U.S. Department
of Transportation

**Federal Railroad
Administration**

Rail vs. Truck Fuel Efficiency:

The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors

---

Office of Policy

FINAL REPORT

Abacus Technology Corporation
Chevy Chase, Maryland

Moving America

New Directions, New Opportunities

A/RRP-91/2

April 1991

Document is available to the
public through the National
Technical Information Service,
Springfield, VA 22161

Technical Report Documentation Page

1. Report No. FRA-RRP-91-02	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Rail vs Truck Fuel Efficiency: The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors	5. Report Date 6. Performing Organization Code ----------
7. Author(s) Abacus Technology Corporation	8. Performing Organization Report No. ----------
9. Performing Organization Name and Address Abacus Technology Corporation 5454 Wisconsin Avenue, Suite 1100 Chevy Chase, Maryland 20815	10. Work Unit No. (TRAIS) ---------- 11. Contract or Grant No. DTFR-53-90-C-00017
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Policy, RRP-32 Washington, DC 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code Federal Railroad Admin.

15. Supplementary Notes

William Gelston (Chief, Economic Studies Division, FRA), Project Sponsor
Marilyn W. Klein (Senior Policy Analyst, FRA), Project Monitor

16. Abstract

This report summarizes the findings of a study to evaluate the fuel efficiency of rail freight operations relative to competing truckload service. The objective of the study was to identify the circumstances in which rail freight service offers a fuel efficiency advantage over alternative truckload options, and to estimate the fuel savings associated with using rail service. The findings are based on computer simulations of rail and truck freight movements between the same origins and destinations. The simulation input assumptions and data are based on actual rail and truck operations. Input data was provided by U.S. regional and Class I railroads and by large truck fleet operators.

17. Key Words fuel efficiency, rail, truck, ton-miles per gallon, lading weight, payload weight, average speed, horsepower per trailing ton, train performance simulator, vehicle mission simulation	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 152	22. Price -----

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The U.S. Department of Transportation, Federal Railroad Administration has undertaken a study of the fuel efficiency of rail freight operations relative to truck freight operations. This report summarizes the study findings and conclusions. The findings are based on computer simulations of rail and truck freight movements between the same origin and destination locations. The simulation input assumptions and data are based on actual rail and truck operations. Input data was provided by U.S. regional and Class I railroads and by large truck fleet operators. Contributors to the study are listed in the appendix.

FINAL REPORT
TABLE OF CONTENTS

GLOSSARY

I. FUEL EFFICIENCY TERMS

Ton-miles per gallon - A measure of the number of miles one ton of freight can be moved with one gallon of fuel or, conversely, the number of tons that can be moved one mile with a gallon of fuel. In this study, ton-miles per gallon were calculated based on the weight of the freight and fuel required to move the rail car or truck with contents over the specified route.

Fuel efficiency - A relative term which expresses the productive use of fuel. There are several fuel efficiency units of measure. In this study, ton-miles per gallon of fuel was selected as the fuel efficiency unit of measure.

Fuel consumption - In this study, fuel consumption refers to the number of gallons of fuel expended in the process of moving the specified commodity by either rail or truck.

Scenario - A numerical designation affixed to each unique rail and truck configuration studied. Each scenario includes the route, commodity, equipment, speed, and locomotive and car consists.

II. RAIL TERMS

Class I railroad - A railroad with operating revenues of $93.5 million or more in 1989, as classified by the Interstate Commerce Commission. For a carrier to fall into or out of Class I status, it must be above or below the threshold for three consecutive years.*

Class I rail route - In this study, a route which exceeds 100 miles.

Regional railroad - A non-Class I line-haul railroad which operates 350 or more miles of road, and/or which earns revenues of at least $40 million.*

Regional/ local rail route - In this study, a route less than 100 miles.

Local railroad - A railroad which is neither a Class I nor Regional railroad, and which is primarily engaged in providing line-haul service.*

Rail TOFC - Car with flat deck, no sides or roof designed to carry highway truck trailers

Rail Doublestack - A flatcar with a low well designed to carry removable containers loaded two-high

III. TRUCK TERMS

Over-the-Road Service - Movement of a truck trailer over a long distance (greater than 100 miles) from shipper to consignee

Local Service - Movement of a truck trailer over a short distance (less than 100 miles) from shipper to consignee

---

* As defined by the Association of American Railroads

SUMMARY OF FINDINGS

A fuel efficiency study was performed by Abacus Technology for the U.S. Department of Transportation, Federal Railroad Administration (FRA). Rather than attempting to make broad judgments about the relative fuel efficiency of all rail freight versus all truck freight as other studies have done, this study compares the fuel efficiency of rail service with competing truckload service in the same corridors, taking account of the circuity of the routing. Only major rail-truck competitive commodities were compared, and the study anticipated that results would vary according to differing conditions.

The rail fuel efficiency findings are based on simulations using a train performance simulator (TPS). Truck fuel efficiency findings are based on simulations performed with the Cummins Engine Company vehicle mission simulation (VMS) model. Both models are respected for their accuracy and are used extensively by industry. Characteristics of the routes and operating scenarios are defined to reflect real world operating conditions and are simulated separately for rail and truck. The rail scenarios include calculations of fuel used in local rail switching, terminal operations, and truck drayage, as relevant to the move. Parametric analysis is not used in this study.

Additional findings are based on reviews of relevant literature, discussions with equipment operators and manufacturers, and consultations with railroad and motor carrier industry representatives. The study findings are consistent with previous studies reporting the superiority of rail fuel efficiency over truckload service.

FINDINGS

This study analyzes the fuel efficiency of truck and rail freight movement; it does not consider transportation cost, speed of delivery or quality of service. The key findings are:

1. <u>TON-MILES PER GALLON WAS DETERMINED TO BEST MEET THE STUDY REQUIREMENTS FOR A FUEL EFFICIENCY MEASUREMENT</u>.

Ton-miles per gallon is the unit selected to express relative fuel efficiency. To support this selection, 21 previous studies of rail and truck fuel efficiency were examined. From those studies, five candidate units of measure were identified, including:

- Ton-miles per gallon
- Miles per gallon
- BTUs per ton-mile
- Gallons per 40 foot container
- Price per ton-mile.

Ton-miles per gallon was selected because i) it measures the size of the freight as well as the distance moved, ii) it has been used in several previous studies of modal fuel efficiency and iii) it best meets the objectives of this study. The weight of the commodity was used to express the ton-miles per gallon measure. The fuel consumed by the railcar and its contents were used in the ton-mile per gallon calculation. Similarly, the fuel used by the truck with its commodity was used to calculate the commodity ton-miles per gallon for truck.

2. WHERE RAIL IS MORE CIRCUITOUS, THE RELATIVE ADVANTAGE OF HIGHER RAIL TON-MILES PER GALLON IS SOMEWHAT OFFSET.

Circuity was taken into account in each corridor by comparing the amount of fuel consumed in comparable rail and truck runs. For the model runs where rail is more circuitous than truck, the percentage advantage of rail fuel consumed was not as great as the percentage advantage of rail ton-miles per gallon.

3. THE COMPETITIVE FREIGHT MARKET FOR RAILROADS AND TRUCKS INCLUDES 13 MANUFACTURED COMMODITY GROUPS.

A 1989 study by the Association of American Railroads identified 13 commodity groups which represent an important component of the traffic base of both rail and truck. The commodities range from small items, such as canned fruit, to motor vehicles, as shown in Exhibit S-1. These commodities formed the initial basis for definition of the truck competitive rail scenarios.

EXHIBIT S-1
COMMON AND COMPETITIVE COMMODITIES

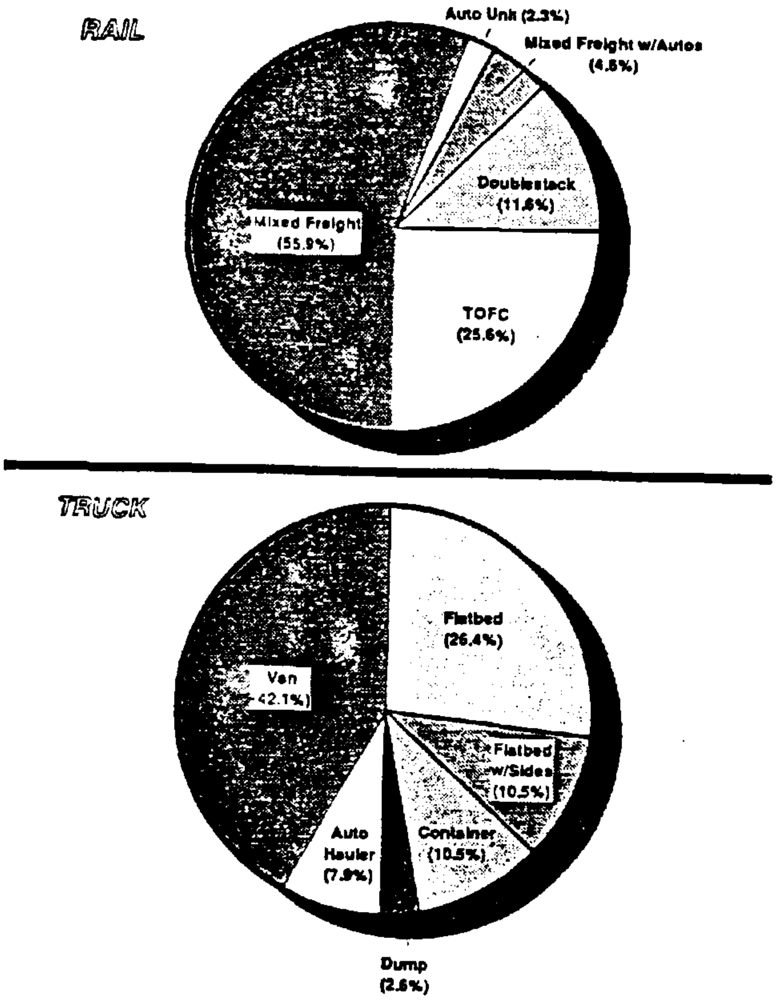
STCC NUMBER	COMMODITY	RANK IN RAIL TON-MILES
203	Canned/Preserved Fruits, Vegetables	12
204	Grain Mill Products	5
208	Beverages or Flavoring Extracts	10
209	Miscellaneous Food Preparations	9
242	Sawmill Products	2
243	Millwork or Prefabricated Wood Products	11
262	Paper	8
281	Industrial Chemicals	3
282	Plastic Materials, Synthetic Fibers	7
289	Miscellaneous Chemical Products	13
331	Steel Works, Rolling Mill Products	6
371	Motor Vehicles or Equipment	4
41-47	Intermodal Traffic	1

Source: Association of American Railroads, 1989. STCC is the Standard Transportation Commodity Code.

4. MIXED FREIGHT TRAINS AND TRUCK VAN TRAILERS ARE THE PREDOMINANT EQUIPMENT TYPES IN THE STUDY.

Mixed freight trains and truck van trailers are the predominant equipment types in use. As shown in Exhibit S-2, these two equipment types also dominate the scenarios selected for this study. The most prevalent advanced equipment in current use was selected for the scenarios. For trucks, this included the frequent use of 48-foot truck trailers with a large carrying capacity, aerodynamic aids to lessen truck fuel consumption and an advanced, commonly used truck engine. Rail double-stacked containers and, in some scenarios, updated locomotives are among the rail innovations used.

EXHIBIT S-2
EQUIPMENT TYPES AS A PERCENT OF ALL STUDY SCENARIOS



5. RAIL ACHIEVED HIGHER TON-MILES PER GALLON THAN TRUCKS IN ALL SCENARIOS.

Although the scenarios in this study represent examples of a range of types of comparable freight services and cannot be averaged, all rail equipment achieved higher ton-miles per gallon than truck equipment, as shown in Exhibit S-3. Rail achieved from 1.4 to 9 times more ton-miles per gallon than competing truckload service. Rail fuel efficiency ranged from 196 to 1,179 ton-miles per gallon while truck fuel efficiency ranged from 84 to 167 ton-miles per gallon.

The extent of track grade and curvature and train resistance (including such factors as rolling and flange resistance) are major contributors to rail fuel efficiency. Lading weight, horsepower per trailing ton and train speed also influence fuel efficiency. Generally, higher speeds adversely affect fuel efficiency.

6. RAIL TON-MILE RANGES ARE CONSIDERABLY LARGER THAN THE TRUCK RANGES.

As shown in Exhibit S-3, there is a wide range of values for most train types while the truck ton-mile ranges are comparatively narrow. Compared to truck scenarios, the rail scenarios use varying horsepower per trailing ton and varying speeds and a variety of locomotives, while only one truck engine, the Cummins 350, was selected for all truck simulations. These factors contribute to the range differences. Three Class I railroads provided energy consumption data for various scenarios to Abacus Technology for analysis and compilation. Although the TPS models they used are basically the same, they may possess some minor variations. However, strong efforts were made to assure that consistent variable values were assumed in all cases. For example, the same railcar and locomotive frontal areas were assumed for each model execution. Thus, differences attributable to the models were minimized as much as possible. The Cummins VMS simulates Cummins truck engines only, and the 350 was selected as best meeting the requirements of all the study scenarios.

7. RAIL ACHIEVED HIGHER TON-MILES PER GALLON THAN TRUCK IN EVERY EQUIPMENT CATEGORY FOR CLASS I/OVER-THE-ROAD SERVICE.

Exhibit S-4 summarizes train and truck equipment types and ton-miles per gallon for the Class I/over-the-road scenarios with routes over 100 miles long. The findings for different equipment are:

EXHIBIT S-3
RANGE IN TON-MILES PER GALLON BY EQUIPMENT TYPE
(All Scenarios)

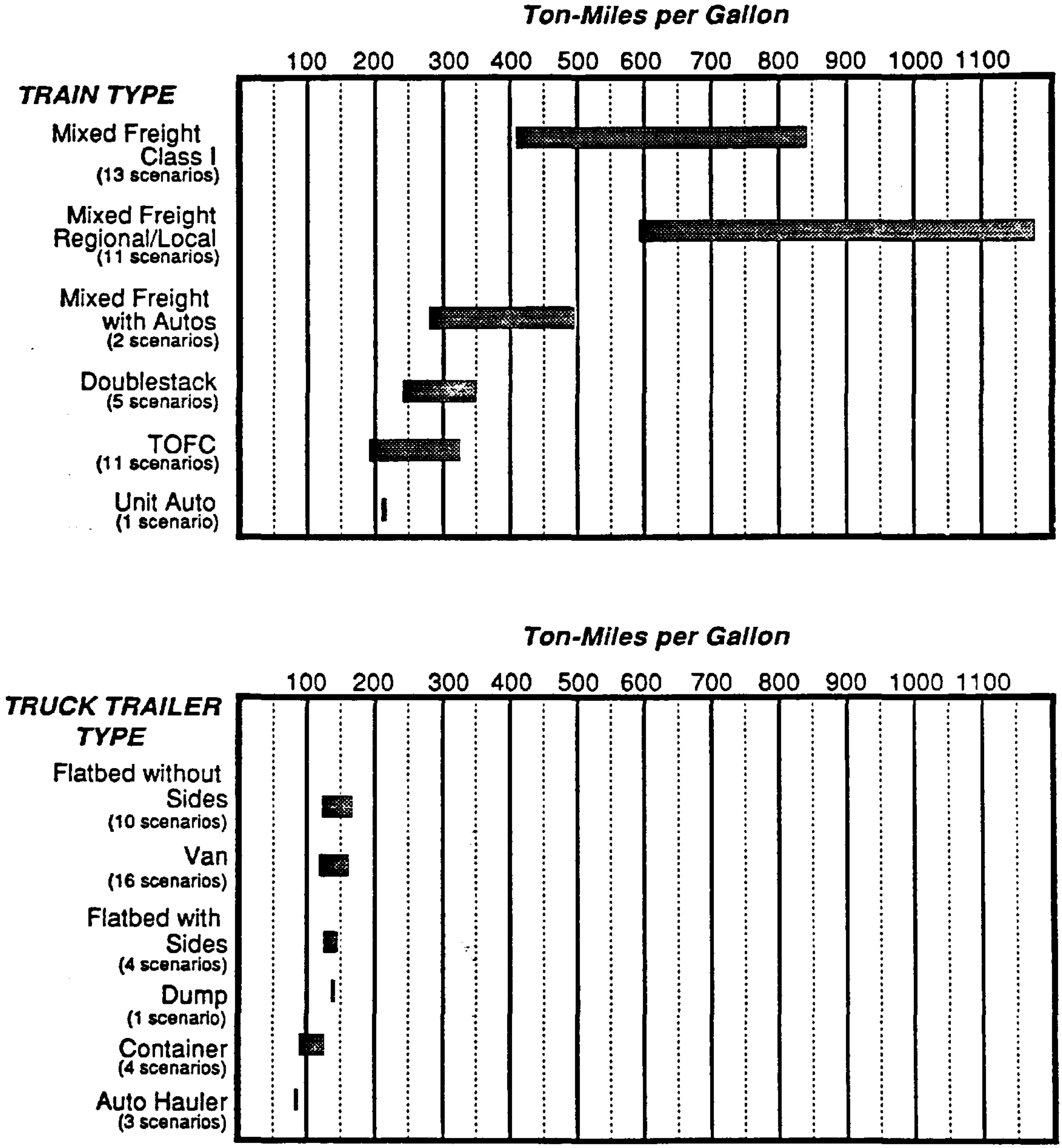


EXHIBIT S-4
FUEL EFFICIENCY BY EQUIPMENT TYPE
FOR CLASS I/OVER-THE-ROAD SCENARIOS (OVER 100 MILES)

TRAIN TYPE	FUEL EFFICIENCY (FE) RANGE (TMI/G)	TRUCK TYPE	FUEL EFFICIENCY (FE) RANGE (TMI/G)	RAIL/TRUCK FE RATIO RANGE
Mixed Freight		Flatbed Trailer		
	471 - 843	- Without Sides	141 - 167	2.82 - 5.51
	414 - 688	Van Trailer	131 - 163	2.96 - 5.25
Mixed Freight with Autos	279 - 499	Auto Hauler	84 - 89	3.32 - 5.61
Double-stack	243 - 350	Container Trlr.	97 - 132	2.51 - 3.43
TOFC		Flatbed Trailer		
	229	- Without Sides	133	1.72
	240	- With Sides	147	1.63
	196 - 327	Van Trailer	134 - 153	1.40 - 2.14
Unit Auto	206	Auto Hauler	86	2.40

Rail: TOFC - Trailer-on-Flatcar

- Rail Mixed Freight Achieved the Highest Level of Ton-Miles per Gallon. The rail mixed freight trains achieved both the highest level and the widest range in ton-miles per gallon. The highest ton-mile per gallon values were obtained using trains with lower average speeds. In addition, lower horsepower per trailing ton and favorable aerodynamics are also factors in rail mixed freight fuel efficiency.

