles at the 18/32/Bridge Formula limit achieve a fuel (at maximum payload) ratio of 1.02 The corresponding ratio at the 20/34 Bridge limit is 0.98.

If improved TOFC is in competition with the fuel-saver Turnpike Doubles at the 18/32 Bridge Formula limit, the ratio of truck to rail fuel is 1.32. The corresponding ratios at the 20/34/Bridge limit is 1.26.

The most significant observation here is that the current TOFC service is less fuel intensive than trucking in all cases, except where fuel-saver trucks are used for truck load service at the maximum payloads.

In these cases, there will be little difference between the two modes until TOFC Sprint services are more universally available. Double 45-ft combinations, when operated at the 20/34/Bridge weight limit, are slightly less fuel-intensive than TOFC service. For other situations, TOFC is less fuel intensive. The difference in fuel intensiveness in truckload service between single 45-ft and double 45-ft rigs is small.

When comparable technology is compared for total trip direct fuel consumption, ratios of fuel consumed in truck and in TOFC range from 1.46 to 1.26, depending upon the vehicle type and weight limit. The corresponding values for line-haul direct fuel consumption range from 2.04 to 1.71. The degree to which the rail inefficiencies can be controlled will determine how much the truck/TOFC fuel use ratios approach that of line-haul fuel ratios.

4.3.2 Less-than-Truckload Services

The main observation about fuel consumption in LTL service is that highway trucking and TOFC show little difference when compared on a door-to-door trip basis (see Footnote 20). Ratios of fuel use range from 1.1 for a standard technology conventional semi-trailer combination compared to dedicated TOFC, to 0.8 for a fuel-saver Turnpike Double, compared to dedicated TOFC. Fuel consumption rates for highway and TOFC services are shown in Table 4-4. Ratios of fuel use between highway trucking and rail TOFC is shown in Table 4-5.

The various truck configurations, listed in order of increasing fuel intensiveness, are 2-45, 3-27, 2-27, and 1-45. The dedicated TOFC service is slightly less fuel intensive than the standard technology conventional semi-trailer and the Western Doubles combination. The Sprint TOFC is somewhat less

TABLE 4-4. FUEL CONSUMPTION FOR CONVENTIONAL SEMI-AND MULTIPLE-TRAILER COMBINATIONS AND FOR RAIL TOFC, FOR LESS-THAN-TRUCKLOAD SIZE SHIPMENTS

Configuration	Payload (Tons)	Standard (Gal/Ton-Mi)	Fuel-Saver (Gal/Ton-Mi)
Line-Haul*			
1-45	17.45	0.01288	0.00931
2-27	20.80	0.01146	0.00857
2-45	34.90	0.00858	0.00650
3-27	31.21	0.00937	0.00712
TOFC Dedicated	15.50	0.00622	-
TOFC Sprint	15.50	-	0.00460
Typical Trip			
1-45	17.45	0.02375	0.01984
2-27	20.80	0.02223	0.01908
2-45	34.90	0.01881	0.01657
3-27	31.21	0.01982	0.01737
TOFC Dedicated**	15.50	0.02089	-
TOFC Sprint**	15.50	-	0.01847
TOFC Dedicated***	15.50	0.01968	-
TOFC Sprint***	15.50	-	0.1758

*No circuity or empty back-haul.

**See Table 4-5, Footnotes 1 and 2, includes 15 percent circuity.

***No circuity included.

TABLE 4-5. RATIOS OF ESTIMATED FUEL CONSUMED, HIGHWAY TO TOFC, LTL SERVICE*,**,***

HIGHWAY / TOFC	1-45		2-27		3-27		2-45	
	ST	FS	ST	FS	ST	FS	ST	FS
Dedicated[†]	1.14	0.95	1.06	0.91	0.95	0.83	0.90	0.79
Sprint[†]	1.29	1.07	1.20	1.03	1.07	0.94	1.02	0.90
Dedicated[††]	1.21	1.01	1.13	0.97	1.01	0.88	0.96	0.84
Sprint[††]	1.35	1.13	1.26	1.08	1.13	0.99	1.07	0.94

[*] Includes pickup and delivery, empty mileage factor
Highway, 400 miles, level terrain, 55 mph speed limit
Rail, 460 miles (15 percent circuity), level terrain,
box car includes intermediate yardings

[**] TOFC access includes round trips at each end between consolidation/distribution terminals and TOFC loading/unloading terminals. If this function is eliminated, all ratios are increased 0.04 to 0.05.

[***] Payloads given in Table 4-4.

[†] Includes 15 percent rail circuity.

[††] No rail circuity included.

fuel-intensive than the fuel-saver and the standard technology conventional semi-trailer and the Western Double combination. Both the dedicated TOFC and the Sprint TOFC are more fuel intensive than either the fuel saver triple 27-ft trailer or the Turnpike Double combinations.

When both LTL rail TOFC and truck are compared on a line-haul only basis, a standard 1-45 rig consumes 2.07 more fuel than a dedicated TOFC, and a fuel-saver 1-45 rig consumes 1.50 more fuel than a dedicated TOFC. The corresponding figures for a 2-45 standard technology rig are 1.38 more fuel when compared to dedicated TOFC and 1.04 more fuel for fuel-saver rig compared to dedicated TOFC.

When compared on comparable levels of technology in line-haul operations, the rail TOFC is substantially more fuel efficient in LTL transportation than is highway. The difference between the TOFC fuel advantage in line-haul operations and the relative equality in trip operations arises from the system and operational characteristics of TOFC activity. Based on the industry average figures used in this study, rail loses 15 percent to a greater circuity and approximately 20 percent to a greater empty backhaul. In addition, the TOFC LTL operations used call for 6 gallons of fuel (2 round trips) consumed between the truck consolidation/distribution terminals and the TOFC loading/unloading terminals. To the extent that any of these TOFC operational inefficiencies can be reduced, the trip comparative advantage between rail and truck fuel will approach that of line-haul TOFC.[21]

4.4 EFFECTS OF RAIL CIRCUITY AND EMPTY BACK-HAUL AND INDIRECT ENERGY ON HIGHWAY-RAIL COMPARATIVE ENERGY PERFORMANCE

Two factors which influence truck/rail fuel comparisons are circuity and empty back-haul. Each mode has circuity and back-haul characteristics affecting fuel consumption which are unique to their design, their operations, and the markets they serve. The use of these factors is given in Appendix A. As stated there, when estimating fuel consumption for specific trips, routes, or markets, the values of circuity and back-haul associated with the

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[21] Note the change in truck to rail fuel consumption ratio in Table 4-5 when rail circuity is made equal to highway circuity.

actual operations should be used. If the values of the factors are not known, an estimate must be used. If fuel consumption of an aggregation of activity is being estimated, then some average value must be used. In this section, values of circuity and empty back-haul based on national averages are described along with a brief discussion of the way changing these values would affect the truck to rail fuel consumption ratios.

4.4.1 Circuity

Factors which influence circuity include operating strategy, topography, and regulatory effects. Within each mode a considerable range of circuity may exist. For the rail mode, some general freight service has routes with over 100 percent circuity. In contrast, some cities are linked by rail which is nearly direct. Highway trucking also produces a range of circuity. Direct trucking can be operated, in some cases, with very little circuity. In contrast, substantial circuities can be generated by the use of intermediate terminals.

Circuity effects must be included when making modal fuel comparisons. If specific markets are being compared, actual routes and distances are probably known and fuel consumption with circuity included can be readily found. If a generalized comparison is being made without specific routes or distances known, then an assumed circuity must be used.

In estimating circuity values for rail and highway, the following assumptions are made:

1. Highway distances are approximately 15 percent greater than great circle distances (Reference 8).
2. Short line rail distances are 15 percent greater than competing highway distances, with the exception of major corridor cities in which rail and highway distances are assumed equal (Reference 9 and Footnote 20).
3. Actual rail shipment distances exceed short-line distances by approximately 10 percent.

The absolute highway circuity and rail circuity values are given in Appendix A, Table A-9. The following ratios reflect the relative circuity between typical rail services and typical highway services.

$$\frac{\text{Rail Standard Car Service}}{\text{Highway (all services)}} = 1.25$$

$$\frac{\text{Rail TOFC Service}}{\text{Highway}} = 1.15$$

$$\frac{\text{Rail TOFC (Corridor Routes)}}{\text{Highway}} = 1.00$$

These ratios of relative circuity are the basis for the fuel comparisons shown in this report.

Given below are considerations used in arriving at the above circuities.

1) Since 1964, when much of the short-line to actual route distances were analyzed, there has been a continual errosion of the rail general merchandize freight movement. Large circuities can be caused by isolated shipping points and/or low traffic volumes. Both of these conditions are caused by poor service and rates which are not rail advantageous and hence would create conditions favorable to shifting to highway. Therefore, some of the former high circuity rail traffic has been diverted to trucking, thereby reducing the rail average circuity.

2) In some instances, high circuity is unavoidable (for example, geographical conditions). Any land service would be subject to the same circuity. To assume a blanket major difference in circuities between modes would not give realistic amounts of fuel impacts from model shifts of traffic.

3) On most of the major city-pair routes, there is little difference in mileage for TOFC and for scheduled freight service between rail and highway(see Footnote 20).

4) There has been a trend by rail to offer improved services and economic incentives resulting from circuity reductions.

   a. Abandonments of branch line. Branch lines almost inherently indicate large circuity.

   b. Mergers and track-rights agreements between carriers to reduce circuity.