- Rail double-stack and TOFC achieve the third and fourth highest ton-miles per gallon on the Class I routes. The lower aerodynamic drag of rail double-stack, set in a well, compared to rail TOFC contributes to the double-stack's better fuel efficiency. As shown in Exhibit S-4, rail TOFC achieves the lowest rail to truck fuel efficiency ratio of 1.40. Double-stack competes directly with truck container trailers and is 2.51 to 3.43 times more energy-efficient than comparable truck moves.

8. RAIL MIXED FREIGHT ACHIEVED HIGHER TON-MILES PER GALLON THAN ALL TRUCK EQUIPMENT CATEGORIES IN THE REGIONAL/LOCAL SCENARIOS.

Exhibit S-5 summarizes the fuel efficiency of different equipment types simulated on regional/local routes under 100 miles long. Only rail mixed freight trains were assumed on these routes. The range of rail mixed freight ton-miles per gallon and the rail/truck fuel efficiency ratios show better ton-miles per gallon than the competing truckload service. Including all the truck equipment types in Exhibit S-5, the rail mixed freight achieved ton-miles per gallon from 4.03 to 9.00 times greater than truck. The lower average speed of the rail mixed freight contributed to the higher fuel efficiency performance.

IN REGIONAL & LOCAL MOVES

EXHIBIT S-5
FUEL EFFICIENCY BY TRAIN TYPE FOR REGIONAL/LOCAL SCENARIOS (UNDER 100 MILES)

TRAIN TYPE	FUEL EFFICIENCY (FE) RANGE (TMI/G)	TRUCK TYPE	FUEL EFFICIENCY (FE) RANGE (TMI/G)	RAIL/TRUCK FE RATIO RANGE
Mixed Freight		Flatbed Trailer		
	596 - 890	- Without Sides	148 - 150	4.03 - 5.93
	641 - 1,104	- With Sides	135 - 148	4.51 - 7.77
	625 - 1,179	Van Trailer	131 - 140	4.46 - 9.00
	619	Dump Trailer	144	4.30

9. THE TRUCK FLATBED WITHOUT SIDES TRAILER ACHIEVED THE HIGHEST TON-MILES PER GALLON OF THE TRUCK TRAILERS.

The truck flatbed without sides trailer achieved a high of 167 ton-miles per gallon. The truck van trailer achieved the next highest truck fuel efficiency of 163 ton-miles per gallon.

10. TRUCKS WITH THE HIGHEST PAYLOAD ACHIEVED THE HIGHEST TRUCK TON-MILES PER GALLON.

All trucks were assumed to operate with the Cummins 350 engine. Trucks hauling high payload weights exhibited a higher average level of ton-miles per gallon than trucks with low payload weights. As shown in Exhibit S-6, the average ton-miles per gallon for trucks carrying 24 tons is 4 percent greater than for trucks carrying 23 tons. Similar improvements in ton-miles per gallon are noted for all the truck payload weight categories.

EXHIBIT S-6
TRUCK PAYLOAD WEIGHT IN RELATION TO TON-MILES PER GALLON

PAYLOAD WEIGHT (TONS)	NUMBER OF SCENARIOS	AVERAGE FUEL EFFICIENCY (TMi/G)
24	11	154
23	2	148
22	13	141
21	5	132
20	1	131
15	6	93
	38	

11. THE MOST GALLONS OF FUEL ARE SAVED ON THE LONGEST ROUTES.

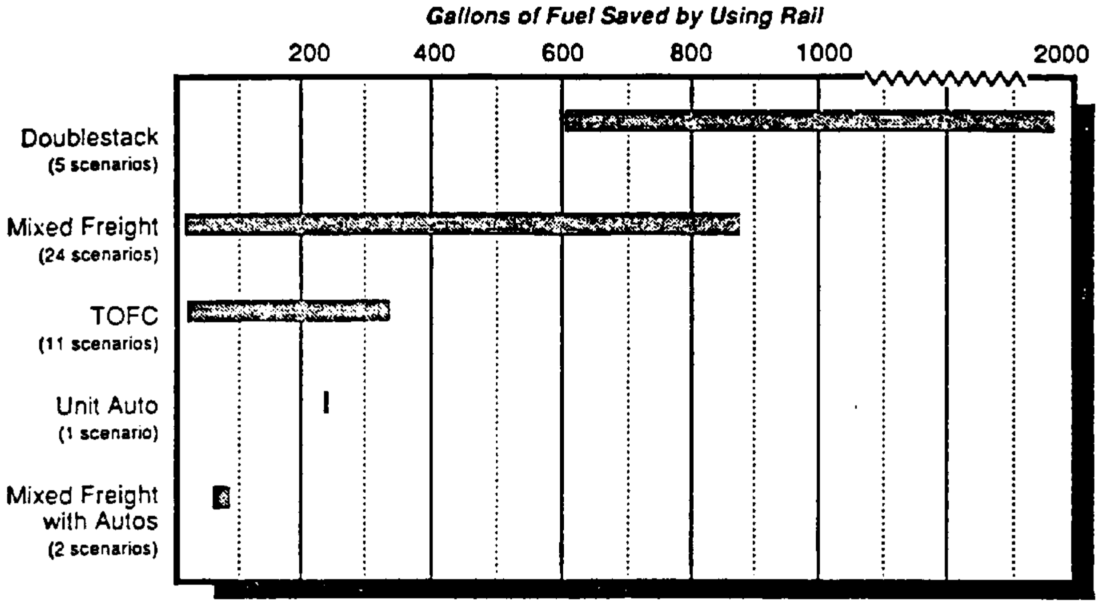
The most fuel efficient train in terms of ton-miles per gallon does not necessarily contribute the highest fuel savings in comparison with truck service. Obviously, the longer the route distance the greater the rail gallons of fuel saved. As the route extends, the difference between rail and truck fuel consumption is greater because of rail's fuel efficiency. The amount of fuel saved per carload using rail ranged from 7 gallons on a small local route of 22 rail miles to 1,965 gallons on a 1,891-mile rail route.

The long distance moved, combined with heavy lading of the double-stack cars which carry 10 containers on each car, results in considerable fuel savings--ranging from 602 to 1,965 gallons. To move the equivalent lading requires 10 trucks. As shown in Exhibit S-7, the next highest levels of fuel savings were with the rail mixed freight and the rail trailer-on-flatcar (TOFC). Exhibit S-8 presents a graphic comparison of fuel saved using rail by equipment type.

EXHIBIT S-7
RANGE OF FUEL SAVED BY RAILCAR TYPE FOR ALL STUDY SCENARIOS

RAILCAR TYPE	FUEL EFFICIENCY RANGE (TON-MILES/GALLON)	RANGE OF FUEL SAVED PER RAILCAR (GALLONS)	DISTANCE RANGE (MILES)
Double-stack	243 - 350	602 - 1,965	778 - 2,162
Mixed Freight	414 - 1,179	7 - 875	261 - 2,162
Trailer-On-Flatcar	196 - 327	11 - 338	251 - 2,162
Auto Unit Train	206	234	1,799
Mixed Freight/Auto	279 - 499	51 - 86	343 - 579

EXHIBIT S-8
RANGE OF GALLONS SAVED BY USING RAIL FOR ALL STUDY SCENARIOS



12. COMPARING A FULL TRAIN TO A COMPARABLE NUMBER OF TRUCKS, FUEL SAVINGS WITH RAIL WOULD BE SUBSTANTIAL.

Although this study did not focus on fuel savings of a trainload of freight versus the same commodities carried by truck, such a comparison is useful. For example, a 34 car TOFC unit train carrying 1,360 tons of commodity over a 1,007-mile rail route saves 3,555 gallons of fuel. A 26 car double-stack unit train carrying 3,900 tons of commodity over a 778-mile distance saves 15,652 gallons of fuel.

13. THE USE OF MORE ADVANCED EQUIPMENT AND CHANGES IN CARRYING CAPACITY REGULATIONS HAS RESULTED IN BETTER FUEL EFFICIENCY FOR BOTH RAIL AND TRUCK.

Greater allowable payload weight, more efficient engines and improved aerodynamic aids and features has contributed to better truck fuel efficiency compared with previous decades. Rail has realized improvements through more efficient locomotives, more aerodynamic and lighter car design and even better lubricants for the track itself to decrease the effects of friction.

* * * * *

In summary, Class I/over-the-road and regional/local rail and truck service scenarios were analyzed. Rail fuel efficiency (ton-miles per gallon) for the scenarios studied ranged from 196 to 1,179 ton-miles per gallon. Truck fuel efficiency ranged from 84 to 167 ton-miles per gallon. Where rail is more circuitous, the relative advantage of higher rail ton-miles per gallon is somewhat offset. However, there are some scenarios where rail circuity does not explain the difference between the fuel efficiency ratio and the fuel consumption ratio. In these scenarios, factors such as average speed, terrain, equipment types and aerodynamics may influence the relationship between these ratios. The next chapter describes the objectives, scope and methodology of this investigation.

1.0 INTRODUCTION

The Federal Railroad Administration requested a study of the fuel efficiency of rail freight operations relative to competing truckload service. The goal of the study was to identify the sets of circumstances in which rail freight service offers an advantage in terms of fuel efficiency over alternative truckload options, and to estimate the fuel savings associated with using rail. In previous studies, researchers have noted the futility of developing a single number to depict rail energy intensiveness and have pointed out that the individual circumstances for each run must be considered. This report, by looking at specific routes, equipment and loads, attempts to satisfy the need for route-specific analysis.

The study was executed in four tasks. The first task entailed research to identify the fuel economy improvements in rail and truck technology that have occurred since the 1970s. The second task involved developing rail service scenarios and estimating rail fuel efficiency for those scenarios. In the third task, the fuel efficiency of competing truckload service was calculated and compared to rail service. This final report combines the work performed in Tasks 1, 2 and 3.

This introductory chapter is organized into three sections as follows:

- Project objectives
- Project scope
- Project methodology.

Each topic is discussed below.

1.1 PROJECT OBJECTIVES

The principal objective of this study is to determine the fuel efficiency of rail vs. truck freight service. The work was accomplished in three tasks. Specific objectives of each task are detailed below.

- The objective of Task 1 was to develop an information base relevant to the comparative analysis of rail and truck fuel economy. This information base supported the subsequent work in the project, particularly the evaluation of the differences in rail fuel efficiency by type of service.

- The objective of Task 2 was to evaluate fuel consumption for a broad range of rail freight services. Specific objectives were to determine the best unit of measure for comparing the fuel efficiency of rail and truck services, to identify key rail-shipped and truck competitive types of traffic and to evaluate fuel efficiency for a range of rail freight services, including but not limited to short hauls and long hauls, rail intermodal shipments and key rail-shipped and truck-shipped competitive commodities. Rail fuel use included estimates of fuel consumption for rail switching, rail terminal operations and truck drayage, as relevant to the move.

- The objective of Task 3 was to evaluate fuel consumption for a range of truck freight services. Specific objectives included evaluating fuel consumption for the types of combination trucks and operations performing intercity truckload services, comparing rail and truck fuel efficiencies across the range of freight services examined in Task 2, identifying the general situations or sets of circumstances in which rail freight service offers an advantage over the truck alternative and estimating the approximate fuel or energy savings associated with using rail in those situations.

1.2 PROJECT SCOPE

The scope of the project included rail and truck operations providing intercity freight services of rail-truck competitive commodities. Rail operations include short haul and long haul, intermodal shipments, cars carrying double-stacked containers, conventional freight cars and an auto unit train. Truck operations include short haul and long haul and a variety of truck trailer types. The freight operations scenarios are simulated for a range of topographies, from mountainous areas to plains and low swampy regions.

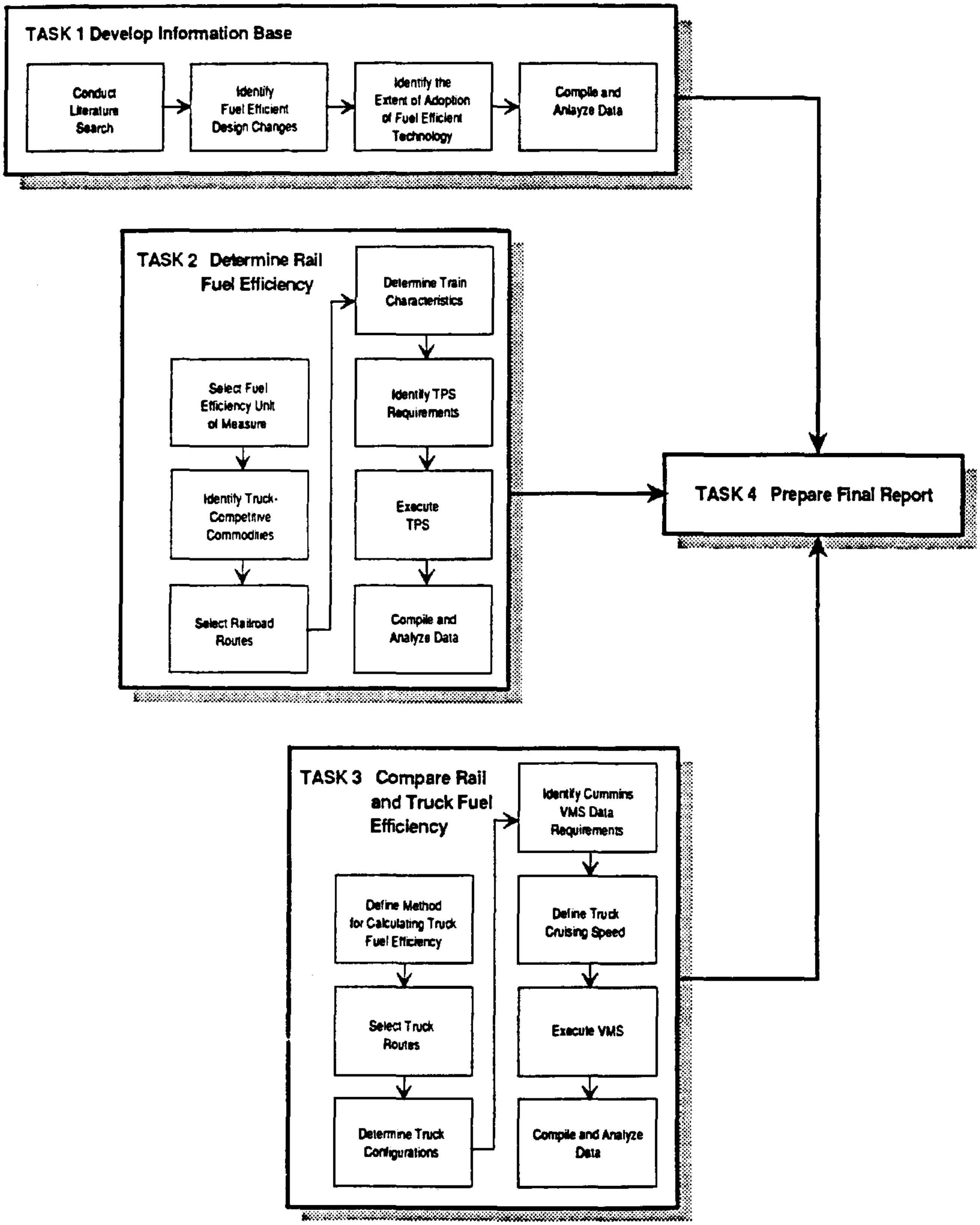
1.3 PROJECT METHODOLOGY

A graphic depiction of the project methodology is presented in Exhibit 1-1. Highlights of some of the key elements of the methodology are presented below.

1.3.1 Identify Truck-Competitive Commodities

The market segment that is competitive between truck and rail was identified by means of commodity studies performed by the Association of American Railroads (AAR). Each competitive commodity selected represents at least one percent of rail traffic and one percent of long-haul truck traffic.