5) The main intent of this analysis is to describe future fuel consumption in terms of what it is likely to be.

The important point here is that the change in truck and rail fuel consumption ratios is roughly equal to any change in circuity between the two modes.

To show the effect of circuity on fuel consumption ratios between standard rail box car service and fuel saver turnpike double trucks (the most favorable truck to rail carload ratios), Table 4-6 gives truck to rail fuel ratios for various rail to highway relative circuity factors.

TABLE 4-6. TRUCK-TO-RAIL FUEL-CONSUMPTION RATIO AS AFFECTED BY RAIL TO HIGHWAY CIRCUITY

Rail to Highway Relative Circuity	Rail Miles	Highway to Rail Fuel Consumption Ratio
1.0	400	1.704
1.15	460	1.687
1.30	520	1.513
1.32	528	1.493
1.50	600	1.331
1.75	700	1.157
2.00	800	1.022
2.25	900	0.916

Note: Highway-Fuel-Saver 2-45 trucks, Bridge/20/34 weight limit.

4.4.2 Empty Back-Haul

As in circuity comparisons between rail and highway, empty back-haul has an effect on fuel use comparison, although not to the degree that circuity does. Truck to rail line-haul fuel use ratios for various rail empty back-haul ratios are shown in Table 4-7.

TABLE 4-7. TRUCK-TO-RAIL FUEL-CONSUMPTION RATIO AS AFFECTED BY RAIL-EMPTY BACK-HAUL

Rail Empty Back-Haul	Truck to Rail Fuel Use Comparison
1.0*	1.84
1.2	1.74
1.4	1.66
1.6	1.57
1.8	1.50
2.0**	1.43

*Equivalent to 100 percent loaded return
**Equivalent to 100 percent empty return

Note: Highway-Fuel-Saver 2-45 trucks, Bridge/20/34 weight limit, Highway includes empty backhaul factor of 1.14 and rail includes 25 percent circuity.

The main observation in Table 4-7 is that for a change in rail empty back-haul ratio, the fuel consumption compairson changes by approximately one half that amount. For example, if the rail empty back-haul is reduced from 1.8 to 1.6, the truck to fuel ratio would increase from 1.50 to 1.57.

4.4.3 Indirect Energy

When indirect energy is included in the total fuel consumption estimates, the values of fuel intensive are given in Table 4-8.

TABLE 4-8. APPROXIMATE TOTAL ENERGY CONSUMPTION IN TYPICAL TRIP OPERATIONS (BTU PER PAYLOAD TON-MILE)*

Configuration	Direct Fuel***	Indirect Energy†	Total Energy
1-45 (FS)**	1176	1600	2776
2-45 (FS)**	1141	1600	2741
TOFC (Sprint)	911	515	1426
Box Car (Standard)	735	515	1251

*
- o Highway 400 miles, TOFC 460 miles, Box car 500 miles.
- o Includes pickup and delivery, terminal and intermediate box car terminals.
- o Level terrain, 55 mph speed limit.

**Trucks have fuel saver technology, Bridge/20/34 weight limit.

***Values taken from Table 4-1 and converted to BTU per ton-mile.

†Values taken from Table D-1.

These estimates are given solely on values of national direct and indirect energy use. The direct fuel estimates shown here are representative of less direct fuel intensive services than shown in Appendix D. The services here are for new technology (except box car) equipment and for typical trip operations. The indirect energy shown here is based on national average values and does not attempt to isolate indirect energy for specific vehicles, weight limit, and operations.

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APPENDIX A

INTERCITY UNIT VEHICLE FREIGHT FUEL ESTIMATION

A.1 INTRODUCTION

Appendix A presents and describes the empirical equations developed for estimating unit vehicle intercity freight fuel consumption. The coefficients used for various vehicle, operating and environmental conditions are also listed. The coefficients derived for aggregate fuel consumption estimates will be found in Appendix B.

Many factors affect the amount of fuel consumed in freight transportation. Most important are transportation equipment, size and characteristics of payloads, and carrier type of operations. Fuel consumption factors are given below, showing the major elements within each grouping.

1. Demand

   Weight, density and special features of payloads, distance, route features, origin and destination proximity to terminals and linehaul routes, temporal and spatial distribution of backhaul.

2. Transportation equipment

   Type, configuration, technology, availability, condition.

3. Operations

   Use of consolidation terminals, intermediate re-classification, routing, route conditions.

4. Legal factors

   Size and weight limits, speed limits, operational regulations, route restrictions.

These factors cover a wide range of values and frequently interact. To make fuel consumption estimates, it is necessary to establish average values which adequately represent service and operations and to restrict the number of variables changed when making comparisons.

Section A.1.1 shows a detailed listing of factors included in the fuel estimation analysis. Following the listing of factors, Table A-1 shows maximum payload weights and cubed-out payload weights at LTL shipment density for all vehicle types. Table A-3 gives a detailed description of the truck components used in the line-haul simulation model for standard technology and fuel-saver vehicles.

A.1.1 Highway and Rail Fuel Consumption Analysis Factors

- Highway

  Carrier: Regular route common carrier, irregular route common carrier, private carrier, or exempt carrier.

  Vehicle body type: General service dry van, reefer and insulated van, household goods van, auto transporter, tank, flat/rack/log, dump (see Tables A-1, 2).

  Configuration: Single unit three-axle, conventional tractor/semi-trailer combination, 40-45 foot doubles combinations, 27-foot doubles combination, 27-foot triples combination (see Tables A-1, 2).

  Shipper-receiver distance: Either actual route distance as used in a network analysis or actual city-pair combination, or the great circle distances, with modes compared on an abstract basis and circuity factors accounting for the actual distance traveled.

  Shipment size: Either TL or LTL size shipments.

  Terrain: Level, hilly, mountainous.

  Road classification: Interstate or equivalent primary, secondary.

  Direct shipment and routing through terminals: Highway shipments can be sent either directly from the shipper to the receiver or routed through terminals (origin and destination) at either end of the line-haul movement, as are small shipments on regular route common carriers.

TABLE A-1. HIGHWAY VAN TRUCKS AND RAIL TOFC PAYLOAD WEIGHTS BY TYPE AND TS&W LIMIT

FULL VEHICLES / EQUIPMENT TYPES	TRUCK		RAIL TOFC[*]	
	Max Weight Load	Cubed Out @ 12#/CF	Max Weight Load	Cubed Out @ 12#/CF
Conventional Semi (1-45'trailer)				
73/18/32 Limit (A)[**]	22.70	17.45	21.80	15.50
80/20/34 Limit (B)	25.05	17.45	22.30	15.50
Bridge/18/32 Limit (C)	23.05	17.45	21.80	15.50
Bridge/20/34 Limit (D)	25.05	17.45	22.30	15.50
Bridge/22.4/36 Limit (E)	25.95	17.45	24.40	15.50
Western Double (2-27'trailers)				
73/18/32 Limit (A)	21.00	20.80	20.00	20.00
80/20/34 Limit (B)[†]	24.30	20.80	23.30	20.00
Bridge/18/32 Limit (C)[†]	24.30	20.80	23.30	20.00
Bridge/20/34 Limit (D)[†]	24.30	20.80	23.30	20.00
Bridge/22.4/36 Limit (C)[†]	24.30	20.80	24.35	20.00
Triple 27's (3-27' trailers)				
73/18/32 Limit (A)	15.50	15.50[††]	N/A	N/A
80/20/34 Limit (B)	19.00	19.00[††]		
Bridge/18/32 Limit (C)	36.00	31.20		
Bridge/20/34 Limit (D)	37.00	31.20		
Bridge/22.4/36 Limit (E)	38.00	31.20		
Turnpike Doubles (2-45' trailers)				
73/18/32 Limit (A)	—[†††]	—	N/A	N/A
80/20/34 Limit (B)	—	—		
Bridge/18/32 Limit (C)	32.74	32.74		
Bridge/20/34 Limit (D)	34.79	34.79[††]		
Bridge/22.4/36 Limit (E)	37.25	37.25[††]		

NOTE: Payloads reported for both truck and rail are listed in tons.

[*] The conventional semi-trailer used for rail TOFC operation is a single 40-foot trailer, while the 27-foot trailer is used for consistency with the truck mode.

[**] A,B,C,D,E, used to designate weight limits. See Section 2.4.4.

[†] Western doubles, with weight limits B,C,D,E are limited to an MGVW of 80,000 because of the capacity limit of double axle tractors.

[††] MGVW is limiting value.

[†††] Not practical.