EXHIBIT 1-1
OVERVIEW OF STUDY METHODOLOGY



1.3.2 Select Railroad Routes

Several steps were involved in determining which railroad routes would be used for the study. First, a railroad network map with projected traffic patterns[1] was analyzed to identify rail corridors that carry a relatively heavy volume of one or more of the competitive commodities. Based on this analysis, several candidate routes were identified for each Class I railroad. The final routes were selected through joint discussion between Abacus Technology, the FRA and cooperating railroads. All the selected routes are truck-competitive for the commodities specified.

1.3.3 Determine Train Characteristics

Once the routes were selected, work proceeded on defining the characteristics of the trains to be run on each route. The FRA required that the trains must be representative of real-world freight traffic and must incorporate locomotives, consists and other train characteristics typical for each railroad. Accordingly, the director of transportation, the area dispatcher, and/or a field engineer for each railroad was consulted in structuring the trains to reflect actual train traffic.

1.3.4 Identify TPS Data Requirements

A train performance simulator (TPS) or train performance calculator (TPC) is a computer program which simulates the operation of a train over a railway route. It has become a useful tool for many of the larger railroads which have run simulations to support their in-house analysis needs.

The TPS used by Abacus Technology was originally developed by the Missouri Pacific Railroad (MP) for its own use, and was validated with operating data from MP freight traffic. The TPS was adapted for use by the Federal government for fuel efficiency studies in the 1970s and is now in the public domain. The program has been adapted to run on a microcomputer.

Abacus Technology worked with the TPS model to identify the data requirements and realistic assumptions required to establish the profiles of rail freight service.

1.3.5 Define TPS Assumptions

The key assumptions for TPS execution are the mathematical

---

[1] Railroad Freight Traffic Flows Projected for 1990, U.S. Department of Transportation, Federal Railroad Administration, December, 1980.

resistance equation and coefficients used for the simulation runs. Abacus Technology consulted with the participating railroads in selecting the most appropriate TPS assumptions. In addition, standard fuel of reasonable quality and clear weather and dry track conditions were included in the basic operating assumptions.

Three Class I railroads executed versions of the TPS and provided the output to Abacus Technology for compilation and analysis. Care was taken to standardize resistance equation coefficients and other variables as much as possible to ensure model consistency and consequent data integrity. The data compilation phase involved analyzing the results of the TPS runs from Abacus Technology and from the participating railroads. Exhibits were prepared to summarize the data and support the task findings.

1.3.6 Define Method for Calculating Truck Fuel Efficiency

The unit of truck fuel efficiency is ton-miles per gallon; all truck movements are assumed to move directly from shipper to consignee. The method selected for calculating comparative fuel consumption is to determine the number of trucks required to move one railcarload of commodity.

1.3.7 Select Truck Routes

The truck routes are defined to parallel the rail routes but some differences exist between the two.

- Definition of Truck Routes. The first step in determining the truck routes was to identify the most direct route between each specified origin and destination city. The routes were confined to interstate highways and primary roads. The next step was to compare the estimated truck routes with the routes in the truck simulation model, the Vehicle Mission Simulator (VMS) owned by Cummins Engine Company. In cases where the estimated routes were not contained in the Cummins VMS, routes similar in topography and distance were selected and substituted by Cummins.

- Differences Between Routes. The rail route distance differs from the truck route distance in most scenarios. When necessary, Cummins used a route optimization program to assist in the determination of the shortest distance between alternative routes. Minimization of driving time was also factored into truck route selection. In some cases, a longer route via interstate highway results in a shorter driving time than would travel over other routing.

1.3.8 Determine Truck Configurations

Once the routes were selected, work proceeded on defining the characteristics of the trucks to be run on each route. Traffic and operations managers of truck fleets were consulted in defining the truck sizes, payload weights and equipment characteristics. Representatives of the Cummins Engine Company recommended some modifications to the configuration assumptions. Also, Mr. Ron Weiss, former owner and operations manager of the Maryland Transportation Company, reviewed all truck configuration assumptions.

1.3.9 Identify Cummins VMS Data Requirements

The VMS (Vehicle Mission Simulator) is a computer model which simulates the operation of a truck over a specified route. Cummins uses the VMS to support its dealerships in customizing truck engine characteristics to customer requirements.

1.3.10 Define Truck Cruising Speed

One of the inputs to the model is average truck cruising speed. An average cruising speed of 60 miles per hour was recommended by Cummins as representative of typical truck operations. The speed limit for trucks in many states is currently set at 65 mph, while in others it is 60 mph. A few interstate highways, such as the Pennsylvania turnpike, still retain a 55 mph speed limit.

1.3.11 Define VMS Assumptions

The key assumptions for VMS execution are the truck configurations and the routes to be driven. Clear weather with no wind and dry road conditions and use of standard fuel of reasonable quality were assumed to exist. A fuel conscious driver is assumed to be driving each truck.

1.3.12 Compile and Analyze Data

Once the assumptions were determined, the computer runs were executed and the output reports were printed. The data compilation phase involved analyzing the results of the VMS runs. Exhibits were prepared to summarize the data and support the task findings.

* * * * *

This investigation of the fuel efficiency of rail freight operations relative to competing truckload service is based on actual fleet operating data for both modes. Activities performed to analyze the comparative fuel efficiency of rail vs. truck service included a literature search of previous fuel efficiency studies, identification of rail and truck competitive commodities, development of rail and truck service scenarios and execution of two computer simulation models. The next chapter describes the changes in rail and truck equipment/operations that have contributed to improved fuel economy in the last 15 years.

2.0 CHANGES IN RAIL AND TRUCK EQUIPMENT/OPERATIONS THAT HAVE CONTRIBUTED TO IMPROVED FUEL ECONOMY

This chapter describes the types of technology changes to improve fuel economy that have occurred in rail and truck operations since the 1970s. The chapter is organized into five sections as follows:

- Locomotive design changes
- Rail equipment design changes
- Truck equipment design changes
- Rail operations changes
- Truck operations changes.

Each is discussed below.

2.1 LOCOMOTIVE DESIGN CHANGES

Design improvements have been incorporated into successive series of locomotives, with each new model containing greater levels of fuel economy improvement. These design changes are made on an evolutionary basis and work in concert to improve overall locomotive fuel efficiency. Locomotive fuel economy improvements have been added in the areas of the engine, auxiliary systems and rail lubrication as described in the following paragraphs.

2.1.1 Engine Modifications

Engine modifications include changes made to regulate the amount of air and fuel flow into the engine, thereby improving the overall combustion capability and efficiency of the locomotive. These modifications include:

- Increasing the size of the turbocharger, injector plunger and/or piston stroke to more precisely match the tractive effort requirements of today's higher horsepower (i.e., 3,000+) locomotives

- Adjusting the throttle control positions to allow locomotives to be run at lower idling speeds (i.e., 200-250 rpm's versus 450 rpm's).

Manufacturers and fleet operators agree that these changes have contributed significantly to improved rail fuel economy.

2.1.2 Auxiliary System Modifications

Auxiliary system modifications reduce the auxiliary load (i.e., engine output for operating locomotive machinery such as compressors, fans, motors and blowers), thereby increasing the tractive horsepower available for actually pulling the train. Modifications made since the 1970s include:

- Sizing the radiator fans, equipment blowers and air ducts to conserve energy by reducing the demand on cooling system auxiliaries
- Converting the mechanically-driven cooling and dynamic braking system auxiliaries to operate electrically so that their power supply can be generated while the engine is idling rather than running at high speed
- Adding a clutch to the air compressor drive shaft, enabling it to be turned off whenever the auxiliary air system is not needed (typically 95 percent of the time)
- Upgrading the traction motor together with improved wheel slip detection devices to achieve higher locomotive-rail adhesion levels and to provide for faster train acceleration as well as reduced time on grades
- Installing a microprocessor control system that continuously monitors and automatically adjusts the locomotive's electrical component settings in order to maximize engine performance and minimize unnecessary shutdowns.

Exhibit 2-1 shows how the various engine and auxiliary system modifications have been incorporated by General Electric (GE) and General Motors-Electromotive Division (GM-EMD) into their locomotive product lines since 1977. The exhibit also shows that the latest models of locomotives produced by these manufacturers (i.e., GE's -8 and GM-EMD's -60 models) have each achieved estimated average fuel savings of 16 percent over earlier models (i.e., GE's -7 and GM-EMD's -50 and -40-2 models).

2.1.3 Wheel Lubrication Changes

Another relevant locomotive technology/design improvement concerns the installation of flange lubricators. These devices apply a lubricant (e.g., grease, oil, graphite) between the flange of a locomotive's driving wheel and the rail in order to reduce the rolling resistance of the train. This product has been on the market since 1984 and has been estimated by one of its manufacturers, Technical Service Marketing, to provide a reduction in fuel consumption ranging from 5 to 10 percent. Several railroads support this claim by estimating that the flange lubricators have resulted in a fuel savings of approximately 7 percent. However, estimates of fuel economy benefits vary. One railroad reports a 12 percent improvement in

EXHIBIT 2-1
RECENT TECHNOLOGY ADVANCES IN LOCOMOTIVES

Make and Model of Locomotive	GE		GM-EMD		
	-7	-8	-40-2	-50	-60
Years Available	1977-1984	1985-present	1977-1979	1980-1984	1985-present
Technology/Design Improvements					
• Engine Modifications					
- Sizing turbochargers, injectors & piston strokes	●	●	●	●	●
- Adjusting throttle control positions	●	●	●	●	●
• Auxiliary System Modifications					
- Sizing fans, blowers & air ducts	●	●		●	●
- Converting mechanical systems to electrical drives	●	●		●	●
- Adding air compressor clutches		●			●
- Upgrading traction motors/ wheel slip detectors		●			●
- Installing microprocessor control systems		●			●
Estimated Fuel Economy Benefits (using initial 1977 units as a baseline)	12%	16%	3%	13%	16%

SOURCE: General Electric and General Motors - Electromotive Division, respectively.

fuel efficiency due to the use of flange lubricators, while another railroad states that the flange lubricators have not provided any significant fuel economy benefits.

2.2 RAIL EQUIPMENT DESIGN CHANGES

Recent advances in rail equipment design include changes in the car body and in car components. Exhibit 2-2 summarizes the advances in rail equipment design that contribute to improved fuel efficiency. The exhibit also identifies representative manufacturers of the design improvement, the date it was first available and the expected fuel economy benefits. The improvements are discussed below.

2.2.1 Car Body Changes

Two new intermodal car designs were developed in the mid-1980s which provide fuel efficient alternatives to the conventional flatcar used for TOFC/COFC[1] service. These new railcars, which are being produced by Thrall Car Manufacturing Co., Trinity Industries Inc. and Gunderson, include:

- The well car for double-stack container operation
- The spine car for single level transport of containers or trailers.

Both of these intermodal cars feature lightweight, articulated designs and more uniform, aerodynamic loading configurations (e.g., shorter and narrower platforms). Furthermore, they are estimated to provide a significant fuel savings for linehaul service, ranging from 15 to 20 percent depending on the quantity of goods being shipped.

2.2.2 Component Changes

Four major changes in railcar component design have been made to help reduce the rolling resistance of the train. Specifically, these component changes include:

- Air Foils. The new air foils are for use on hopper cars and gondolas. These fiberglass structures can be applied to the tops and sides of the railcars to provide them with a smoother, more aerodynamic shape which reduces wind resistance. Aero Transportation Products has held the license to manufacture this

---

[1] Trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) are types of intermodal service.

EXHIBIT 2-2
SUMMARY OF RECENT TECHNOLOGY ADVANCES IN RAILCAR DESIGN

Technology/Design Improvement	Representative Manufacturers	First Year of Availability	Estimated Fuel Economy Benefit*
<u>Car Body Changes</u>			
• Well Car	Thrall Car Mfg. Co., Trinity Industries Inc. Gunderson	1985	15-40%
• Spine Car	Thrall Car Mfg. Co., Trinity Industries Inc. Gunderson	1986	15-40%
<u>Component Changes</u>			
• Air Foils	Aero Transportation Products	1985	14-17%
• Framebrace Trucks	Standard Car Truck Co.	1986-87	8.5%
• Bearing Seals	Timken Co.	1990	2-3%

* Fuel economy benefits estimated by product manufacturer.

product since 1985, and estimates its fuel savings capability at 14 to 17 percent.

- Framebrace Railcar Trucks. These trucks are for use on high mileage railcars. The framebrace truck is designed to be "self-steering" and includes an additional crossbar to maintain better axle alignment and reduce wheel slippage while the train is moving around curves. Standard Car Truck Co. began manufacturing this product in the 1986 to 1987 timeframe and expects it to improve fuel efficiency by 8.5 percent.

- Bearing Seals. An estimated 2 to 3 percent fuel savings is expected from these bearing seals because they reduce friction on the car axle journal bearings.

Timken Company is the sole manufacturer of these bearing seals which are due on the market before the end of 1990. They are suitable for all types of railcars.

- Lighter Weight Equipment. Fuel savings are being realized through use of lighter weight equipment such as aluminum, fiberglass and lighter weight steel cars. These cars have good handling capability without sacrificing the strength and durability of older models.

2.3 TRUCK EQUIPMENT DESIGN CHANGES

There have been a number of changes in truck equipment design in recent years that have contributed to improved fuel economy. As shown in Exhibit 2-3, truck technology improvements have been introduced almost continuously since the mid 1970s. These improvements can be categorized into two areas:

- Engine and auxiliary improvements
- Trailer improvements.

The specific technology changes and how they contribute to improved truck operating efficiency are described below.

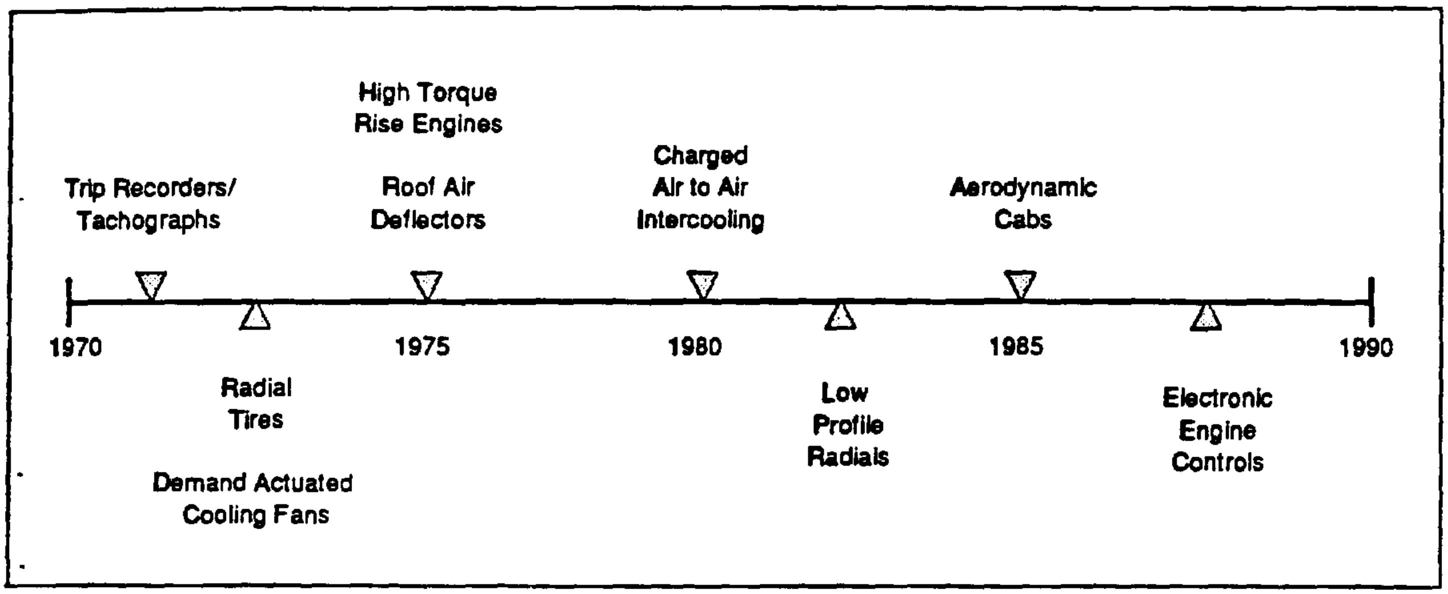
2.3.1 Engine and Auxiliary Improvements

Improvements in truck engines include the addition of electronics for better engine control, changes in engine cooling procedures, the widespread use of high torque rise engines and trip recorders.

- Electronic Engine Controls. The greater use of electronics in truck engines offers more precise engine management and operating control. Within the past year Detroit Diesel, Cummins and Caterpillar have offered their own versions of advanced, fully electronic controlled engines, which promise to enhance operating efficiency and provide diagnostic capabilities. Added capabilities include tracking fuel consumption, idling time, average speed/rpm's, number of stops, occurrences of over-revving and overall driving/operating characteristics. Electronic warning and prevention systems alert drivers of poor driving technique or engine malfunctions and have the ability to shut down the engine in the event the driver does not correct the situation in a given amount of time. The engine's operating information for a given trip can be downloaded onto a computer and analyzed in detail.

- Electronic Fuel Controls. Improved fuel control capabilities include more precise fuel flow metering and electronically activated fuel pumps and injectors. Programmable speed governing also assists in controlling fuel consumption.

EXHIBIT 2-3
TRUCK DESIGN CHANGE INTRODUCTION DATES



- Demand Actuated Cooling Fans. Demand actuated cooling fans are utilized only when needed, thereby reducing their energy requirements. Electrically operated models and the use of various fan clutching mechanisms allow demand actuated fans to operate at a fraction of the time that conventional fixed cooling fans operated. Horton Industries and Kysor Industrial Corporation are large suppliers of cooling fans and fan clutches. Both companies emphasize fuel is saved as a result of the fan operating at only 5 percent of the time on average. Manufacturers Caterpillar, Navistar and Peterbilt began installing these fans during the mid 1970s, and report fuel savings estimates between 3 and 4 percent with their use, as compared with trucks equipped with fixed cooling fans.

- Charged Air-to-Air Intercooling. Charged air-to-air intercooling enhances fuel economy and reduces exhaust emissions by improving engine combustion efficiency. It works by reducing the temperature of intake air, resulting in a more dense volume of air being forced into the cylinder which leads to more complete combustion. Manufacturers introduced charged air-to-air intercoolers during the early 1980s. Caterpillar claims a 1/2 to 1 mpg improvement in fuel mileage and Peterbilt estimates a 1 to 2 percent improvement with the use of these compared with non-intercooled turbocharged diesels.

- High Torque Rise Engine. This type of engine is capable of generating increased torque capacity while operating at relatively low rpm's. This is accomplished by various design changes to the engine. These include increasing the turbo efficiency and calibrating the fuel system at lower rpm's in order to increase the fuel/air mixture and bringing up the torque without significantly increasing engine speed. Fuel savings are most apparent when operating cross-country over hilly terrain. The engine's torque remains high when approaching inclines, with little or no downshifting of the gears thus resulting in a lower level of required rpm's.

- Trip Recorder. A trip recorder/tachograph is an electronic device used in the cab to automatically record operating data such as miles driven, average speeds, number of gear shifts, average rpm's, time spent in each gear and rpm range, number of starts/stops plus other trip-related factors. Most of these functions are incorporated in the new electronic engine controls that have been recently introduced.

2.3.2 Truck Body and Trailer Improvements

Truck body and trailer improvements include more aerodynamic truck body designs, the use of enhanced radial tires and auxiliary sources of cab heat.

- Aerodynamic Streamlining. Trucks have been using roof air deflectors since the mid 1970s in order to minimize air resistance encountered over the cab and in front of the trailer. In the mid 1980s, the extensive streamlining of trucks was introduced. Today's fully integrated, aerodynamic designs incorporate full roof fairings, smooth wrap-around bumpers, sloped hoods, side panels covering up the fuel tanks, cab-side extenders and reduced distance between the rear of the tractor and the front of the trailer. Manufacturers' estimates of the fuel savings achievable with the use of fully aerodynamic designed cabs over conventional cab designs vary from 5 to 20 percent. Mack Trucks indicates a 5 to 8 percent improvement, Navistar suggests a 12 to 13 percent gain, while Peterbilt suggests a 15 to 20 percent overall improvement in fuel economy.

- Radial Tires. Most trucks have been operating on radial tires since the mid 1970s. Radials provide more fuel efficiency than bias-ply construction by reducing rolling resistance. Rolling resistance contributes to excessive heat build-up, shortening the life of the tire. Today, bias-ply constructed tires are mainly limited to use on heavy construction equipment. Truck manufacturers Mack Truck, Navistar and Peterbilt indicate estimated fuel economy savings between 4 and 7 percent with the use of conventional radial tires over bias-ply on their long haul truck equipment in the early 1980s.

- Low Profile Radial Tires. An enhanced radial design, the "low profile" radial tire, became widely available in the mid to late 1980s. The low profile design provides a further reduction in rolling resistance, increased stability and the ability to lower the overall height of the truck and trailer. Trailer manufacturer, Dorsey Corporation, reports an additional 1.5 to 3 percent improvement in fuel economy among its customers by switching to low profile radials in the past 2 to 3 years.

- Auxiliary Sources of Cab Heat. Auxiliary sources of cab heat reduce the overall rate of truck fuel consumption by eliminating the practice of idling to provide heat during rest-overs. Some fleets have equipped trucks with small auxiliary diesel fueled engines that heats forced air, which is then routed to the cab area. An alternative approach is to heat the engine coolant by the same means, and circulating it through a heat exchanger. Heated air is then generated and directed to the interior by a fan. Esbar, Incorporated is a major manufacturer of these two types of auxiliary cab heaters.

2.4 RAIL OPERATIONS CHANGES

Railroad operations managers have suggested that the advanced technology of the new locomotives contributes more to fuel savings than any type of train operating improvement. Nevertheless, railroads have instituted a number of operating improvements to reduce fuel consumption. Changes that are mentioned in the literature or reported by railroad operating managers are summarized in Exhibit 2-4. They include improvements in locomotive use, dispatching and education programs.

EXHIBIT 2-4
TRAIN OPERATIONS IMPROVEMENTS TO REDUCE FUEL CONSUMPTION

Locomotive Use	• Shutting down locomotives rather than allowing them to idle between runs • Idling one or more trailing units in service on low-tonnage trains • Maximizing use of fuel-efficient locomotives when towing idling units or extra locomotives • Maintaining constant speed for maximum use of the train's energy • Using dynamic braking instead of power braking
Dispatching	• Dispatching engines and operating trains with the lowest feasible horsepower/ton ratio • Relaying information on delays ahead to allow the engineer to pace the train accordingly • Selecting meet locations by considering which train yields the lower fuel penalty for the stop involved • Minimizing train stops and starts • Avoiding meets or stops at points of congestion
Education and Incentives	• Educational tips for engineers and dispatchers • Bulletin boards, mail-outs • Recognition and reward programs.

- Changes in Locomotive Use. Railroads are working to conserve the use of locomotives by shutting them down rather than allowing them to idle. In the winter, railroads will shut down locomotives when the ambient temperature is 40 degrees or above.

- Changes in Dispatching. Dispatchers are paying greater attention to the selection of meet and stop points to eliminate or minimize unnecessary stops. This includes identifying congestion on the railroad and notifying the engineer of delays ahead. Dispatchers are also working to dispatch engines with consideration of maximum horsepower/ton efficiency.

- Changes in Education. Many railroads have instituted awareness programs to educate train engineers and dispatchers on the importance of increasing fuel efficiency. In some cases these programs are supplemented by recognition and reward programs.

Two relatively complex operating improvements, pacing and computer assisted dispatching, are increasingly being used in railroad operations.

- Pacing. Pacing is the planned speed reduction of a train to avoid anticipated stops or delays, thus allowing the train to arrive at its destination at the same time as if it had not reduced its speed. Pacing enables the trains to save fuel while still arriving in the allotted time. Effective use of pacing requires good communication between the engineers and dispatchers. For example, in a situation where two trains must meet on a single track with a siding, each of the two engineers must communicate to the dispatcher any necessary train operation or delay information. The dispatcher can relay this information to the other train as well as use it to properly choose the meeting location, determine which train will take the siding and which train to instruct to "pace."

- Computer Aided Dispatching. Some of the larger railroads have installed computer-assisted dispatching (CAD) systems that provide real-time calculation of the fuel penalties associated with alternative stops or meeting locations. These CAD systems enable the dispatcher to provide more accurate pacing directions to train engineers. Suppliers of the CAD systems include Railroad Signal Company, Union Switch and Signal, Harmon Electronics and General Railway Signal.

2.5 TRUCK OPERATIONS CHANGES

Truck fleet operators have instituted improvements in their operations that contribute to improved fuel economy. The principal operating improvements include driver training, computer assisted routing and the use of multiple trailers. Each is described below.

- Driver Training. Large truck fleets provide instruction for their drivers in ways to reduce fuel consumption. Techniques such as quick and progressive shifting, running in the highest possible gear, cruising at moderate speeds, reducing idling, accelerating more gently and using the hills to build momentum are taught to assist the drivers to save fuel while still meeting delivery deadlines.

- Computer Assisted Routing. Computer assisted routing assists fleets to save fuel by identifying the most direct route or the route that allows the driver to reduce the trip time. Computer assisted routing also provides assistance in areas that are congested. Other functions include calculating mileage, travel time and fuel requirements. "Milemaker" by Rand McNally was a frequently mentioned routing software package used by the fleets contacted. Systems by Sony Corporation and Hughes Network Systems utilize on-board computers to track fleet status by the use of satellite positioning and 2-way messaging services. Some fleet operators have introduced their own in-house routing tools such as "Compumap" developed by Country Wide Truck Service and "Logistics" developed by Crete Carriers Corporation.

- Use of Multiple Trailers. The use of multiple trailers is governed by Federal, state and local laws. However, fleet operators suggest that the use of multiple trailers could contribute to fuel savings. Multiple trailer configurations consist of:

    - Western Doubles: two 27- or 28-foot trailers with single axles

    - Turnpike Doubles: two 40-, 45- or 48-foot trailers or another combination of these, all with tandem axles

    - Triples: three 27- or 28-foot trailers all with single axles.

  An increase in fuel economy would be achieved by allowing an increase in payload weight and density

> while maintaining a single tractor. The resulting increase in cargo weight over 48 foot semi-trailer vans would improve the ton-mile per gallon ratio.

* * * * *

Both railroad and truck equipment manufacturers estimate high levels of fuel savings resulting from the many technology improvements that have been introduced since the 1970s. Actual operating fuel efficiency of each fleet will depend on the extent to which these fuel economy improvements have been incorporated into the fleet and actual operating conditions such as the amount of load, traffic delays, the number of stops and terrain. The next chapter discusses the extent to which energy saving technologies have been adopted by rail and truck fleets.

3.0 ADOPTION OF ENERGY SAVING IMPROVEMENTS INTO OPERATING FLEETS

This chapter describes the extent to which energy saving improvements have been adopted into and characterize carrier fleets today. The chapter is organized into two sections:

- Current rail fleet characteristics
- Current truck fleet characteristics.

Each is discussed below.

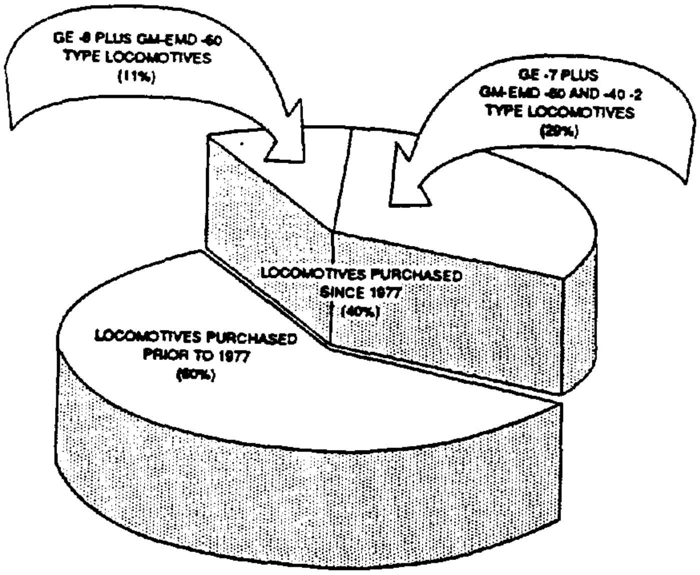
3.1 CURRENT RAIL FLEET CHARACTERISTICS

This section provides perspective on the status of the locomotive and railcar operating fleets with respect to the use of fuel efficient technologies and designs. The discussion addresses locomotives, railcars, intermodal cars and wheel lubrication.

3.1.1 Locomotives

Approximately 40 percent of the Class I locomotive fleet is estimated to have been purchased since 1977 and, thus, includes some type of improved fuel efficient technology. The estimated distribution between older and newer, more fuel efficient locomotives based on a sample of eight railroads is shown in Exhibit 3-1. Of the locomotives purchased since 1977, an

EXHIBIT 3-1
STATUS OF LOCOMOTIVE FLEET



NOTE: BASED ON ESTIMATES PROVIDED BY EIGHT RAILROADS estimated 11 percent of the eight railroads' purchases are either a GE-8 model or GM-EMD-60 model, and thus incorporate the most recent advances in locomotive fuel efficiency.

The number of locomotives sold to all Class I railroads since 1977, according to the manufacturers, is summarized in Exhibit 3-2. As shown, 7,450 new units were added to the overall locomotive fleet during this time period. This number is approximately 38 percent of the AAR's estimate of 1988 total operating diesel locomotives. These units, however, because of their higher horsepower and the types of services performed, represent more than 38 percent of the work performed by the Nation's locomotives.

EXHIBIT 3-2
LOCOMOTIVES SOLD TO CLASS I RAILROADS SINCE 1977

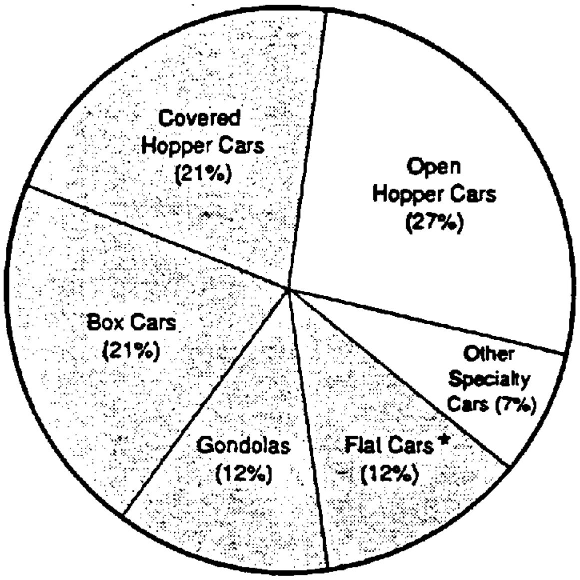
Manufacturer	Model	Number of Units*
GENERAL ELECTRIC	-7	1,921
	-8	959
	Total	2,880
GENERAL MOTORS-EMD	-40-2	3,049
	-50	720
	-60	801
	Total	4,570
TOTAL LOCOMOTIVES		7,450

* Source: Figures provided by the manufacturers.

3.1.2 Railcars

The AAR estimates that there is a total of 724,840 railcars in the Class I railroad fleet. A distribution of these railcars by car type is presented in Exhibit 3-3. As shown, the car

EXHIBIT 3-3
DISTRIBUTION OF RAILCAR FLEET BY CAR TYPE



SOURCE: AAR Transportation Division, Railroad Facts 1989.

NOTE: Shaded areas indicate those car types which commonly carry commodities that are also hauled by truck.

* : Includes intermodal cars.

categories that carry commodities competitive with trucks compose approximately two-thirds of the railcar fleet. Within these car categories it was found that recent fuel economy improvements in railcar design have not been widely adopted by the railroads.

In recent years, railroads have experienced surpluses in many car types. Railroads have concentrated their new car investments in autorack cars and advanced intermodal equipment, and more recently in new light weight coal cars. Railroad representatives say that there is little incentive for the railroads to purchase new cars simply to achieve greater energy efficiency, when the price of fuel is relatively inexpensive and represents a small proportion of railroad operating costs, and capital improvement budgets are tight. As railcar surpluses are reduced and replacements are made, fuel conservation improvements are incorporated in the new equipment. The operational characteristics of individual railroads such as train speed, service areas covered and type of service provided also determine whether a specific improvement, such as air foils or bearing seals, makes sense for a particular fleet, as explained below.

- Air Foils. According to Aero Transportation Products, only 125 car sets of air foils have entered the Class I railroad market. These air foils were purchased in

  1986 by:

  - Santa Fe Railway for 10 of its open hopper cars
  - Union Pacific for 115 of its gondolas.

  The manufacturer stated that its market is primarily limited to western railroads since eastern railroads typically operate at low speeds (i.e., an average of less than 45 mph) and therefore will not be able to realize significant fuel savings from the more aerodynamically designed railcars.

- Framebrace Trucks. Standard Car Truck Co. estimated that approximately 500 pairs of their framebrace trucks have been placed into service since 1987. Union Pacific has installed this type of truck on 200 to 300 of its coal and ore cars. The remainder of the market for this product consists of western railroads such as Burlington Northern and Canadian National Railway as well as Trailer Train.

- Bearing Seals. The Timken Company's Hydrodynamic Labyrinth (HDL) bearing seal is a brand new product that is not yet commercially available. It has been fully tested and is currently pending AAR approval. Once approved, this seal will be actively marketed among all Class I railroads.

3.1.3 Intermodal Cars

The majority (80 to 90 percent) of all intermodal cars belong to Trailer Train, a non-profit organization owned by and operated on behalf of the Class I railroads. As a result, most railroads use these cars to move intermodal freight based on a joint leasing agreement. Trailer Train's fleet consists of 38,500 cars, which is equivalent to almost 94,000 platforms of capacity (i.e., spaces for a container or trailer). In addition to flatcars, this fleet includes:

- 2,100 of the new, lightweight five-unit well cars (or 21,000 platforms)
- 350 of the new five-unit spine cars (or 1,750 platforms).