TABLE A-2. HIGHWAY TRUCKS AND RAIL CAR AND TOFC (EXCEPT VANS) PAYLOAD WEIGHTS BY TYPE AND TS&W LIMIT

FULL VEHICLES		TRUCK		RAIL CARLOAD & TOFC
EQUIPMENT TYPES	Max. Weight Convent. Semi	Max. Weight Turnpike Double	Max. Weight Straight Truck	Ave. Weight Load*
Auto Transport			N/A	23.70
73/18/32 Limit (A)	18.64	—		
80/20/34 Limit (B)	21.00	—		
Bridge/18/32 Limit (C)	19.00	26.70		
Bridge/20/34 Limit (D)	21.00	28.70		
Bridge/22.4/36 Limit (E)	21.90	31.20		
Dump				100.00
73/18/32 Limit (A)	19.25	—	15.55	
80/20/34 Limit (B)	19.75	—	16.55	
Bridge/18/32 Limit (C)	19.25	28.00	15.55	
Bridge/20/34 Limit (D)	19.75	29.50	16.55	
Bridge/22.4/36 Limit (E)	21.35	32.00	17.55	
Rack/Platform			N/A	50.13
73/18/32 Limit (A)	23.79	—		
80/20/34 Limit (B)	26.15	—		
Bridge/18/32 Limit (C)	24.15	34.55		
Bridge/20/34 Limit (D)	26.15	36.55		
Bridge/22.4/36 Limit (C)	27.05	39.05		
Refrigerated Van			N/A	47.30 - reefer car 21.20 - TOFC van
73/18/32 Limit (A)	21.20	—		
80/20/34 Limit (B)	23.55	—		
Bridge/18/32 Limit (C)	21.55	29.45		
Bridge/20/34 Limit (D)	23.55	31.45		
Bridge/22.4/36 Limit (E)	24.45	33.95		
Tank			N/A	61.13
73/18/32 Limit (A)	23.70	—		
80/20/34 Limit (B)	25.00	—		
Bridge/18/32 Limit (C)	24.00	35.20		
Bridge/20/34 Limit (D)	25.00	37.20		
Bridge/22.4/36 Limit (E)	26.00	39.20		
Rail Box Car				48.00

* Reported average payloads for rail equipment types were obtained by matching predominate equipment types to commodity types and observing reported payloads from the Carload Waybill Statistics for 1977(Reference 1).

** A,B,C,D,E, used to designate weight limits. See Section 2.4.4.

TABLE A-3. TSC SIMULATION, SIMULATION MODEL, VEHICLE CHARACTERISTICS*

	SINGLES (1-45 FT)		WESTERN DOUBLES (2-27 FT)		TURNPIKE DOUBLES (2-45 FT)		TRIPLES (3-27 FT)
Description	Standard (1974)	Fuel Saver (1979)	Standard (1974)	Fuel Saver (1979)	Standard	Fuel Saver	Fuel Saver
Configuration	3S-2	3S-2	2S-1-2	2S-1-2	3S-2-4	3S-2-4	3S-1-2-2
	Cabover	Cabover	Cabover	Cabover	Cabover	Cabover	Same Tractor as Turnpike Double (Fuel Saver)
Truck Mfg.	GM	GM	GM	GM	GMC	GMC	
Model	Astro 95	Astro 95	Astro 95	Astro 95	Astro 95	Astro 95	
Engine Mfg.	Cummins	Cummins	Cummins	Cummins	Cummins	Cummins	
Model	NTC-290	Formula 300	NTC-290	Formula 300	NTC 350	Formula 350	
Horsepower	290/350	300/350	290/350	300/350	350	350	
Transmission Mfg.	Fuller	Fuller	Fuller	Fuller	Fuller	Fuller	
Model	RTO 910	RT 1110	RTO 910	RT 1110	RT 12515	RT 12515	
No. of speeds	10 speed	10 Speed	10 Speed	10 Speed	12 Speed	12 Speed	
Drive Axle Mfg.	Rockwell	Rockwell	Rockwell	Rockwell	Rockwell	Rockwell	
Model	SLHD	R170	R170	R170	SLHD	SLHD	
Ratio	4.11	3.70	4.11	3.70	4.11	3.70	
Tag Axel	NA**	TKN	NA	NA	NA	NA	
Tires	11.00 x22 Bias	11.00 x 22 Rad.	11.00 x 22 Bias	11.00 x 22 Rad.	11.00 x 22 Bias	11.00 x 22 Rad.	
Cooling Fan	Yew	No	Yes	No	Yes	No	
Power Steering	No	No	No	No	No	No	
Air Condition	Yes	Yes	Yes	Yes	Yes	Yes	
Van Length	1-45'	1-45'	2-27'	2-27'	2-45'	2-45'	
Width	8'	8'	8'	8'	8'	8'	
Height	13.5'	13.5'	13.5'	13.5'	13.5'	13.5'	
Side	Ribbed	Smooth	Ribbed	Smooth	Ribbed	Smooth	
Drag Reducer	No	Yes	No	Yes	No	Yes	

* Characteristics of van combination trucks given, other types use typical trailers

** NA - not applicable

Technology level: Standard 1974 type vehicles, fuel saver 1979 type vehicles ("fuel saver" vehicles incorporate all power and body fuel saving technology commercially available in 1979, i.e., engine design, axle ratio, accessory power consumption, aerodynamics, rolling resistance) (See Table A-3).

- Rail

  Service: Carload general mixed consist train, dedicated TOFC, special TOFC.

  Vehicle body type: TOFC general service dry van, TOFC reefer or insulated van, general service boxcar, reefer car, tank car, auto carrier, flat or gondola car.

- Technology Level

  Carload services: Use average equipment and operations.

  Dedicated TOFC: Uses existing equipment operations. No intermediate terminals are included. Intermediate pick-up and drop-off is included.

  Special TOFC: Uses the Sprint demonstration fuel performance. Existing equipment and operations are assumed. Matched power units to load and no intermediate pick-up or drop-off is allowed.

A.1.2 Carrier Operations and Transportation Functions

The type of operations conducted by a carrier significantly affects the functions required to move intercity freight. Transportation functions are normally designated as line-haul, pick-up and delivery (PU&D), terminal and "other." In this paper, the functions for direct fuel use analysis are line-haul and access. The access function includes pick-up and delivery and terminal fuel (both transportation equipment and supporting equipment).

The particular service offered establishes the functions. With highway travel the major distinction is whether the shipments proceed directly from shipper to receiver, or through origin and destination terminals for either shipment consolidation or equipment specialization. In rail transportation, except for special unit trains (single commodity, single origins and destinations), most rail services require terminal functions, at either end of the line-haul.

All highway LTL* shipments and regular route common carrier TL shipments go through terminals. To account for the fuel used in these activities, access fuel is added to line-haul fuel. Private trucking and irregular route motor carrier services are represented as moving directly without going through terminals. LTL shipments, via TOFC, are shown going through forwarder terminals for consolidation and rail terminals for loading/unloading. In addition, all rail carload shipments pass through intermediate terminals, thereby adding an extra fuel charge.

Line-haul is, for most truck and rail transportation activity, the most significant consumer of fuel. On occasions when TL traffic goes through terminals, access fuel is approximately 5-10 percent of the line-haul fuel. For LTL traffic, the access fuel use is considerably greater. When short trips are involved, the LTL access fuel can be equal to or be greater than the line-haul fuel.

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*For a common carrier handling LTL shipments, the decision to select single or double-trailers is based on the way regional collection and distribution is integrated into their total operations. For example, most major carriers have several terminals in each major metropolitan area and, since each originating terminal may not have a trailer full of shipments to go to each of the terminals in the destination city, an intermediate terminal between major regions is used to provide further consolidation of shipments. However, since each 27-foot trailer carries approximately half the number of shipments of a single 45-foot trailer, there are more opportunities to send the smaller trailers directly from the origin city to the terminals in the destination city, thus by-passing the intermediate terminal handling.

A.2 EQUATIONS

This section gives the equations and coefficients for calculating unit vehicle fuel consumption.* The equations begin with a simple expression of line-haul fuel consumption rate (gallons per vehicle-mile) based on typical equipment and performance. Separate equations are used for each vehicle body type. The equations are then expanded to more detailed expressions which include:

1. Line-haul fuel consumption (for use in direct vehicle comparisons);
2. Trip (shipper to receiver) fuel consumption (including access fuel); and
3. Trip fuel consumption (including system average empty miles and circuity inefficiencies).

A.2.1 Line-Haul

Line-haul is the major fuel consuming function. The most affected by truck size and weight laws, line-haul fuel consumption is, consequently, covered in the most detail in this report.

A.2.1.1 Highway

All highway fuel consumption coefficients are based on a truck performance computer simulation by the Cummins Engine Company, Inc. The different truck types and configurations were run at several gross vehicle weights, ranging from empty truck to maximum gross vehicle weights.

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*For estimating fuel aggregations from VMT traffic forecasts, the trip gallons based on system operations is used for appropriate disaggregation of regional traffic.

The Cummins simulation provided line-haul fuel consumption over "typical" and simulated primary and secondary routes for different trucks for the following variables: (1) vehicle configuration and gross vehicle weight, (2) terrain, (3) "standard" or "fuel saver" technology, (4) engine size, and (5) speed limit. An example of fuel consumption for single and double van trailer rigs relationships taken from the simulation, is shown in Figure A-1.

The curves shown in Figure A-1 are typical of the fuel consumption rates for interstate or equivalent highways generated in this simulation. Twin-trailers (2-27 ft) are shown with a fuel consumption rate greater than a single conventional trailer when operated at the same gross weight. Fuel consumption for hilly terrain is greater than level terrain throughout the vehicle weight range. Mountainous-route fuel consumption, in some situations, acts differently. At low vehicle weights, less fuel is consumed per mile on mountainous routes than on level or hilly routes as a result of trade-offs of energy gained from elevation to energy lost in climbing Since climbing speed is lower than level travel speed, there is less net drag loss (rolling plus aerodynamic) in climbing than in traversing level travel. As long as downhill braking is not significant, there will be less fuel required (at low vehicle weights and longer travel time) in mountainous routes. Curves were generated to fit the fuel consumption rates established by the simulation. For the most part, linear equations were the most suitable.