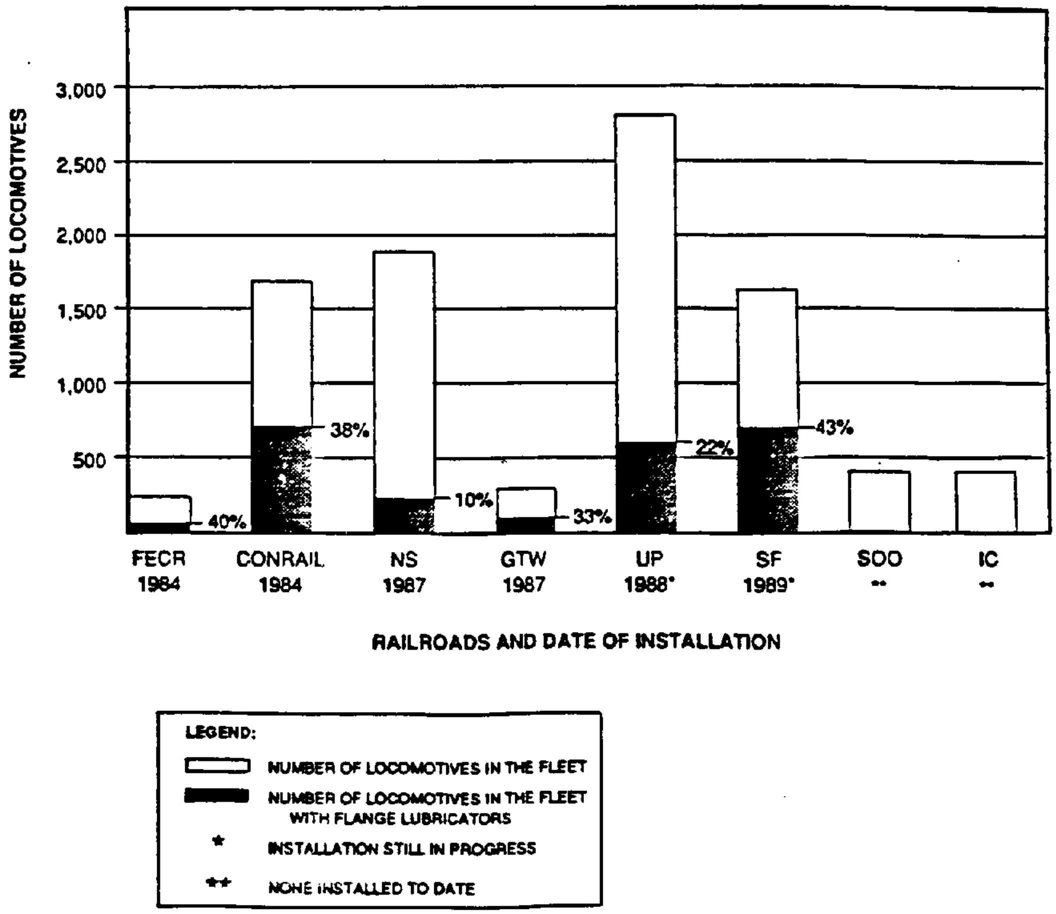
While both of these types of fuel efficient intermodal cars are in service on a nationwide basis, the single level spine car is most often used in the East due to the higher concentration of tunnels and other clearance restrictions.

3.1.4 Wheel Lubrication

Approximately 3,500 flange lubricators manufactured by Technical Service Marketing and Kipp Lubrication Systems have been sold to North American railroads since 1984. Six out of eight railroads contacted have installed the flange lubricators on a portion of their locomotives. Installation at four of these railroads was completed during the 1984 to 1987 timeframe, while installation at the other two began within the last 6 to 18 months. As illustrated in Exhibit 3-4, the extent of fleet coverage at each of the railroads contacted varies from 10 to 43 percent. It should be noted that 100 percent coverage is not necessary because:

- More than one locomotive is normally assigned to each train consist
- Only one locomotive per consist need be applying the lubricant to the wheel flange.

EXHIBIT 3-4
INSTALLATIONS OF FLANGE LUBRICATORS



SOURCE: BASED ON ESTIMATES PROVIDED BY A SAMPLE OF EIGHT RAILROADS.

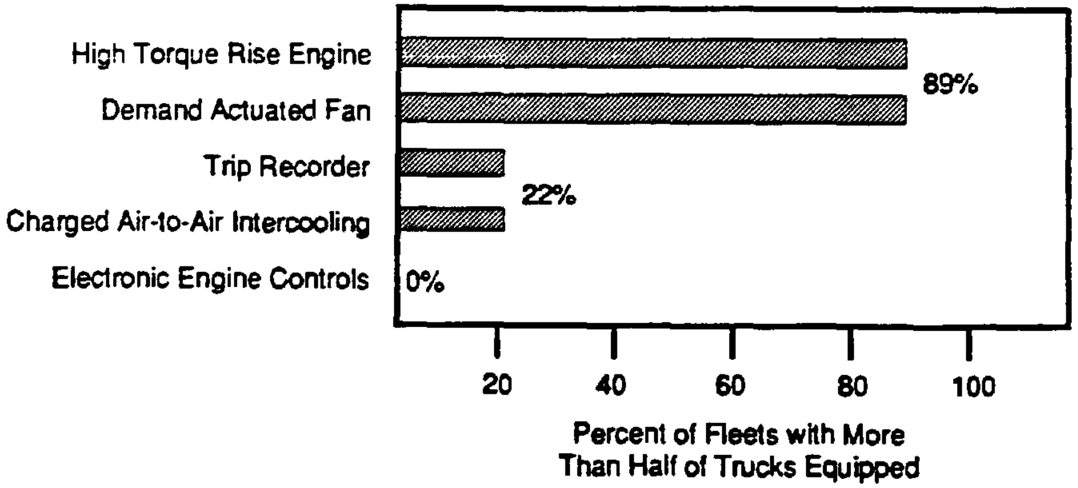
3.2 CURRENT TRUCK FLEET CHARACTERISTICS

Nine motor vehicle fleets that carry truckloads over long hauls were contacted to determine the extent to which advanced fuel efficient technology has been adopted in their fleets. It was found that the fuel efficient technologies that have been available since the 1970s, such as roof air deflectors and high torque rise engines, are the most prevalent. More recent technology improvements introduced in the 1980s are gradually being adopted by the truck fleets. The relative extent of use of specific engine and body/trailer fuel economy improvements are discussed below.

3.2.1 Truck Engines

The percent of fleets reporting that more than half of their trucks are equipped with fuel efficient engine technologies is shown in Exhibit 3-5. As shown, high torque rise engines and demand actuated engine cooling fans are prevalent among the fleets; 8 out of 9 operators report that their fleets are fully equipped with these technologies. Comparatively fewer trucks are equipped with charged air-to-air intercooling, electronic engine controls and trip recorders. None of the operators report that more than half of their vehicles are equipped with electronic engine controls, and most report that fewer than 10 percent of their trucks presently have the controls.

EXHIBIT 3-5
USE OF FUEL EFFICIENT ENGINE TECHNOLOGIES

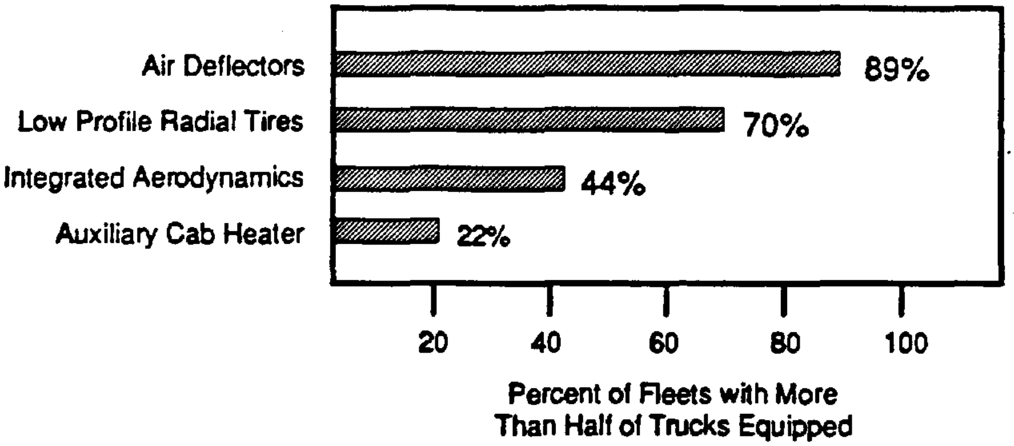


SOURCE: BASED ON A SAMPLE OF NINE LARGE TRUCK FLEETS

3.2.2 Truck Bodies and Trailers

Exhibit 3-6 summarizes the fleet use of truck body and trailer fuel economy improvements discussed in section 2.3.2. Almost all of the fleets are fully equipped with roof air deflectors to reduce aerodynamic drag. About half of the fleets report a high percent of trucks that have fully integrated aerodynamic designs. Several mentioned that this is particularly important for their long haul fleets. Two-thirds of the fleets report that a high portion of their trucks are equipped with low profile radial tires. Two out of nine fleets report that over half of their trucks are equipped with auxiliary cab heaters. In the remainder of the fleets, a small minority of trucks are currently equipped with these heaters.

EXHIBIT 3-6
USE OF FUEL EFFICIENT BODY AND TRAILER TECHNOLOGIES



SOURCE: BASED ON A SAMPLE OF NINE LARGE TRUCK FLEETS

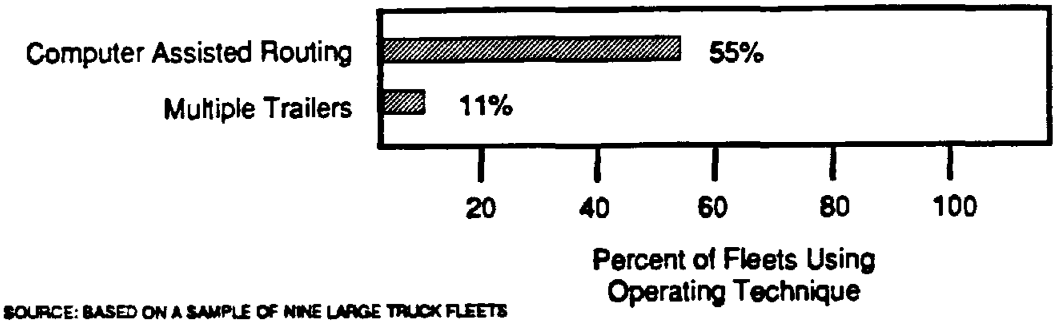
3.2.3 Truck Operations

The use of fuel efficient operating techniques by the long haul truckload fleets is shown in Exhibit 3-7.

- Computer Assisted Routing. Computer assisted routing is presently installed in over half of the fleets and is being investigated by others. Two companies, Universal Am-Can, Ltd. and J.B. Hunt Transport Inc., report that they are evaluating computer assisted routing software packages.

- Use of Multiple Trailers. Only two of the long haul fleets are using multiple trailers. Universal Am-Can, Ltd. estimates that 20 percent of its fleet uses multiple trailers. Overnite Transportation Company estimates that 70 percent of its fleet uses multiple trailers.

EXHIBIT 3-7
USE OF FUEL EFFICIENT OPERATING TECHNIQUES



SOURCE: BASED ON A SAMPLE OF NINE LARGE TRUCK FLEETS

* * * * *

The extent of adoption of fuel efficient technology changes in rail equipment can be evaluated by examining the locomotive fleet. An estimated 38 to 40 percent of the operating diesel-electric locomotives were purchased after 1977 and incorporate some fuel efficiency improvements. The extent of adoption of fuel efficient technology among truck fleets is harder to assess. The fleets are more numerous and more varied in the types and amounts of technologies that have been installed. Based on discussions with truck manufacturers and fleet operators, average long haul truck fuel economy improvement since the mid-1970s is estimated at 20 to 30 percent. The next chapter discusses fuel efficiency units of measure and calculation methods.

4.0 FUEL EFFICIENCY UNIT OF MEASURE AND CALCULATION METHODS

This chapter discusses the selection of ton-miles per gallon as the fuel efficiency unit of measure for this study. It also describes the fuel efficiency calculation methods for rail and truck. The chapter is organized into five sections as follows:

- Fuel efficiency unit of measure
- Assumptions for measuring fuel efficiency
- Rail fuel efficiency calculation
- Truck fuel efficiency calculation.

Each is discussed below.

4.1 FUEL EFFICIENCY UNIT OF MEASURE

Five units of measure for comparing rail and truck fuel efficiency have been applied or discussed in the literature. They are:

- Ton-miles per gallon
- Miles per gallon
- BTUs per ton-mile
- Gallons per 40 foot container
- Price per ton-mile.

Twenty-one reports were published during the period 1971 to 1989 by a variety of organizations including:

- U.S. Department of Transportation, Federal Railroad Administration
- U.S. Department of Transportation, Transportation Systems Center
- The Transportation Research Board
- Association of American Railroads
- American Trucking Association
- The National Science Foundation
- The Railway Fuel and Operating Officers Association
- The Congressional Budget Office.

A summary of each of the 21 previous fuel efficiency studies is presented in Appendix H. Each summary identifies the unit of measure for fuel efficiency that was discussed by the author and provides an abstract of the author's conclusions.

The unit of measure, ton-miles per gallon, was applied or discussed in 13 of the 21 studies. It is, however, not a universally accepted measure of modal fuel efficiency. In a 1974 report, the American Trucking Association criticized the use of ton-miles per gallon as a measure of fuel efficiency because of differences in terrain, mileage, volume of freight, distance, speed, promptness and level of service that occur between freight moves by rail versus truck.

A 1977 report by the Transportation Systems Center stated the position that it is futile to develop a single number for rail energy intensiveness, and pointed out that the individual circumstances for each run must be considered. This report presents an analysis that attempts to satisfy this need for route-specific analysis. Rather than attempting to make broad judgements about the fuel efficiency of each mode, this study looks at specific routes, equipment and loads.

The advantages and disadvantages of each measure for meeting the objectives of this FRA fuel efficiency study are discussed below.

4.1.1 Ton-Miles per Gallon

Ton-miles per gallon is a measure of the number of tons of freight and the distance they can be moved with one gallon of fuel. Ton-miles per gallon was selected as the unit of measure for this study because it measures both the tons of freight for the commodity under investigation and the distance moved, and it thus permits the comparison of truck operations to rail service. It is calculated as follows:

$$\begin{array}{c}\text{Ton-Miles}\\ \text{per}\\ \text{Gallon}\end{array} = \frac{\text{Weight x Distance}}{\text{Fuel (Gal.)}}$$

This unit of measure has been used in previous studies of modal fuel efficiency performed by the U.S. Department of Transportation, (1975, 1977, 1981 and 1986) the Transportation Research Board (1977) and the Federal Energy Administration (1976).

4.1.2 Miles per Gallon

Miles per gallon is a measure that is easy for most people to understand and calculate. It is useful for comparing vehicles of equivalent capacity such as two similar-sized trucks. However, it does not take into consideration the weight or volume of freight being shipped. Thus, this measure is not appropriate for comparing the fuel efficiency of competing modes of transportation.

4.1.3 BTUs per Ton-Mile

BTUs[1] per ton-mile is potentially a very accurate measure of comparative fuel efficiency. It is a scientific measure that requires controlled testing methods and very accurate data. Use of BTUs per ton-mile to compare rail and truck operations could require the actual operation of the vehicles and measurement of the fuel consumed. Gallons of fuel are the customary energy units used in the U.S. rail and trucking industries.

4.1.4 Gallons per 40 Foot Container

Gallons per 40 foot container can be useful when looking at dry freight, such as comparing double-stack train fuel efficiency to that of long-haul dry van truckloads. However, this measure is not useful for comparing mixed consist trains with competing truckload service. The majority of trains in this study are mixed consist trains, thus, this unit of measure could not be usefully applied to all cases in the study.

4.1.5 Price per Ton-Mile

Price per ton-mile is a measure of transportation efficiency and service. This measure has been suggested by the American Trucking Association[2] as a comparison unit that eliminates distortions due to freight volume, weight, distance shipped and speed. However, price per ton-mile is not a direct measure of fuel efficiency and thus does not meet the objectives of this study.

4.2 ASSUMPTIONS FOR MEASURING FUEL EFFICIENCY

Assumptions for the unit of measure, ton-miles per gallon, that are applied in this study include:

- Freight Only. Only freight ton-miles are measured. No passenger rail miles are addressed.
- Fuel Comparisons are Made by Commodity and Origin/Destination Pairs. In this study, unlike previous studies, the fuel comparisons are made for

---

[1] A BTU or British thermal unit is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

[2] See "Debunking the Rail Energy Efficiency Myth", August 1974, by the American Trucking Association.

truck competitive commodities for specific train types and truck equipment and between specified origin/destination pairs, rather than making broad generalizations about the fuel efficiency of all rail freight versus all truck freight.

- Rail Fuel Consumption is Adjusted to Include Freight Movements at the Origin and Destination Terminals. Since rail operations are limited to movement on fixed track, the freight must be either trucked in or moved into the terminal area from a rail siding. Assumptions have been made about fuel consumption for 1) the required railcar movement between the warehouse and the railyard and 2) truck drayage in the case of intermodal rail freight at the origin and destination. Assumptions about fuel consumption during rail terminal operations have also been made. All assumptions for fuel consumption have been included in the fuel efficiency calculation. They are described in Appendix G.

- Truck Freight Moves Directly from Shipper to Consignee. In contrast to the rail freight movements, all truck freight is assumed to move directly from the origin (shipper) to destination (consignee).

4.3 RAIL FUEL EFFICIENCY CALCULATION

The TPS (Train Performance Simulator) simulates the operation of the train over the specified route and then calculates the number of gallons of fuel consumed during the run. Additional amounts of fuel required for railcar switching, terminal operations and truck drayage are added to the TPS result. Algebraic calculations are then performed on this total to obtain ton-miles per gallon. The rail fuel efficiency calculation method is presented in Exhibit 4-1.