Direct unit fuel consumption is approximated by a linear function of weight in which the constant term represents the fuel consumed in moving the empty vehicle, and the variable term represents the fuel required to move the payload:

Eq.A-1. Gallons per Vehicle Mile (GPVM) = FFC + VFC (P)

where: GPVM is the average line-haul fuel consumption in gallons per vehicle mile;

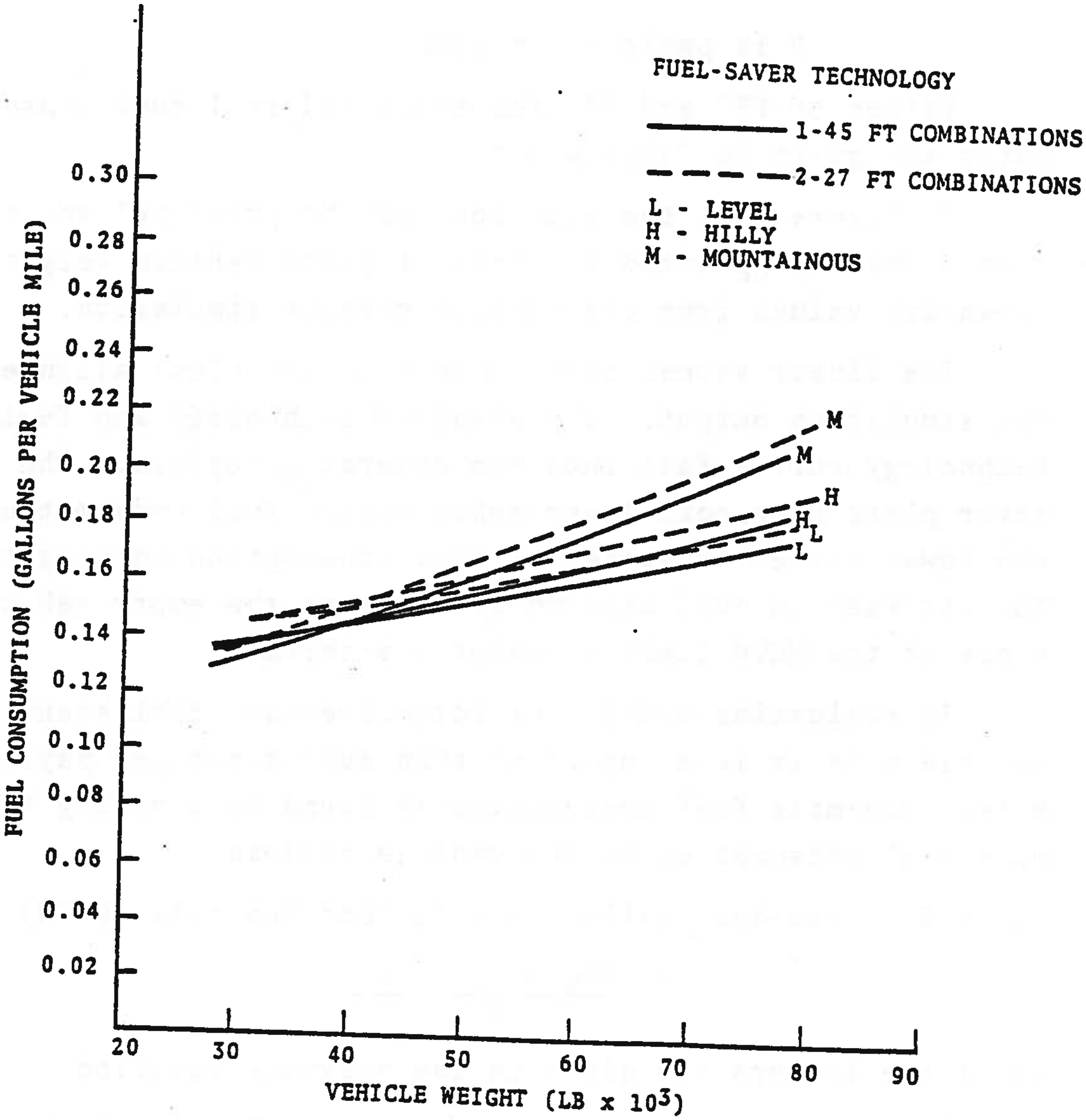

FIGURE A-1. LINE-HAUL FUEL CONSUMPTION AS A FUNCTION OF GROSS VEHICLE WEIGHT FOR CONVENTIONAL SEMI-TRAILERS (1-45) AND WESTERN DOUBLES (2-27) VAN TRUCKS

FFC is the fixed component of fuel consumption and is the fuel required to overcome resistance of the tare weight and aerodynamic drag;

VFC is the variable component of fuel consumption and is the additional fuel required to move the payload; and

P is payload (in tons).

Values of FFC and VFC for truck and rail fuel consumption rates are given in Table A-4.*

In Figure A-2, the equations of the principal van combination trucks are plotted in terms of gross vehicle weight. Also shown are values from the vehicle mission simulation.

The linear values plotted in A-2 show close alignment with the simulation output. The standard technology and fuel-saver technology curves fall into two general groupings. The fuel saver plots have both lower empty weight fuel consumption values and lower values of slopes of fuel consumption to weight increases. The increase in fuel consumption between the empty vehicles and those at the MGVW limit is about one-third.

In evaluating model fuel intensiveness, fuel spent per vehicle mile is less important than fuel spent per payload ton-mile. Ton-mile fuel consumption is found by dividing the vehicle mile fuel consumption by the vehicle payload.

Eq. A-2. Line-haul gallons per Payload Ton-mile (GPTM)

$$= \frac{FFC + (VF\ )(P)}{P}$$

where the factors are given in the previous equation.

The unit of gallons per payload ton-mile is the basic unit of fuel intensiveness used in this analysis. As an example, Figure A-3 shows the fuel used per vehicle mile divided by the vehicle payload. This figure illustrates that the reduction in

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*Four significant figures are shown to indicate small differences in fuel consumption rates between competitive vehicles and not to determine fuel consumption with that degree of precision.

TABLE A-4. INTERCITY TRUCK LINE-HAUL FIXED (FFC) AND VARIABLE (VFC) FUEL CONSUMPTION COEFFICIENTS

BODY TYPE AND CONFIGURATION	STANDARD TECHNOLOGY						FUEL SAVER TECHNOLOGY					
	LEVEL		HILLY		MOUNTAINOUS		LEVEL		HILLY		MOUNTAINOUS	
HIGHWAY	FFC	VFC	FFC	VFC	FFC	VFC	FFC	VFC	FFC	VFC	FFC	VFC
VAN												
Single Unit	0.1546	0.0027	0.1551	0.0030	0.1537	0.0036	0.1172	0.0017	0.1178	0.0020	0.1158	0.0025
Conv. Semi Tr.	0.1776	0.0027	0.1776	0.0030	0.1746	0.0036	0.1346	0.0016	0.1349	0.0021	0.1290	0.0027
Turnpike Dbl.	0.2121	0.0025	0.2109	0.0031	0.2106	0.0037	0.1675	0.0017	0.1668	0.0024	0.1681	0.0029
27-Ft. Dbl.	0.1842	0.0026	0.1845	0.0028	0.1810	0.0034	0.1451	0.0016	0.1450	0.0020	0.1422	0.0025
27-Ft. Triples	0.2143	0.0025	0.2113	0.0031	0.2096	0.0037	0.1692	0.0017	0.1671	0.0024	0.1673	0.0029
REEFER												
Single Unit	0.1560	0.0027	0.1566	0.0030	0.1557	0.0036	0.1180	0.0017	0.1189	0.0020	0.1172	0.0027
Conv. Semi Tr.	0.1823	0.0027	0.1829	0.0030	0.1809	0.0036	0.1374	0.0016	0.1386	0.0021	0.1337	0.0027
Turnpike Dbl.	0.2204	0.0025	0.2211	0.0031	0.2228	0.0037	0.1731	0.0017	0.1747	0.0024	0.1777	0.0029
HOUSEHOLD GOODS VAN												
Singl Unit	0.1560	0.0027	0.1566	0.0030	0.1557	0.0036	0.1180	0.0017	0.1189	0.0020	0.1172	0.0025
Conv. Semi-Tr.	0.1803	0.0027	0.1806	0.0030	0.1782	0.0036	0.1362	0.0016	0.1370	0.0021	0.1317	0.0027
Turnpike Dbl.	0.2152	0.0025	0.2148	0.0031	0.2152	0.0037	0.1696	0.0017	0.1698	0.0024	0.1717	0.0029
AUTO TRANSPORTER												
Conv. Semi-Tr.	0.2140	0.0025	0.2102	0.0026	0.2067	0.0031	0.1622	0.0016	0.1597	0.0018	0.1527	0.0023
TANK												
Single Unit	0.1399	0.0026	0.1401	0.0027	0.1397	0.0032	0.1192	0.0017	0.1202	0.0020	0.1188	0.0025
Conv. Semi Tr.	0.1512	0.0028	0.1527	0.0032	0.1510	0.0037	0.1288	0.0018	0.1310	0.0024	0.1314	0.0029
Turnpike Dbl.	0.1661	0.0028	0.1684	0.0031	0.1672	0.0037	0.1429	0.0019	0.1442	0.0026	0.1469	0.0031
FLAT/RACK/LOG												
Single Unit	0.1510	0.0027	0.1511	0.0030	0.1508	0.0036	0.1150	0.0017	0.1150	0.0020	0.1124	0.0025
Conv. Semi. Tr.	0.1512	0.0028	0.1527	0.0032	0.1510	0.0037	0.1288	0.0018	0.1310	0.0024	0.1314	0.0029
Turnpike Dbl.	0.1667	0.0028	0.1690	0.0031	0.1679	0.0037	0.1433	0.0019	0.1447	0.0026	0.1475	0.0031
DUMP												
Single Unit 3Axle	0.1148	0.0020	0.1163	0.0023	0.1142	0.0027	0.0870	0.0012	0.0883	0.0016	0.0844	0.0020
Single Unit 4Axle	0.1189	0.0019	0.1200	0.0024	0.1190	0.0029	0.0901	0.0012	0.9113	0.0017	0.0879	0.0022
Conv. Semi Tr.	0.1276	0.0021	0.1297	0.0028	0.1305	0.0033	0.0967	0.0013	0.0985	0.0020	0.0964	0.0025
Turnpike Dbl.	0.1565	0.0020	0.1639	0.0027	0.1702	0.0032	0.1233	0.0014	0.1296	0.0021	0.1357	0.0025

FCC = Fixed Fuel Coefficient
VFC = Variable Fuel Coefficient
Values are based on the Cummins Truck Simulation Model. They are for interstate or equivalent roads. Average driving conditions and assume compliance with the 55 mph speed limit.

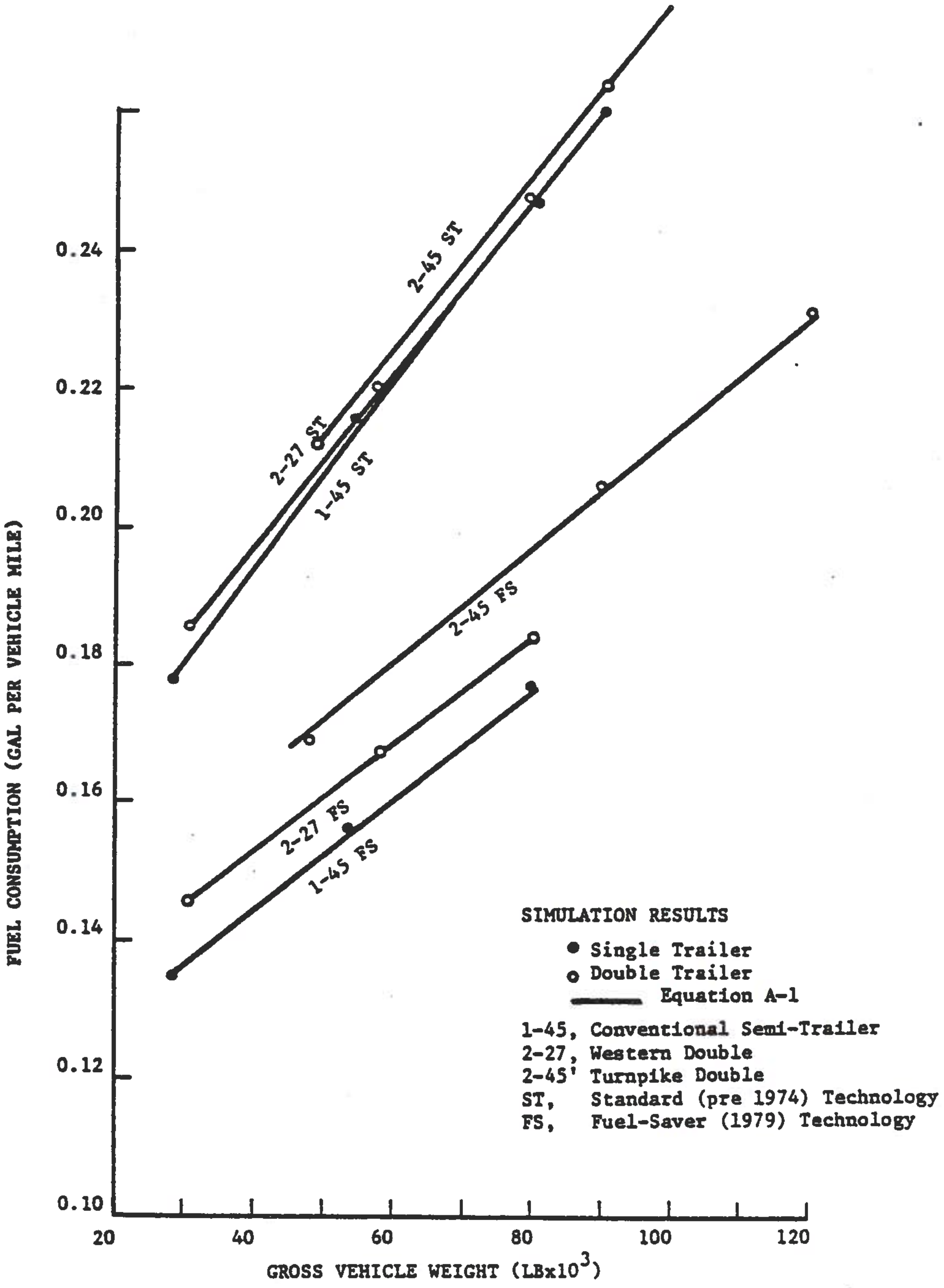

FIGURE A-2. COMPARISON OF LINE-HAUL FUEL CONSUMPTION VALUES FROM SIMULATION AND EQUATION A-1

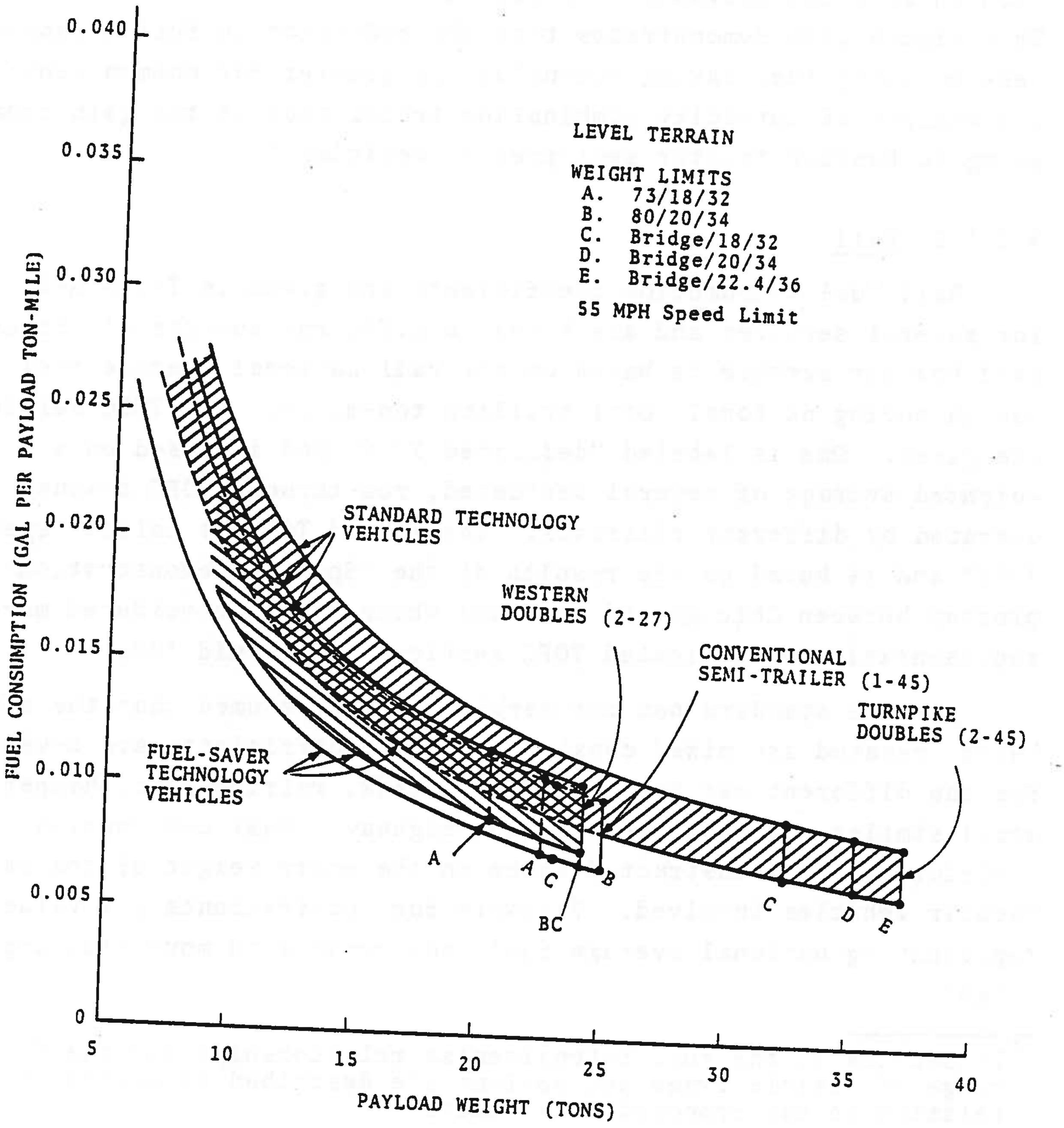

FIGURE A-3 LINE-HAUL FUEL CONSUMPTION PER PAYLOAD TON-MILE AS A FUNCTION OF PAYLOAD WEIGHT fuel intensiveness per payload ton-mile is important, but that, as the maximum gross weight of the vehicle increases, the reduction in fuel intensiveness per payload ton-mile is decreasing. This figure also demonstrates that the reduction in fuel intensiveness by using fuel saving technology is greater for common vehicle weights of intercity combination trucks than is the gain from going to heavier tractor semi-trailer vehicles.*

A.2.1.2 Rail

Rail fuel consumption coefficients are given in Table A-5 for several services and are based on different sources.** Standard box car service is based on the rail national average fuel use in moving national total trailing ton-miles. Two TOFC services are given. One is labeled "dedicated TOFC" and is based on a weighted average of several dedicated, run-through TOFC trains operated by different railroads. The second TOFC is called "special TOFC" and is based on the results of the "Sprint" demonstration program between Chicago and St. Paul which may be considered more representative of dedicated TOFC services in the mid '80s.