4.4 TRUCK FUEL EFFICIENCY CALCULATION

The Cummins Vehicle Mission Simulation (VMS) Model simulates the operation of the truck over the specified route and then computes the number of gallons of fuel consumed during the run. Algebraic calculations are then performed to translate the gallons of fuel into ton-miles per gallon. These calculations are based on the number of trucks required to transport one railcarload of the commodity.

The truck fuel efficiency calculation method is presented in Exhibit 4-2. This method attributes all fuel consumed to movement of the truck payload.

EXHIBIT 4-1 (P.1 OF 2)
RAIL FUEL EFFICIENCY CALCULATION

RAIL FUEL EFFICIENCY CALCULATION

The following is the method used to calculate railroad fuel efficiency by commodity, by train and by route. The train weight, trip distance and other route and train factors are used as model inputs and the fuel consumption is calculated by the TPS.

CALCULATION ASSUMPTIONS:

1. The objective of the analysis is to determine the fuel efficiency of moving one carload of a specified commodity on a selected route.
2. Fuel efficiency is expressed in ton-miles per gallon for the lading, excluding the tare weight of the car and the locomotive weight.

OBJECTIVE: **DETERMINE FUEL CONSUMPTION FOR THE LADING BASED ON THE PERCENTAGE OF GROSS TRAIN WEIGHT**.

This methodology calculates fuel efficiency for a commodity (lading) based on that commodity's percent of the gross train weight, including the locomotives. The explanation below is based on an example of a 24-mile train trip.

Step 1. Calculate the Percent of Gross Train Weight for the Loaded Car Being Measured.

For example, assume that the commodity weight, or lading, is 46 tons, and the car weight is 30 tons; one carload of the commodity, including car (tare) weight is 76 tons. Assume that the total weight of the train is 3,684 tons. The percent of total train weight for the commodity is calculated as follows:

$$\text{The Percent of Total Train Weight for Commodity} = \frac{76 \text{ Tons}}{3{,}684 \text{ Tons}} = .0206 = 2.06 \text{ Percent}$$

EXHIBIT 4-1 (P.2 OF 2)
RAIL FUEL EFFICIENCY CALCULATION (CONTINUED)

Step 2. <u>Calculate the Amount of Fuel Consumed in Moving the Loaded Car</u>.

To continue the example, assume that the total fuel consumed by the train is 131.73 gallons. The amount of fuel consumed in moving the loaded car is calculated as follows:

$$\text{The Amount of Fuel Consumed by the Loaded Car} = 131.73 \text{ Gal.} \times .0206 = 2.71 \text{ Gallons}$$

Step 3. <u>Calculate the Ton-Miles per Gallon to Move the Commodity</u>.

Assume that the total distance travelled on the railroad is 24 miles. The weight of the commodity being analyzed (lading) is 46 tons. Total ton-miles per gallon is calculated as:

$$\text{Ton-Miles per Gallon} = \frac{\text{Weight} \times \text{Distance}}{\text{Fuel}} = \frac{46 \text{ Tons} \times 24 \text{ Mi.}}{2.71 \text{ Gals.}} = 407.4 \text{ TMi/GAL.}$$

As shown above, the final figure is the measure of fuel efficiency for the commodity in ton-miles per gallon.

EXHIBIT 4-2 (P. 1 OF 2)
TRUCK FUEL EFFICIENCY CALCULATION

TRUCK FUEL EFFICIENCY CALCULATION

The following is the method used to calculate truck fuel efficiency by commodity, by truck and by route. Fuel consumption is calculated by the Cummins Vehicle Mission Simulator (VMS).

CALCULATION ASSUMPTIONS:

1. The objective of the analysis is to determine the fuel efficiency of moving a specified payload.
2. Fuel efficiency is expressed in lading weight ton-miles per gallon. The fuel used in the calculation includes the consumption attributable to the defined tractor, trailer and the lading.
3. The specific moves assume no empty truck miles.

OBJECTIVE: **DETERMINE FUEL EFFICIENCY BASED ON THE NUMBER OF TRUCKS REQUIRED TO MOVE ONE RAILCARLOAD OF A SPECIFIED COMMODITY**.

This methodology calculates fuel efficiency based on the number of trucks required to move one railcarload of a specified commodity.

The following example assumes that the payload is transported in a 48 foot long, 102 inch wide trailer over a distance of 33.2 miles. Total gallons of fuel consumed is generated by the VMS.

Step 1. Define the Amount of Fuel Consumed.

Since the truck moves its payload in one self-contained vehicle, the total truck fuel consumption is attributed to transportation of the payload. The VMS provides the gallons of fuel as an output. In this example, the total fuel consumed is 5.8 gallons.

Note: Fuel use is attributed to the commodity in order to maintain a comparable basis between truck and rail.

EXHIBIT 4-2 (P.2 OF 2)
TRUCK FUEL EFFICIENCY CALCULATION (CONTINUED)

Step 2. Calculate the Number of Trucks Required to Transport a Payload Equivalent to One Railcar Lading.

The number of trucks required to carry the same amount of lading as one railcar is calculated by dividing the tons of railcar lading by the tons of truck payload.

$$\text{The Number of Truckloads Required to Transport a Payload Equivalent to One Railcar Lading} = \frac{\text{Railcar Lading (Tons)}}{\text{Truck Payload (Tons)}} = \frac{46}{24} = 1.92$$

Step 3. Calculate the Ton-Miles per Gallon to Move the Commodity.

Assume that the total truck route distance is 33.2 miles. The total weight of the commodity being analyzed is 46 tons (that is, the railcar lading). Total truck ton-miles per gallon is calculated as:

$$\text{Ton-Miles per Gallon} = \frac{\text{Wt.} \times \text{Distance}}{\text{No. of Trucks} \times \text{Fuel per Truck}} = \frac{46\ \text{Tons} \times 33.2\ \text{Mi}}{1.92 \times 5.8\ \text{Gals.}} = 137.1\ \text{TMi/GAL.}$$

As shown above, the final figure is the fuel efficiency for the commodity in ton-miles per gallon.

* * * * *

In summary, ton-miles per gallon was selected as the unit of measure of fuel efficiency for this study because it provides a measure of both weight and distance in moving freight and permits the comparison of rail and truck fuel efficiency. Fuel efficiency for each mode is calculated based on the amount of fuel required to move one railcarload of a specified commodity from the origin to the destination. The next chapter presents a description of the rail and truck service scenarios.

5.0 DESCRIPTION OF FREIGHT SERVICE SCENARIOS

This chapter describes the freight service scenarios for both rail and truck service. The chapter is organized into three sections:

- Rail/Truck freight competitive commodities
- Rail service scenarios
- Truck service scenarios.

Each is discussed below.

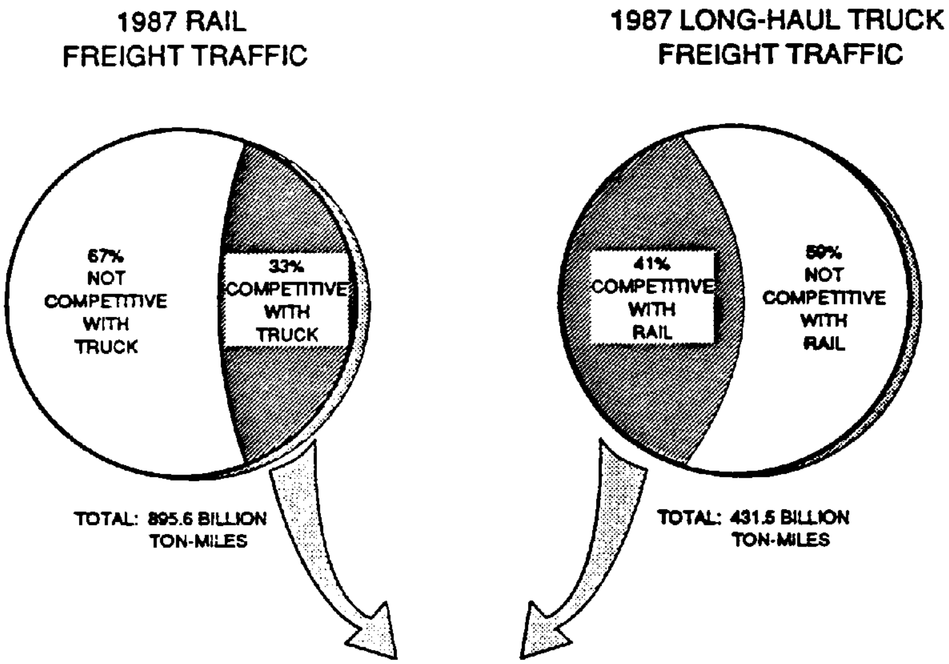
5.1 RAIL/TRUCK FREIGHT COMPETITIVE COMMODITIES

The most recent and complete study of market share between rail and truck is a paper published by the Association of American Railroads (AAR) in March 1989, "Key Commodities in Rail/Truck Competition." This paper focuses on the manufactured commodities that are important to both railroading and trucking.

The percentage of 1987 rail and truck freight traffic that consisted of common and competitive commodities is summarized in Exhibit 5-1. As shown, approximately one-third of rail freight ton-miles carried commodities that are competitive with trucks, while approximately 41 percent of truck long-haul traffic carried the competitive commodities. As shown in Exhibit 5-1, railroads moved 63 percent of the ton-miles for competitive commodities in 1987 versus 37 percent moved by trucks.

Exhibit 5-2 identifies the thirteen commodity groups that are important sources of both rail and truck freight traffic. They include canned fruits and vegetables, grain products, beverages, miscellaneous food preparations, sawmill products, prefabricated wood products, paper, industrial chemicals, plastic materials, miscellaneous chemical products, steel products, motor vehicles and intermodal freight traffic. As shown, intermodal freight traffic is the top-ranked competitive commodity group for rail; it represented 22.6 percent of rail ton-miles of manufactured commodities in 1987. The next highest ranked competitive commodities for rail are sawmill products, chemicals, transportation equipment and grain. The competitive commodities ranked highest for their percent of long haul trucking miles of manufactured commodities are canned or preserved fruits, sawmill products and intermodal freight.

EXHIBIT 5-1
COMPETITIVE FREIGHT SERVICE FOR RAIL AND TRUCK


1987 RAIL FREIGHT TRAFFIC

1987 LONG-HAUL TRUCK FREIGHT TRAFFIC

COMMON AND COMPETITIVE COMMODITIES

	Commonly Important Commodities (1987)		
	Rail	Long Haul Truck	Total
Ton-Miles (Millions)	299,177.5	176,256.0	475,433.5
Percent of Ton Miles	63	37	100

SOURCE: ASSOCIATION OF AMERICAN RAILROADS "KEY COMMODITIES IN RAIL/TRUCK COMPETITION"

EXHIBIT 5-2
COMMON AND COMPETITIVE COMMODITIES

		RAIL			TRUCK		
STCC NUMBER	COMMODITY	RANK *	PERCENT OF RAIL TON-MILES OF MANUFACTURED COMMODITIES	PERCENT OF 1987 RAIL INDUSTRY TOTAL TON-MILES	RANK **	PERCENT OF LONG HAUL TRUCK TON-MILES OF MANUFACTURED COMMODITIES	PERCENT OF 1987 TOTAL LONG HAUL TRUCKING TON-MILES
203	Canned/Preserved Fruits, Veg. or Seafood	12	3.64	1.22	1	20.59	8.41
204	Grain Mill Products	5	7.66	2.56	9	4.04	1.65
208	Beverages or Flavoring Extracts	10	4.23	1.41	10	3.97	1.62
209	Miscellaneous Food Preparations	9	5.40	1.80	8	6.13	2.50
242	Sawmill Products	2	11.72	3.92	2	12.12	4.95
243	Millwork or Prefabricated Wood Products	11	4.17	1.39	11	3.05	1.25
262	Paper	8	5.77	1.93	5	8.93	3.65
281	Industrial Inorganic or Organic Chemicals	3	11.15	3.73	6	6.72	2.74
282	Plastic Materials, Synthetic Fibers, Resins	7	6.76	2.26	12	2.87	1.17
289	Miscellaneous Chemical Products	13	1.14	0.38	13	2.29	0.93
331	Steel Works, Rolling Mill Products	6	7.56	2.53	4	11.02	4.50
371	Motor Vehicles or Equipment	4	8.53	2.85	7	6.24	2.55
41-47	Intermodal Traffic Categories	1	22.26	7.44	3	12.03	4.91
	TOTAL		100.00%	33.4%		100.00%	40.85%

* Rank in the percent of rail ton-miles of competitive commodities.

** Rank in the percent of long haul truck ton-miles of competitive commodities.

Source: Association of American Railroads, 1989.

5.2 RAIL SERVICE SCENARIOS

The rail service scenarios in this study were selected from two distinct industry segments, Class I and regional/local rail service. The characteristics of scenarios assumed for each segment are described below.

5.2.1 Class I Service Characteristics

Thirty-two rail scenarios were analyzed to determine the fuel efficiency of trains providing Class I rail service. The scenarios are based on route and consist data from currently operating Class I U.S. railroads. The data was provided with the agreement that the railroads not be identified.

The Class I rail service scenarios reflect typical freight movements for each of the contributing railroads. The discussion of Class I rail service is organized into four sections:

- Route characteristics
- Locomotive equipment characteristics
- Consist characteristics
- Load characteristics.

Each is discussed below.

5.2.1.1 Route Characteristics

The TPS model uses the actual rail routes with all of their grades, curves and speed limits. However, to describe these routes, a numeric rating system was developed for both the Class I and the regional/local railroad routings to represent the level of difficulty of the grades, curvatures and the frequency of speed limit changes. The rating numbers are not the actual percent grade, degree of curvature or speed limit change frequency, rather, they are ratings on a scale of 1 (low) to 5 (high). They report a weighted average for the specified route characteristic. Appendix E provides further explanation of these numeric codes.

The following paragraphs describe the distance, grade severity, curvature severity and frequency of speed limit changes of the Class I scenario routes. The values given exclude switching and drayage.

- Distance. The length of the Class I rail service scenario routes ranges from 126 to 1,891 miles. Twenty-one of the 32 scenarios, or 66 percent, have routes longer than 500 miles. Ten scenarios, or 31 percent, have routes between 250 and 500 miles; and 1 scenario includes a route that is only 126-mile long. The route distances are summarized for all scenarios in Exhibit 5-3.

- Grade Severity. The severity of the grades on the Class I routes ranges from light to moderate, with grade severity ratings of from 1.35 to 3.67 on a scale of 1 to 5.[1] Sixty percent of the scenarios have a rating higher than 2.0 for grade severity. None of the scenarios have grade severity ratings higher than 3.67 even though some of the trains pass over mountain ranges. This is due to the fact that the mountain grades are offset by long distances travelled over flatter terrain as part of the same route.

EXHIBIT 5-3
ROUTE DISTANCES OF CLASS I SCENARIOS

ROUTE DISTANCE (MILES)	NUMBER OF CLASS 1 RAIL SERVICE SCENARIOS
≤ 250	1
251 TO 500	10
501 TO 1000	10
1001 TO 1500	5
1501 +	6
TOTAL	32

- Curvature Severity. The severity and frequency of the curves ranges from mild to moderate, with curvature severity ratings of from 1.1 to 3.53 on a scale of 1 to 5. Sixty-two percent of the scenarios for which data was available have curvature ratings below 2, while 38 percent have curvature ratings above 2. Curvature data was not available for six of the 32 scenarios.

- Frequency of Speed Limit Changes. Speed limit change frequency for the scenarios studied ranges from low to high, with ratings of 1 to 5 based on a scale of 1 to 5. Sixteen of the thirty-two scenarios, or one half are characterized by a frequency of speed limit change rating higher than 3.

---

[1] Exhibit C-1 in Appendix C lists the grade severity ratings for each scenario. Appendix E describes the method for evaluating route severity.

5.2.1.2 Locomotive Equipment Characteristics

Appendix C-2 lists the Class I rail service locomotive characteristics (scenarios Rail01 to Rail32). As shown, from 1 to 5 unit locomotives are used, with the predominant number of scenarios, 50 percent, running with 3 unit locomotives. The locomotive models are representative of typical units in use by the participating railroads. The types of locomotives include nine different models. General Motors locomotives include the GP-9, GP-40, SD-40, GP40-2, SD40-2 and SD60. General Electric locomotives include the B36-7, the C36-7 and the C40-8.

5.2.1.3 Consist Characteristics

The consists of the Class I rail service scenarios are characterized by the type of train, the number of cars and the trailing weight of the train. As shown in Exhibit 5-4, 15 of 32 scenarios are mixed freight trains including mixed freight trains with autos. Another one-third, or 11 scenarios, are trains that include trailers-on-flatcars (TOFC). The remaining 20 percent of the trains include 5 intermodal double-stack trains that haul containers-on-flatcars and one solid auto train that hauls bi-level or tri-level auto rack cars. Exhibit 5-5 illustrates the train types. The consist sizes and the trailing weights are discussed below.

- Consist Size. The number of cars per train for the 32 scenarios ranges from 21 to 120 cars. Eighty percent of the trains pull 80 or fewer cars. There are 4 mixed freight trains that pull from 82 to 96 cars, and two mixed freight trains that pull 119 and 120 cars respectively. All of the TOFC trains have from 30 to 63 cars. Each TOFC car carries two trailers. The double-stack trains haul from 21 to 26 cars per train, each of which is capable of carrying 10 containers. The solid auto train pulls 55 bi-level or tri-level auto rack cars.

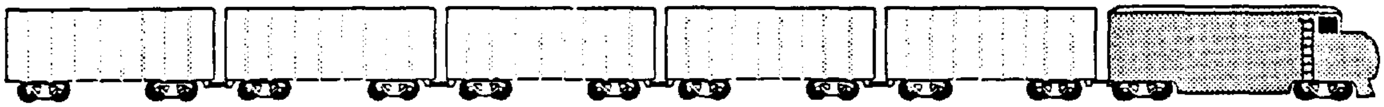
- Trailing Weight. The train trailing weights for the different rail service scenarios range from 1,909 to 10,320 tons (see Exhibit 5-6). The heaviest are the large mixed freight trains with over 80 cars; the trailing weight of these trains ranges from 7,000 to 10,320 tons. The double-stack trains are the second

EXHIBIT 5-4
CLASS I RAIL SERVICE CONSIST CHARACTERISTICS

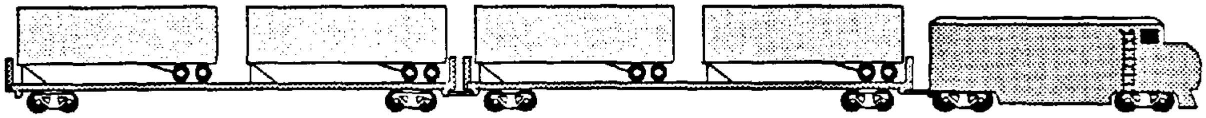
TRAIN TYPE	NO. OF CARS	NUMBER OF CLASS I SCENARIOS	PERCENT OF SCENARIOS
Mixed Freight	19 to 40	1	
	41 to 60	1	
	61 to 80	5	
	81 to 100	4	
	101 to 120	2	
		13	41
Mixed Freight/A	75 to 80	2	
		2	6
TOFC	19 to 40	3	
	41 to 60	5	
	61 to 80	3	
	81 to 100	0	
	101 to 120	0	
		11	34
Double-stack	21 to 26	5	
		5	16
Solid Auto	55	1	
		1	3
	TOTAL	32	100 %

Mixed Freight/A - Mixed Freight with Autos
TOFC - Trailer-on-Flatcar
Note: See Appendix C for number of empty and loaded cars.

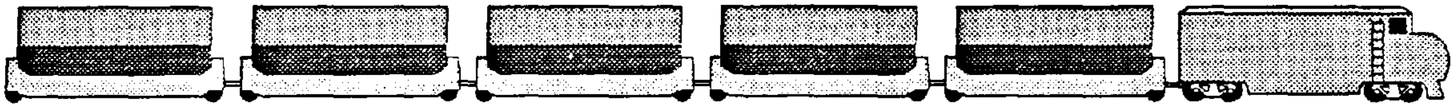
EXHIBIT 5-5
TRAIN TYPES



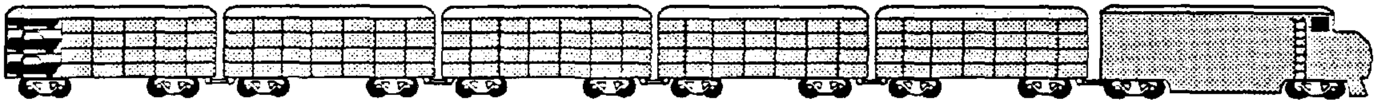
RAIL MIXED FREIGHT



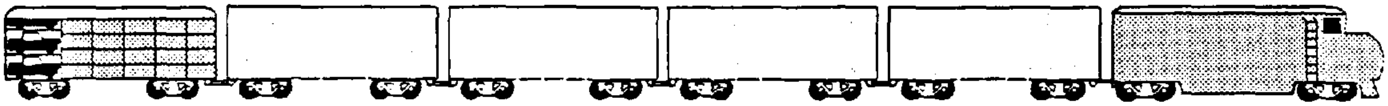
RAIL TRAILER ON FLATCAR (TOFC)



RAIL DOUBLESTACK (DSTK)



RAIL AUTO UNIT



RAIL MIXED FREIGHT WITH AUTOS

heaviest train type. Although the double-stack trains in this study haul only 21 to 26 cars, each car can carry as many as 10 loaded containers. Thus, these double-stack trains are characterized by an average trailing weight of 5,695 tons. The solid auto train has a trailing weight of 4,580 tons. The TOFC trains studied are considerably lighter, with an average trailing weight of 3,410 tons. The double-stack cars carry 210-260 containers versus 60-126 for trailers-on-flatcars.

EXHIBIT 5-6
TRAILING WEIGHT CHARACTERISTICS OF CLASS I SCENARIOS

TRAIN TYPE	AVERAGE TRAILING WEIGHT (TONS)	RANGE IN TRAILING WEIGHT (TONS)	TOTAL CLASS I SCENARIOS
Mixed Freight	6,484	1,909 to 10,320	13
Mixed Frt/A	5,938	5,475 to 6,400	2
Double-stack	5,695	4,421 to 6,908	5
TOFC	3,410	1,980 to 4,536	11
Solid Auto	4,580	4,580	1
All Scenarios	5,245	1,909 to 10,320	32

Mixed Frt/A - Mixed Freight with Autos
TOFC - Trailer-on-Flatcar

- Horsepower per Trailing Ton. Exhibit 5-7 portrays the horsepower per trailing ton ratio ranges for the equipment types used in this study. The exhibit shows that rail mixed freight has the largest number of scenarios, 9, with the lowest horsepower per trailing ton range. On the other hand, rail TOFC has the largest number of scenarios, 5, with horsepower per trailing ton values of 3.1 or above.

5.2.1.4 Load Characteristics

The Class I scenarios include truck competitive commodities that are typically carried on the respective rail routes. One carload of each commodity is assumed for the purpose of determining fuel efficiency for each scenario. The types of commodities assumed to be carried by type of train are as follows:

- Mixed Freight Trains. Commodities carried on the mixed freight trains include sawmill products, plywood, steel products, plastic materials, lumber products, automobiles, miscellaneous food products and canned food products.

EXHIBIT 5-7
CLASS I RAIL SERVICE HORSEPOWER PER TRAILING TON RATIO RANGE

EQUIPMENT TYPE	RAIL HP PER TRAILING TON RANGE	NUMBER OF CLASS SCENARIOS
Mixed Freight	0.6 to 1.6	9
	1.7 to 2.7	4
		13
TOFC	2.0 to 3.0	6
	3.1 to 4.0	4
	4.1 to 5.7	1
		11
Double-stack	2.3 to 2.8	5
Mixed Freight/Autos	0.9	2
Unit Auto	2.1	1

TOFC - Trailer-on-Flatcar
Mixed Freight/Autos - Mixed Freight with Autos

- TOFC Trains. Commodities carried on the TOFC intermodal trains include beverages, canned food, grain products, miscellaneous food products and other miscellaneous merchandise freight.

- Double-stack Trains. Commodities on the double-stack trains can include almost any containerized freight. A commodity that is assumed in two of the scenarios is imported electronics.

The car type is significant because it affects the train's aerodynamic profile. That is, the train's fuel efficiency is affected by the consist and car configurations. In the TPS, the different car types have different cross-sectional area values. Consist configuration differences are reflected in changes in the coefficients for the car cross-sectional area and for train resistance (see discussion of TPS coefficients in Appendix A).

The types of cars carrying each commodity for all rail scenarios are identified in Exhibit C-4 in Appendix C.

5.2.2 Regional/Local Service Characteristics

Eleven rail scenarios were analyzed to determine the fuel efficiency of trains representative of regional/local rail service. The scenarios are based on route and consist data from currently operating small and regional U.S. railroads. The data was provided with the agreement that the railroads not be identified.

The regional and local rail service scenarios reflect typical freight movements for each of the contributing railroads. Profiles of the routes were developed and coded into the TPS computer model using track data provided by each railroad. All the routes are truck competitive for the commodities specified. Train consist information such as commodities, number and types of locomotives and types of cars are based on information supplied by the railroads. The train speeds are based on the speed limits provided in the railroads' timetables.

The description of regional/local service scenarios is organized into four sections:

- Route characteristics
- Locomotive equipment characteristics
- Consist characteristics
- Load characteristics.

Each is discussed below.

5.2.2.1 Route Characteristics

The following paragraphs describe the distance, grade severity, curvature severity and frequency of speed limit changes of the regional/local service routes. Appendix C, Page C-1 contains a detailed list of these values for each scenario:

- Distance. The lengths of the selected regional/local rail service scenario routes range from 22 to 74 miles. As Exhibit 5-8 indicates, the eleven scenarios are distributed among the three distance categories; 22, 54 and 74 miles. Four rail mixed freight scenarios each are executed over the 22- and 74-mile routes and three are run over the 54-mile route.

EXHIBIT 5-8
ROUTE DISTANCES OF REGIONAL/LOCAL SERVICE SCENARIOS

ROUTE DISTANCE (MILES)	NUMBER OF CLASS 1 RAIL SERVICE SCENARIOS
22	4
54	3
74	4
TOTAL	11

- Grade Severity. The severity of the grades on the regional/local service routes ranges from a fairly easy 1.56 on the 22-mile route to a more moderate 2.80 on the 54-mile route. The 74-mile route has a rating of 1.75.

- Curvature Severity. All eleven scenarios had curvature ratings under 2.00, which is in the low range. The 74-mile route registered a very easy 1.21 rating. The highest curvature rating was 1.93 on the 54-mile route.

- Frequency of Speed Limit Changes. The frequency of speed limit changes is estimated by dividing the total speed limit changes on the route by the total route miles to determine the percentage of miles that contain speed limit changes. The 22-mile route rating of 4.46 was the most severe of the regional/local scenarios. The 74- and 54-mile routes had more moderate ratings of 2.97 and 2.21 respectively.

Since the regional/local trains in this study are mixed freight trains, no truck drayage is assumed[2]. Also, since no drayage is necessary, it is assumed that the loads are moved directly from origin to destination on the regional/local railroad. In addition, terminal switching operations are not required.

5.2.2.2 Locomotive Equipment Characteristics

The locomotive equipment assumed in the regional/local rail service scenarios are typical of the motive power in use by these railroads. The locomotives include the GP-7, the GP-9 and the SD-40, all built by General Motors, ElectroMotive Division. Seven of the regional/local scenarios include a 4 unit locomotive, while four of the scenarios include a 1 unit locomotive. Additional characteristics of the locomotives for Rail33 through Rail43 are contained in Appendix C-2.

Exhibit 5-9 summarizes the horsepower per trailing ton ratio for regional/local service. As indicated, this ranges from 1.0 to 2.5 for all eleven scenarios. A little over 50 percent of the scenarios have ratios 1.3 and less. The values are typical for rail mixed freight operated over the regional/local service track included in this study.

---

[2] Truck drayage is required for intermodal shipments of containers or trailers. The regional/local rail scenarios in this study do not carry intermodal shipments.

EXHIBIT 5-9
REGIONAL/LOCAL SERVICE HORSEPOWER PER TRAILING TON RATIO RANGE

EQUIPMENT TYPE	RAIL HP PER TRAILING TON RANGE	NUMBER OF CLASS SCENARIOS
Mixed Freight	1.0	2
	1.3	4
	2.1	3
	2.5	2
	Total	11

5.2.2.3 Consist Characteristics

The consist characteristics of the regional/local rail service scenarios are summarized in Exhibit 5-10. The consists reflect typical trains for the specified routes as reported by the transportation managers of the contributing railroads.

The train gross weights are based on the railroads' recommendations of the total train consist, including locomotives and cars. The gross train weights for the regional/local service scenarios range from 854 tons for a train with 1 locomotive and 10 cars, to 6,146 tons for a train with 4 locomotives and 90 cars (regional railroad).

EXHIBIT 5-10
REGIONAL/LOCAL SERVICE CONSIST CHARACTERISTICS

RAIL SERVICE SCENARIO	NO. OF CARS	NO. LOADED	NO. EMPTY	TRAILING WEIGHT (TONS)	GROSS WEIGHT (TONS)
33-36R	90	70	20	5,650	6,146
37-39R	60	60	0	4,380	5,024
40-41	10	10	0	730	854
42-43	25	25	0	1,825	1,949

R = Regional Railroad

5.2.2.4 Load Characteristics

The load characteristics of the regional/local rail service scenarios are summarized in Exhibit 5-11. The loads include commodities that are typically carried on the respective rail routes. Also shown is the type of railcar assumed to carry the load in the TPS analysis.

EXHIBIT 5-11
LOAD CHARACTERISTICS OF REGIONAL/LOCAL SERVICE SCENARIOS

RAIL SERVICE SCENARIO	COMMODITY ASSUMED FOR ANALYSIS	CAR TYPE
33	Corn	Covered Hopper
34	Plywood	Box Car
35	Pulpwood	Flatcar
36	Chips	Open Hopper
37	Clay	Box Car
38	Grain Products	Covered Hopper
39	Canned Goods	Box Car
40	Grain Products	Covered Hopper
41	Steel Products	Flatcar
42	Misc Food Products	Box Car
43	Chemical Products	Box Car

5.3 TRUCK SERVICE SCENARIOS

The truck transportation scenarios are described in this section. Each scenario description includes characteristics of the engine and drivetrain, vehicle, payload and route.

5.3.1 Engine and Drivetrain Characteristics

The engine and drivetrain truck components are important variables to consider when defining a truck configuration. The match of these elements has a direct bearing on truck torque and power.

The engine selected for use in this study is the Cummins Formula 350. This engine, when coupled with the generic 9-speed direct transmission and generic 3.40 drive axle ratio, meets the demands of all 43 truck service scenarios. The following paragraphs describe the engine and drivetrain components.

- Engine. The Cummins Formula 350 (F-350) engine was selected for use in all 43 truck service scenarios. This turbocharged diesel engine has a rated speed of 1800 revolutions per minute (rpm) and achieves 1200 lb.-ft. peak torque at 1300 rpm. The engine was selected based on its appropriate combination of torque and power to meet the weight and terrain demands required by the truck service scenarios. Detailed engine specifications including engine speed, power output and torque graphs are included in Appendix I.

- Drivetrain. The drivetrain components include the choice of transmission and drive axle ratio. Based on the required engine operating rpm range, a standard step category, generic 9-speed direct transmission was selected. This transmission features 25-30 percent gear splits over the full road speed range and provides enough flexibility to keep the F-350 engine at or above 90 percent of rated power. A tandem axle with an axle ratio of 3.40 was chosen to maintain a geared speed within the limits of Federal law.

5.3.2 Vehicle Characteristics

The vehicle description includes cab type, trailer type, truck aerodynamics, tire type and accessories. Each is discussed below.

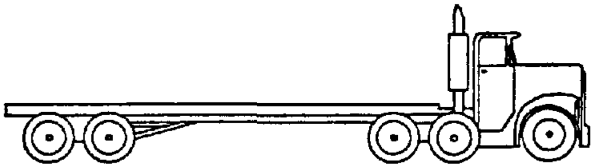
- Cab Type. There is considerable debate in the trucking industry as to which cab type is more fuel efficient, conventional or cabover. The conventional cab resembles an automobile with the engine compartment located under the hood in front of the driver whereas a cabover is similar to a passenger bus with its engine located underneath or behind the driver. Manufacturers of each cab type claim theirs is more fuel efficient due to a more favorable drag coefficient. Since the coefficients of drag are proprietary information and because empirical evidence is non-conclusive, the VMS model does not distinguish between the two cab types. Thus, for the purpose of this study, they may be used interchangeably and are not considered when evaluating fuel efficiency in this study.

- Trailer Type. As Exhibit 5-12 indicates, the truck van is the most heavily represented trailer type in this study. It is used in 16 scenarios. Other trailer types used in this investigation, in descending order, include the truck flatbed, with and without sides, truck container, truck dump trailer and truck auto hauler. Illustrations of each trailer type are shown in Exhibit 5-13.