For the standard box car service, it is assumed that the trains being operated are mixed consist trains. Coefficients are developed for the different car services (e.g., tank, refrigerator, hopper, etc.) similar to those used for the highway. Fuel consumption coefficients are constructed based on the empty weight of the particular vehicles involved. Variable fuel coefficients are values representing national average fuel requirements to move trailing weight.

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*In Section 3, the fuel intensiveness relationships for the full range of vehicle types and options are described in detail in relation to the proposed TS&W limits.

**Standard car service is based on national aggregate fuel consumption; therefore, the effect of terrain is generally included when estimating national fuel consumption by use of the average fuel consumption rates given here. The average values should slightly overestimate level terrain fuel consumption and slightly underestimate mountainous terrain fuel consumption.

TABLE A-5. INTERCITY RAIL LINE-HAUL FIXED (FFC) AND VARIABLE (VFC) FUEL CONSUMPTION COEFFICIENTS*

BODY TYPE AND CONFIGURATION	DEDICATED TOFC		SPECIAL TOFC		MIXED CONSIST	
RAIL	FFC**	VFC**	FFC	VFC	FFC	VFC
TOFC						
General Service Dry Van	0.0572	0.00253	0.0423	0.00187	-	-
Reefer & Insulated Van	0.0585	0.00253	0.0432	0.00187	-	-
CARLOAD						
Box Car	-	-	-	-	0.0654	0.00218
Reefer	-	-	-	-	0.0872	0.00218
Tank	-	-	-	-	0.0807	0.00218
Gondola	-	-	-	-	0.0654	0.00218
Hopper	-	-	-	-	0.0589	0.00218
Auto Carrier	-	-	-	-	0.1046	0.00218

FOOTNOTES:

- Service either not provided or insignificant for this study.

*Rail values are based on previous DOT rail fuel tests and the intermodal Sprint demonstration program.

**FFC (Fixed Fuel Coefficient) is in gallons/vehicle-mile
VFC (Variable Fuel Coefficient) is in gallons/payload ton-mile.

Analysis of rail fuel consumption is much less exact than is analysis of intercity highway fuel consumption. For rail, there is a greater range of factors affecting fuel consumption. These include horsepower to weight ratios, operating speeds, condition of track over which the trains move, delays and other effects. Accordingly, there is a range of ton-miles per gallon values encountered in different types of operations.

A.2.2 Trip Fuel Consumption

To account for pickup and delivery and terminal activity (called access), and for the fuel used for refrigeration, average trip fuel is found by adding terms to the basic line-haul equation. For rail, there is an additional fuel requirement for fuel consumed in intermediate yards.

Eq. A-3. $\text{Trip Fuel (Gallons)} = [FCC + VFC\,(P)]\,[D] + AF + REEF + INTER$

where: FFC, VFC, P, D are given previously.

AF is the access fuel per line-haul vehicle trip and is given in Section A.2.2.1.

REFF is the additional fuel required by refrigerated service and is given in Section A.2.2.2.

INTER is the rail intermediate yard fuel and is given in Section A.2.2.3.

Trip fuel consumption in fuel intensiveness terms (gallon per payload ton-mile) is found in a manner similar to that shown in the line-haul fuel estimation equation.

Eq. A-4. Trip Gallons per Payload Ton-mile.

$$= \frac{[(FFC) + (VFC)(P)][D] + AF + REFF + INTER}{(D)(P)}$$

where the terms are those given for the previous equations.

A.2.2.1 Access

Access fuel use (i.e., all of the PU&D operations and all of the terminal activities) is neither as significant as line-haul fuel consumption nor as well known. There is a much greater range of values of access fuel than there is of line-haul fuel. This is due to a greater variation in geographical factors (distances and routing between origins/destinations and line-haul routes), equipment types, method of terminal operations, and such factors as percent of time engines spent in idling. In Table A-6, the access fuel assumed for this study is given.

Access distances estimated for the PU&D operations are based on data in the National Intermodal Network Feasibility Study[1] and represent averages for each mode for six medium and large sized cities. PU&D fuel consumption values used in this study are a synthesis of sources (i.e., conversion of average PU&D miles to gallons, TOFC terminal equipment fuel usage from "Sprint" test documentation, and carload terminal fuel costs derived from the TSC Staff Study on truck and rail costs[2]). LTL PU&D fuel is based on an assumed number of trips and shipment sizes and is adjusted for the size of payload for the different size truck volumes.

All PU&D fuel consumption is based on simple operations in which typical conditions are attempted to be described.[3] These provide fuel consumption rates which are used to estimate trip fuel consumption. The fuel consumption rates, while only representative, provide a consistent basis for making comparisons between modes and different vehicle sizes. Some of the specific features are: 1) TOFC truckload has longer PU&D runs than highway truckload, reflecting the fewer TOFC terminals, 2) all LTL PU&D fuel rates are in proportion to the truck sizes, 3) TOFC LTL has

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[1] Reference 2, Exhibit D-9.

[2] Reference 3.

[3] The PU&D operations are described in Appendix E.

TABLE A-6. INTERCITY FREIGHT ACCESS FUEL (AF)

SERVICE	OPERATION	FUEL (GAL)
Highway		
TL Regular Route TL	PU&D (4.8 miles x 4 Trips)	6
	Terminal (hostling, warm-up)	1
	Interstate Access (2.2 miles x 2)	1
		8
LTL		
Single Trailer	PU&D	64
	Terminal	1
	Interstate Access	1
		66
Multiple Trailer	PU&D	$64\left(\frac{W}{17.45}\right)^*$
	Terminal	1
	Interstate Access	n**
TL Contract, Irregular, Private	PU&D	-
	Terminal	1
	Interstate Access	1
		2
Rail		
TL TOFC	PU&D	8
	Terminal	1
	TOFC	1
		10
LTL	PU&D	$64\left(\frac{W}{17.45}\right)^*$
	Terminal	1
	Truck Terminal to TOFC Terminal	6
	TOFC Loading	1
BOXCAR LOAD	PU&D (10 miles x 4 trips)	
	Switching	
	Inter-yard transfer (5 miles x 4 trips)	
	Road Engine Idling	
		18

*W LTL Payload at Density of 12 lb/cu.ft.
2-27' Trailers, Payload (W) = 20.8 TONS (PU&D GAL = 76.29)
3-27' Trailers, Payload (W) = 31.2 TONS (PU&D GAL = 114.47)
2-45' Trailers, Payload (W) = 34.9 TONS (PU&D GAL = 128)

** n = number of gallons equal to the number of trailers per line-hau combination.

an additional fuel charge for movement between trucking consolidation/distribution terminals and the TOFC terminals, and 4) multiple trailer vehicles are given a fuel penalty for moving single trailers between multiple trailer terminals at the highway access point and the trucking terminal.

A.2.2.2 Fuel Consumed in Refrigeration Services

Additional fuel consumption for refrigerated services should be used when estimating fuel for this service.

Fuel consumption of refrigerator units is largely independent of both load or vehicle size and temperature requirements. For pre-cooled loads and vehicles, the fuel consumed depends mostly upon door-to-door shipping time. Rate of fuel use for line-haul highway reefer trailers, rail TOFC reefer trailers, and rail refrigerated cars is taken as 16.8 gallons per day.* This fuel need puts an extra burden on the slower types of service. Terminal waiting or delays are significant. Door-to-door time can be actual time, if known, or may be estimated from the Appendix to Technical Supplement, Volume 7.

A.2.2.3 Fuel Consumed in Rail Intermediate Yards

Additional rail fuel consumption, consisting of the fuel used in passing through intermediate yards is included for all carload service. A value of 3 gallons is assumed for each car and the intermediate yards are assumed every 500 miles of line-haul travel. Fuel is proportioned for distances traveled between the intermediate yards.

A.2.2.4 Effects on Fuel Consumption at Secondary Routes, Higher Power Engines, and Higher Speeds

The fuel consumption coefficients given for use with the Equations are for average equipment and operating conditions. Use of average coefficient values is limited when a wide range

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*Communication with Thermo King Corp., Minneapolis, MN. Fuel used in pre-cooling loads and vehicles is not included.

of conditions exist. To help provide for more accuracy in estimating fuel under different conditions, additional coefficients are included to account for (1) routing over secondary roads, (2) use of higher horsepower engines, and (3) operating with a 65 mph speed limit. These coefficients are assumed to be independent and hence are used singly or in combination. The detailed trip fuel consumption equation is

Eq. A.5. Detailed Trip Fuel (Gallons) =

Total Trip Fuel x (a_1, a_2, a_3)

where: Total Trip Average Fuel is given by Equation 3.

a_1 is the secondary road correction coefficient to convert the fuel consumption values given in Table A-1 based on interstate/primary roads. The secondary road correction coefficients are given by terrain type:

Level - 0.99
Hilly - 1.01
Mnt. - 1.12;

a_2 is the engine size correction coefficients for combination rigs. Small engines are normally used by motor carriers in regular route TL and LTL service, larger engines are used by contract and private carriers and agricultural exempt carriers. For services using larger size engines, a correction factor of 1.05 is employed.*

a_3 is a speed limit correction coefficient. All values in Table A-4 are for a speed limit of 55 mph. If a 65 mph limit were allowed, fuel use would be increased by the amount shown in Table A-7.

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*There is no fuel consumption increase with the larger engines if the same speeds are maintained. In practice, even with the same speed limits, the trucks with larger engines can achieve higher speeds over parts of the routes and consequently consume more fuel because of increased aerodyanmic losses.

TABLE A-7. 65 MPH SPEED LIMIT FUEL CONSUMPTION COEFFICIENTS

		TERRAIN	
PAYLOAD	LEVEL	HILLY	MOUNTAINOUS
Empty	1.221	1.176	1.017
Aerage	1.130	1.098	1.023
Maximum	1.069	1.045	1.027

Note: Standard technology conventional semi-trailer van trucks.

A.2.3 System Fuel Consumption

Transportation systems, however, usually have certain inefficiencies imposing additional fuel requirements which must be allocated to the freight moved. The most common are backhauls when empty transportation equipment is moved within the system to meet traffic demand; and circuity when additional miles are traveled due to the carriers' route structure and operating practices or when legal restrictions prevent direct movement.

The previous equations assumed average equipment and operating conditions, and neglected fuel penalties imposed by operating within a transportation system. Fuel consumption coefficients are added to account for system inefficiencies resulting from empty back-haul and circuity. Empty back-haul is the movement of empty transportation equipment within a system to meet traffic demand. The additional distance traveled because of carriers' operating practices or legal restrictions on routing is circuity.

Total trip fuel for average equipment and system operating conditions is given by Equation 3, below.

Total trip fuel for the equipment types and conditions specified is given by the following equation:

Eq. A-5. Total Trip Fuel (Gallons) Average =

$$[(FFC)(EBH) + (VFC)(P)](D)(CIR) + AF + REFF + INTER$$

where:

FFC is the fixed fuel coefficient.
EBH is the empty back-haul coefficient.
VFC is the variable fuel coefficient.
P is the payload in tons.
D is the distance in miles.
CIR is the circuity coefficients (if actual miles are unknown).
AF is the access fuel required for TL and LTL size shipments[7].
REFF is the additional fuel required by refrigerated service.
INTER is the fuel required in processing at intermediate terminals (rail only).

where all factors except EBH and CIR are those used with previous equations. EBH and CIR are given below.

Total trip fuel intensiveness may be found by dividing the above equation by the payload tons as done for the other measures of fuel consumption.

A.2.3.1 Empty Back-Haul

Empty back-haul factors EBH are shown in Table A-8. These values are the best estimates for national average values. As stated throughout this report, actual values should be used if they are known.

A.2.3.2 Circuity

Circuity correction factors based on national average values to correct for actual trip distances are given in Table A-9. These factors are for the national averages of actual route distances to great-circle distances (see discussion in Section 4.4.1). Actual route distances should be used when they are available.

A.3 References (Appendix A)

1. Federal Railroad Administration, 1977 Carload Waybill Statistics, U.S. Department of Transportation, Washington, DC, 1978.
2. Reebie Associates, "National Intermodal Network Feasibility Study--Volumes I - IV--Part 1, "Report No. FRA/OPPD-76/2.I, May 1976, Exhibit D-9.
3. Kochanowski, R.J., and Sullivan, D.P., "Truck and Rail Cost Effects on Truck Size and Weight Limits," Technical Supplement, Volume 2.
4. Rose, A.B., and Reed, J.K., Energy Intensive and Related Parameters of Selected Transportation Modes: Freight Movement, Oak Ridge National Laboratory, ORNL-5554, June 1979.
5. Interstate Commerce Commission, Bureau of Economics, Circuity of Rail Carload Freight, Statement No. 68-1, April 1968.

TABLE A-8. EMPTY BACK-HAUL FACTORS (EBH) FOR NATIONAL AVERAGE SERVICES

HIGHWAY*	REGULAR ROUTE		CONTRACT IRREGULAR ROUTE PRIVATE	
	Empty Miles / Total Miles	Empty Back-Haul / Factor (EBH)	Empty Miles / Total Miles	Empty Back-H / Factor (EBH
General Service Dry Van	12.2%	1.14	26.7%	1.36
Reefer and Insulated Van	11.0	1.12	24.2	1.32
Household Goads Van	2.5	1.03	-	-
Auto Transporter†	40.0	1.68	40.0	1.67
Tank	41.0	1.70	37.5	1.50
Flat/Rack/Log	16.6	1.20	23.2	1.30
Dump	40.0	1.68	40.0	1.67

	Empty Miles / Loaded Miles	Empty Back-Haul / Factor (EBH)
TOFC*** (All services)		
General commodity	0.5	1.5
Reefer and Insulated	0.5	1.5
Carload**		
Boxcar	0.7	1.7
Reefer	1.0	2.0
Tank	1.1	2.1
Gondola	0.9	1.9
Hopper	1.0	2.0
Auto Carrier†	1.0	2.0

*Highway empty miles/loaded miles based on data in: ICC, "Empty/Loaded Truck Miles on Interstate Highways During 1976," April, 1977, Tables I-IV.

**Rail empty/loaded carload miles based on data in: ICC, "Rail Carload Cost Scales, 1975," Statement No. 1C1-75, February, 1975, Table 14.

***Rail empty/loaded, TOFC car miles and TOFC trailer miles based on: ICC No. 1C1-75, Table 17.

†Estimated

TABLE A-9. CIRCUITY (CIR) FACTORS FOR NATIONAL AVERAGE SERVICES*

SERVICE	CIRCUITY FACTOR
Highway	
All Services	1.15
Rail	
Carload Services	1.43
TOFC	
National Average	1.32
Corridor	1.15

*Based on great-circle distances

Highway

$$\frac{\text{Actual highway distance}}{\text{Great circle distance}} = 1.15^{*}$$

Rail

$$\frac{\text{Standard car distance}}{\text{Great circle distance}} = 1.43^{**}$$

$$\frac{\text{TOFC National average distance}}{\text{Great circle distance}} = 1.32$$

$$\frac{\text{TOFC Corridor distance}}{\text{Great circle distance}} = 1.15$$

*From Rose and Reed, Reference 4.

**From I.C.C. Statement No. 68-1, Reference 5.

APPENDIX B

METHOD FOR CALCULATING AGGREGATE FUEL CONSUMPTION

B.1 INTRODUCTION

The method for estimating national aggregate truck fuel consumption is described in general terms in Appendix B. National aggregate truck fuel estimates and a detailed description of the method used is given in the Appendix to Technical Supplement, Volume 7.

Fuel consumption aggregations are calculated by multiplying the various components of freight transportation activity by the corresponding unit vehicle average fuel consumption rates.

B.2 VEHICLE ACTIVITY

Vehicle activity in this project is in units of vehicle miles traveled (VMT). Source of the vehicle activity projections of the Status Quo Base Case and each of the alternative TS&W limit scenarios is the traffic analysis, fully documented in Technical Supplement, Volume 4. The VMT data is classified by state, and study region by vehicle axle configuration, by gross vehicle weight, and by highway class. Highway class is further classified by terrain type, by gasoline and diesel power-plants, by empty or full loads, and by truck load or LTL size shipments.

B.3 AVERAGE FUEL CONSUMPTION RATES

Average fuel consumption rates for each of the aggregation components are modified fuel consumption rates based on the fuel consumption factors described in Appendix A. The values are given in Table A-4. The procedure to modify the fuel consumption rates is described below.

First, for each truck configuration, the fuel coefficient of the different types of trucks are given a weighted average based on the national distribution of truck body types within each axle configuration group. Results of this calculation are given in Table B-1.

TABLE B-1. WEIGHTED FUEL CONSUMPTION FACTORS

Vehicle	STANDARD TECHNOLOGY					
	Level Terrain		Hilly Terrain		Mountainous Terrain	
	FFC	VFC	FFC	VFC	FFC	VFC
3-Axle Single Unit	.1497	.0027	.1410	.0029	.1507	.0035
Conventional Semi-trailer	.1749	.0026	.1694	.0030	.1675	.0036
Turnpike Double	.1979	.0026	.1983	.0031	.1984	.0037
Double 27	.1842	.0026	.1845	.0028	.1810	.0034
Triple 27	.2143	.0025	.2113	.0031	.2096	.0037

Vehicle	FUEL SAVER TECHNOLOGY					
	Level Terrain		Hilly Terrain		Mountainous Terrain	
	FFC	VFC	FFC	VFC	FFC	VFC
3-Axle Single Unit	.1112	.0017	.1164	.0020	.1142	.0025
Conventional Semi-Trailer	.1322	.0016	.1332	.0022	.1294	.0027
Turnpike Double	.1594	.0017	.1601	.0024	.1623	.0029
Double 27	.1451	.0016	.1450	.0020	.1422	.0025
Triple 27	.1692	.0017	.1671	.0024	.1673	.0029

FFC (Fixed Fuel Coefficient) is in gallons/vehicle-mile
VFC (Variable Fuel Coefficient) is in gallons/payload ton-mile.

In the second step, a fleet mix fuel consumption is determined by estimating the percengage of new technology which creates an average fuel consumption for both the base year and the forecast year. This is described in Section B.4.

The third step develops a weighted average by averaging the fuel consumption coefficients for each state based on the percentage of level, hilly, and mountainous miles given for each state in Reference 4.

The fuel consumption coefficients are further adjusted to account for 1) gasoline or diesel engines, 2) interstate, primary, or secondary highway type, 3) payload size, and 4) whether TL or LTL type shipments. Details are given in the Appendix to the Technical Supplement, Volume 7.

B.4 FLEET MIX

A major influence in aggregate fuel consumption is the fleet mix, the percentage of "standard technology" and of fuel saver vehicles. To estimate fleet fuel consumption, it is necessary to 1) predict the rate of new technology adoption by industry, 2) estimate future truck sales, 3) estimate the rate of attrition, and 4) calculate the fuel savings for each of the applicable scenarios. For 1977, the estimated technology mix was 80 percent standard and 20 percent fuel saver, while in 1985 the projected mix is estimated to be 30 percent standard and 70 percent fuel saver. These line-haul coefficients are presented in Table B-2.

TABLE B-2. FUEL CONSUMPTION COEFFICIENTS FOR 1977 AND 1985 TECHNOLOGY MIXES

1977 TECHNOLOGY MIX (80% Standard, 20% Fuel Saver)

Vehicle	Level Terrain		Hilly Terrain		Mountainous Terrain	
	FFC	VFC	FFC	VFC	FFC	VFC
3-Axle Single Unit	.1420	.0025	.1361	.0027	.1434	.0033
Conventional Semi-Trailer	.1664	.0024	.1622	.0028	.1539	.0034
Turnpike Double	.1902	.0024	.1907	.0030	.1912	.0035
Double 27	.1764	.0024	.1766	.0026	.1732	.0032
Triple 27	.2053	.0023	.2025	.0030	.2011	.0035

1985 TECHNOLOGY MIX (30% Standard, 70% Fuel Saver)

Vehicle	Level Terrain		Hilly Terrain		Mountainous Terrain	
	FFC	VFC	FFC	VFC	FFC	VFC
3-Axle Single Unit	.1228	.0020	.1238	.0023	.1252	.0028
Conventional Semi-Trailer	.1450	.0019	.1441	.0024	.1408	.0030
Turnpike Double	.1752	.0020	.1716	.0026	.1732	.0031
Double 27	.1568	.0019	.1569	.0022	.1538	.0028
Triple 27	.1827	.0019	.1803	.0024	.1780	.0031

FFC (Fixed Fuel Coefficient) is in gallons/vehicle-mile
VFC (Variable Fuel Coefficient) is in gallons/payload ton-mile.

APPENDIX C

COMPARISON OF FUEL ESTIMATES FROM THIS STUDY WITH OTHER SOURCES

C.1 INTRODUCTION

The results of other intercity truck fuel tests and studies are briefly given here. Comparisons of fuel test results and of analytical estimates must be treated with caution because of the necessity to compare equal conditions.* As presented here, the comparisons do offer a rough validation of the absolute fuel estimation method presented in this report. As stated in the report, given the method and sources used, relative fuel changes should be more accurately estimated than absolute fuel consumption. Below are several rough comparisons.

C.2 GENERAL SOURCES

1) The interagency study of Post-1980 Goals for Commercial Motor Vehicles (Reference 1) gives a theoretical value for specific fuel consumption. Based on the fuel consumption equation in that reference, the specific fuel consumption at GCW of 53,000 lb is:

$$SFC = 0.01761 \frac{\text{Gal}}{\text{Ton-Mi}}$$

The equation for 1-45 ft van given by the coefficients in Table A-4 for a payload corresponding to a GVW of 53,000 lb gives a specific fuel consumption value of:

$$SFC = 0.01663 \frac{\text{Gal}}{\text{Ton-Mi}}$$

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*The Transportation Research Board (Reference 2) gives a discussion of qualifications and limitations of fuel estimation methods.

2) The Truck and Bus Panel Report (Reference 3) gives a vehicle mile value of fuel consumption based on 220 trip of Class VII and Class VIII trucks between Chicago and Kansas City for a Tare weight of 13 tons of

$$GPM = 0.177 + 0.0029\ (P)$$

From Table A-4, the equation for 1-45 ft van for level terrain and a 55 mph speed limit is

$$GPM = 0.1776 + 0.0027\ (P)$$

3) The Highway Research Board Bulletin 301 (Reference 4) makes some interesting points. Figure 47 gives test results and straight-line curves computed by least-squares of fuel consumption as a function of weight. This report claims straight-line curves appear to best show the trends.... The equation estimated from Figure 47 is

$$GPM = 0.152 + 0.0028\ (P)$$

Figure 38 gives fuel costs as a function of weight for different terrain. It shows different slope lines for level, rolling, and mountainous terrains with a crossover between level and rolling terrain fuel use at about 60,000 lb AVW. Above that weight, less fuel is used in rolling terrain than on level terrain.

4) Rose (Reference 5) presents several fuel use rates. Included are tables of empty back-haul and circuities of various services. This source states that the best estimate of average fuel efficiency in intercity freight is 4.5 miles per gallon.

If an average payload in conventional semi-trailer vans operating under the 80/18/32 weight limit is 13 tons (Reference 6), then the miles per gallon estimate given by Equation A-1 is 4.7 miles per gallon.

C.3 FIELD TESTING

The DOT/SAE Truck and Bus Fuel Economy Measurement Study is a source of comparison between the fuel prediction method developed in this study and actual field testing. Preliminary comparison indicates reasonable agreement between the field tests and the prediction method. The SAE/DOT Study makes use of instrumented vehicles in regular commercial fleet service to determine fuel consumption in actual operations. The test fleet consists of eight trucks, four Class 6 and four Class 8 vehicles. Within each class there are two trucks, a "standard" vehicle and a "fuel-saver" vehicle, from each of two different manufacturers. The Class 6 trucks are single unit vehicles, and the Class 8 are tractors used with the carrier's trailers in regular operations.

The results are compared by finding the percent difference for each vehicle type between the fuel consumed and service provided as indicated by the trucks logs and the fuel predicted for the corresponding average vehicles and terrain conditions on typical interstate/primary roads.*

Comparison of the fuel predicted by Equation A-1 in Appendix A and results of truck logs indicate fairly close agreement for the standard vehicles. A difference exists between the predicted fuel and the field test field rates for the fuel-saver vehicles. The class 8 comparison is summarized in Table C-1.

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*For each trip, one gallon is added to account for additional fuel use between the carrier terminal and the interstate/primary road. This is consistent with the access fuel method described in the report.

TABLE C-1. COMPARISON OF DOT/SAE TRUCK AND BUS FUEL ECONOMY MEASUREMENT STUDY AND PREDICTION METHODOLOGY

VEHICLE TECHNOLOGY	MFG.	FLEET MPG	PREDICTED MPG	PERCENT DIFFERENCE, PREDICTED FUEL AND ACTUAL FUEL
STANDARD	A	4.35	4.52	3.8%
	B	4.30	4.62	6.9%
FUEL-SAVER	A	5.29	6.01	12.0%
	B	5.40	6.21	13.0%

The differences between the predicted and actual fuel consumptions for the fuel-saver trucks have not been analyzed in detail. General comments which apply are:

1) The prediction method makes no attempt to include inefficient operating techniques, such as length of engine idling, which are occasionally used in practice.

2) The fuel-saver truck in the prediction method is always matched with a fuel saving technology trailer. This is not so in the field tests.

3) The fuel-saver vehicle designed for the prediction method represents an available technology optimization which is intended to present the lowest fuel consumption possible through 1985.

4) The fuel-saver engine in the prediction method shown in this report is a more advanced model that was used in the DOT/SAE test vehicle.

5) For the total distance over which the field tests were run; the environmental conditions should approximate average conditions. However, the variation between the truck in each category and an "average" truck of that category is not known.

C.4 REFERENCES (Appendix C)

1. U.S. Government, Interagency Study of Post-1980 Goals for Commercial Motor Vehicles, U.S. Dept. of Transportation, June 1976 (Draft Report).

2. Transportation Research Board, Energy Effects, Efficiencies and Prospects for Various Modes of Transportation, National Cooperative Highway Research Program, Report No. 43, 1977.

C.4 References (Appendix C)

3. Truck and Bus Panel Report, Study of Potential for Motor Vehicle Fuel Economy Improvement, U.S. Department of Transportation and the U.S. Environmental Protection Agency, January 10, 1975.
4. Highway Research Board, Line-Haul Trucking Costs in Relation to Vehicle Gross Weights, Bulletin 301.
5. Rose, A.B. and Reed, J.K., Energy Intensity and Related Parameters of Selected Modes: Freight Movement, Oak Ridge National Laboratory, ORNL-5554, June 1979.
6. Mergel, J.J., An Investigation of Truck Size and Weight Limits Technical Supplement Volume 1, Report No. DOT-TSC-OST-80-3, U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA, February, 1981 (Table D-4.)