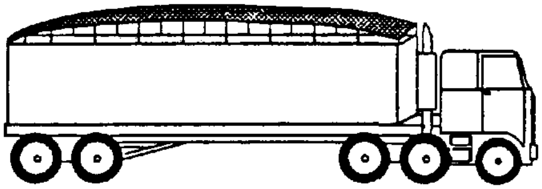
EXHIBIT 5-12
DISTRIBUTION OF TRAILER TYPES

TRAILER TYPE	NUMBER OF SCENARIOS
Van Trailer	16
Flatbed without sides	10
Flatbed with sides	4
Container	4
Dump Trailer	1
Auto Hauler	3
Total	38

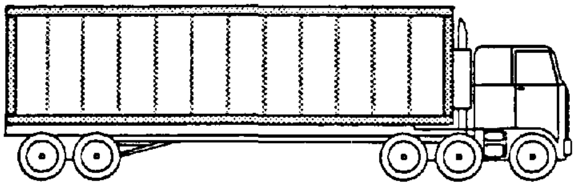
EXHIBIT 5-13
TRUCK TRAILER TYPES



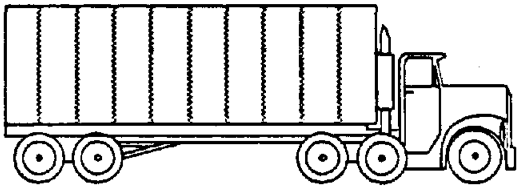
*TRUCK FLATBED WITHOUT SIDES TRAILER (48')
AND CONVENTIONAL TRACTOR*



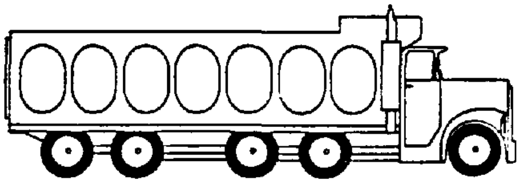
*TRUCK FLATBED WITH SIDES TRAILER (45')
AND CABOVER TRACTOR*



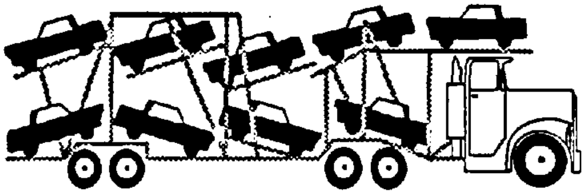
*TRUCK VAN TRAILER (48')
AND CABOVER TRACTOR*



*TRUCK CONTAINER TRAILER (40')
AND CONVENTIONAL TRACTOR*



*TRUCK DUMP TRAILER (40')
AND CONVENTIONAL TRACTOR*



*TRUCK AUTO HAULER TRAILER (44')
AND CONVENTIONAL TRACTOR*

- <u>Truck Aerodynamics</u>. Exhibit 5-14 lists the trailer types and corresponding aerodynamic aids used to improve truck fuel efficiency. It is common for a truck van to have rounded front corners and smooth sides to lower its level of wind resistance and thereby experience improved fuel economy. Truck dump trailers also have this advantage. Truck containers possess square corners and ribbed sides which encourage wind swirls and result in decreased fuel efficiency. Truck auto haulers possess poor aerodynamics due to their open frames. Roof deflectors, cab extenders, side skirts and aerodynamic bumpers with lights are used on the truck vans, truck containers and truck dump trailers but not on the truck auto haulers and truck flatbeds. The use of each type of aerodynamic aid is discussed below.

EXHIBIT 5-14
TRAILER AERODYNAMICS

TRAILER TYPE	TRAILER CORNERS/ SIDES	ROOF DEFLEC- TORS	CAB EXTEN- DERS	SIDE SKIRTS	AERO BUMPER LIGHTS
Van Trailer	Round/Smooth	Yes	Yes	Yes	Yes
Flatbed					
- without sides	Open frame	No	No	No	No
- with sides	Open top with tarp	No	No	No	No
Auto Hauler	Open frame	No	No	No	No
Container	Square ribbed	Yes	Yes	Yes	Yes
Dump Trailer	Round/Smooth	Yes	Yes	Yes	Yes

  - <u>Roof Deflectors</u>. The roof deflector is a device placed on top of the cab and causes the wind to be directed over the top of the trailer. This is effective only if the trailer height is greater than the tractor cab height.

  - <u>Cab Extenders</u>. Cab extenders are located on the back sides of the tractor and are used to minimize the opening between the tractor and trailer where wind may form pockets and negatively impact fuel usage. Because of their open frames, the truck auto hauler and truck flatbed would not benefit from the use of cab extenders.

- <u>Side Skirts</u>. Side skirts are placed on the front sides of the cab about halfway up and are used to deflect the wind to the side of the trailer. Trailers which are wider than their tractor counterpart utilize this aerodynamic aid. Since the truck flatbed is as wide as its tractor, side skirts are not needed.

- <u>Aerodynamic Bumpers With Lights</u>. Aerodynamic bumpers with lights are on the lowest part of the tractor and deflect wind to the side of the vehicle.

- <u>Tires</u>. As shown in Exhibit 5-15, each trailer type uses the same tire size and type except for the truck auto hauler which uses a smaller rim diameter tire. All trailers use the low profile radial which has a rolling resistance value of .63. This value means the low profile radial has less friction than a standard radial which possesses a rolling resistance of .70. This lower rolling resistance value translates into improved fuel economy. The smaller rim diameter tire used by the truck auto hauler increases the required number of revolutions per mile - 516 compared to 501 for the other tire rim diameter. Greater energy is required to move the tire more revolutions. Thus, greater fuel savings can be achieved through use of the larger rim diameter used in this study.

EXHIBIT 5-15
TIRE SIZES OF TRAILER TYPES

TIRE SIZE/TYPE	REVOLUTIONS PER MILE	TRAILER TYPE
275/80R24.5 Low Profile Radial	501	Van Trailer Flatbed with Sides Flatbed without Sides Dump Trailer Container
275/80R22.5 Low Profile Radial	516	Auto Hauler

- <u>Accessories</u>. Each truck scenario uses a cooling fan and power steering as is typical for most line haul trucks. Both of these accessories absorb power which would otherwise be used to move the vehicle, thus they increase fuel use. A modulating fan drive will increase fuel efficiency by turning itself off when not needed. Since horsepower is required to operate the fan, fuel will be saved when it is not being driven. Use of the cooling fan results in a decline of .1 horsepower. Similarly, power steering subtracts 3 horsepower from the engine. Air conditioning was not selected; the truck simulations are assumed to occur during comfortable ambient temperatures.

5.3.3 Payload Characteristics

The truck service scenarios in this study include rail competitive commodities. The types of commodities assumed to be carried by trailer type are as follows:

- Truck Van Trailer. Commodities carried in the truck van include canned goods, miscellaneous food products, beverages, plastic materials, canned vegetables, clay and chemical products.

- Truck Flatbed (With Sides) Trailer. Commodities carried on the truck flatbed with sides include grain products and corn. These commodities are protected from adverse weather conditions by a tarp which is placed over them.

- Truck Flatbed (Without Sides) Trailer. Commodities carried on the truck flatbed without sides include lumber, plywood, steel products, sawmill products, prefabricated wood products and pulpwood.

- Truck Container Trailer. Commodities carried in the truck container in this study include containerized freight and imported electronics.

- Truck Auto Hauler Trailer. Commodities carried on the truck auto hauler include automobiles and light-duty trucks.

- Truck Dump Trailer. Wood chips are the only commodity carried in the single truck dump trailer for this study.

A complete list of scenario trailer type and commodity is contained in Exhibit D-1 in Appendix D.

5.3.4 Route Characteristics

The Cummins Engine Company Vehicle Mission Simulation (VMS) model is based on various road data documented and held as proprietary information by Cummins Engine Co. A variety of sources were contacted to request characteristics data of the studied routes. These sources include the Association of American Railroads, the American Trucking Association, the Transportation Research Board, J.B. Hunt, Inc., Navistar, the Western Highway Institute, the Federal Highway Administration and the National Highway Traffic Safety Administration. The contacted sources were not able to provide terrain information on the routes.

In lieu of route profiles, a scale was developed to rate the truck route characteristics. The scale was developed based on the Cummins VMS output report, which includes data on the extent of engine utilization. These data, as shown in Exhibit D-5 in Appendix D, include time at full throttle, average engine speed, engine load factor, total gear shifts and time on brakes. It was determined that the amount of time on brakes may be indicative of terrain difficulty. This variable was then divided by route distance to normalize the data for each scenario. The calculated values for each scenario were then used to develop a scale to measure route severity. The route severity scale is presented in Appendix F. Route severity is measured in increments of .5 with 0 representing an easy terrain and 5.0 representing a difficult terrain.

* * * * *

Forty-three rail scenarios (11 regional/local and 32 Class I) and thirty-eight truck scenarios were defined prior to the execution of two computer simulation models. The scenario assumptions include equipment type, commodities carried, route and load characteristics. The next chapter presents analysis of the fuel efficiency findings from the computer simulation of the Class I service and regional/local scenarios.

6.0 SIMULATION RESULTS

This chapter compares the fuel efficiency results of the rail and truck simulations. Chapter 7 takes circuity into account, comparing fuel consumption for each mode and each scenario. Forty-three scenarios are defined for rail and thirty-eight for truck. This difference is attributed to the fact that in several scenarios a Class I rail route was separated into two legs. This occurred when the train consist was changed at a midpoint in the Class I route. The energy efficiency of the total rail route is the weighted average of the two legs. Railroads often reconfigure trains at intermediate points. For these scenarios however, the corresponding truck moved over the most direct route between the major origin and destination. Thirty-two of the scenarios reflect Class I rail movements and twenty-seven reflect truck over-the-road movements. Eleven scenarios reflect regional/local railroad and local truck operations. The scenarios are designed to be representative of typical operations of both forms of transportation. Fleet dispatchers, operators, managers, engineers and consultants contributed to definition of the scenarios.

The train performance simulator model (TPS) obtained from the U.S. Department of Transportation, Transportation Systems Center (TSC), was used to simulate rail performance over some of the scenario routes, while results were obtained from individual railroads for other routes. Truck simulation was executed with the Cummins Engine Company Vehicle Mission Simulation (VMS) model.

The simulation results are presented in three sections as follows:

- Summary of results for all scenarios
- Rail vs. truck fuel efficiency in Class I scenarios
- Rail vs. truck fuel efficiency in regional/local scenarios.

Each is discussed below.

6.1 SUMMARY OF RESULTS FOR ALL SCENARIOS

Exhibits 6-1 and 6-2 present summaries of rail and truck scenario characteristics and fuel efficiency findings. The factors in these exhibits contribute to the fuel efficiency for the respective mode of transportation. More detailed analysis of each scenario categorized according to distance is contained in subsequent sections.

EXHIBIT 6-1
SUMMARY OF RAIL SCENARIO CHARACTERISTICS

SCENARIO	EQUIP. TYPE	DISTANCE *** (MILES)	RAIL GRADE SEVRITY*	RAIL CURVATURE SEVERITY*	HP PER TRLNG TON	CAR LADING WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail01	M	343	1.50	2.50	1.1	43	43	471	2.82
Rail02	M	343	1.50	2.50	1.6	43	43	414	2.54
Rail03	M/A	343	1.50	2.50	0.9	43	43	499	5.61
Rail04	TOFC	829	2.16	**	2.7	51	42	281	1.84
Rail05	DSTK	829	2.16	**	2.7	210	41	281	2.13
Rail06	M	829	2.16	**	2.1	75	40	450	2.88
Rail07	TOFC	1,333	1.35	**	2.2	51	54	355	2.32
Rail08	DSTK	1,333	1.35	**	2.7	210	54	367	2.78
Rail09	M	1,333	1.35	**	1.0	75	50	805	5.16
Rail10	TOFC	1,007	1.53	1.50	2.9	40	51	209	1.56
Rail11	M	1,007	1.53	1.50	2.0	68	51	486	3.28
Rail12	TOFC	261	1.50	1.65	2.0	40	44	227	1.61
Rail13	M	261	1.50	1.65	0.7	94	37	843	5.51
Rail14	TOFC	579	2.37	3.53	2.0	40	40	251	1.78
Rail15	M/A	579	2.37	3.53	0.9	28	34	279	3.32
Rail16	TOFC	707	2.82	1.74	3.1	48	39	240	1.63
Rail17	M	426	2.26	2.11	0.6	70	37	654	4.48
Rail18	M	281	3.67	2.66	1.0	72	34	508	3.85
Rail19	TOFC	604	3.07	2.08	3.7	40	38	280	1.84
Rail20	M	604	3.07	2.08	1.2	72	33	688	5.25
Rail21	TOFC	251	1.25	1.10	3.1	40	56	213	1.55
Rail22	TOFC	387	2.25	1.40	5.7	40	62	196	1.40
Rail23	M	462	2.00	1.10	1.5	70	53	767	5.44
Rail24	M	126	1.90	1.40	2.2	70	55	608	4.31
Rail25	TOFC	1,891	2.57	1.62	3.8	30	51	229	1.72
Rail26	M	1,891	2.57	1.62	1.5	96	41	676	4.25
Rail27	DSTK	1,891	2.57	1.62	2.3	150	49	350	3.43
Rail28	AUTO	1,799	2.82	1.71	2.1	24	46	206	2.40
Rail29	DSTK	1,801	2.78	1.71	2.8	150	51	304	3.04
Rail30	DSTK	778	3.38	2.03	2.8	150	46	243	2.51
Rail31	M	1,856	2.20	1.77	2.7	62	49	465	2.96
Rail32	TOFC	961	1.61	1.64	2.8	30	50	265	1.84
Rail33	M	74	1.75	1.21	1.3	98	36	668	4.51
Rail34	M	74	1.75	1.21	1.3	69	36	596	4.03
Rail35	M	74	1.75	1.21	1.3	70	36	635	4.29
Rail36	M	74	1.75	1.21	1.3	77	36	619	4.30
Rail37	M	54	2.80	1.93	2.1	90	22	682	5.21
Rail38	M	54	2.80	1.93	2.1	100	22	641	4.75
Rail39	M	54	2.80	1.93	2.1	75	22	625	4.46
Rail40	M	22	1.56	1.51	2.5	99	14	1,104	7.77
Rail41	M	22	1.56	1.51	2.5	77	14	890	5.93
Rail42	M	22	1.56	1.51	1.0	74	14	1,086	8.29
Rail43	M	22	1.56	1.51	1.0	95	14	1,179	9.00

Rail: TOFC - Trailer-on-Flatcar, M - Mixed Freight, M/A - Mixed Freight with Autos
DSTK - Double-stack, Auto - Solid Auto,

* See Appendix E for an explanation of the method for evaluating rail route severity.

** Data was not available from the participating railroad.

*** Rail distance shown is line-haul distance only. Not shown for the Class I service scenarios are 60 miles of rail switching or 60 miles of truck drayage which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

EXHIBIT 6-2
SUMMARY OF TRUCK SCENARIO CHARACTERISTICS

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)	TRUCK TERRAIN SEVERITY RATING*	PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)
Truck01	F	355	1.5	24	55	167
Truck02	V	355	1.5	24	55	163
Truck03	A	355	1.5	15	55	89
Truck04	V	2,093	3.0	24	58	153
Truck05	C	2,093	2.5	21	58	132
Truck06	F	2,093	3.0	24	58	156
		**				
		**				
		**				
Truck10	V	1,030	1.5	21	59	133
Truck11	V	1,030	1.5	24	59	148
Truck12	V	715	3.0	22	58	141
Truck13	F	299	2.0	24	58	153
		**				
Truck15	A	449	3.0	15	56	84
Truck16	FS	720	2.0	22	60	147
Truck17	F	462	1.0	22	60	146
Truck18	V	258	3.0	21	59	132
Truck19	V	569	1.0	24	60	152
Truck20	V	569	1.0	20	60	131
Truck21	V	237	1.0	22	60	137
Truck22	V	429	3.5	22	56	140
Truck23	F	615	2.5	22	57	141
		**				
Truck25	F	1,910	2.0	22	58	133
Truck26	F	1,910	2.5	24	58	159
Truck27	C	1,910	2.0	15	59	102
Truck28	A	1,608	5.0	15	56	86
Truck29	C	1,608	5.0	15	57	100
Truck30	C	720	3.0	15	58	97
Truck31	V	1,674	1.0	24	58	156
Truck32	V	996	1.0	22	60	143
Truck33	FS	74	1.0	22	59	148
Truck34	F	74	1.0	23	60	148
Truck35	F	74	1.0	23	60	148
Truck36	D	74	1.0	22	60	144
Truck37	V	53	5.0	22	53	131
Truck38	FS	53	5.0	22	53	135
Truck39	V	53	5.0	24	53	140
Truck40	FS	18	1.0	22	58	142
Truck41	F	18	1.0	24	59	150
Truck42	V	18	1.0	21	59	131
Truck43	V	18	1.0	21	59	131

* See Appendix F for an explanation of the method for evaluating truck route severity.

** In selected routes the rail service was separated into two legs, or scenarios, while the truck service required only one scenario. Thus, there are fewer truck than rail scenarios. See Exhibit 7-6 for additional explanation.

Truck: V - Van, F - Flatbed

6.2 RAIL VS. TRUCK FUEL EFFICIENCY IN CLASS I SCENARIOS

This section contains comparative analysis of Class I rail/over-the-road truck service. For the purpose of this report, all Class I rail moves are 100 miles or longer. The thirty-two rail scenarios and twenty-seven truck scenarios comprising this section vary according to route and vehicle configuration. Key factors affecting fuel efficiency include average speed, terrain, weight and equipment type for each mode. Other important fuel efficiency barometers include horsepower per trailing ton for rail and payload weight for truck. Included in the rail Class I service fuel efficiency calculation are fuel consumption for rail switching, rail terminal operations and truck drayage where applicable. A discussion of the fuel efficiency calculation methodology is detailed in Chapter 4.

The Class I/over-the-road scenarios are divided into segments according to distance as follows:

- Medium short: 125- to 355-mile range
- Medium: 387- to 604-mile range
- Medium long: 707- to 1,030-mile range
- Long: over 1,300 miles.

Rail is more fuel efficient than competing truckload service at all distances. Analysis of each distance segment is presented below.

6.2.1 Comparisons on Medium Short Routes of 125 to 355 Miles

Four routes fall into the medium short distance category. They encompass the six scenarios numbered 1, 2, 3, 13, 18 and 21. Exhibit 6-3 compares rail and truck for those in which one scenario per route is simulated.

EXHIBIT 6-3
FUEL EFFICIENCY COMPARISON FOR MEDIUM SHORT ROUTES WITH ONE SCENARIO PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail21	TOFC	251	1.25	1.10		3.1	40	56	213	1.55
Truck21	V	237			1.0		22	60	137	
Rail13	M	261	1.50	1.65		0.7	94	37	843	5.51
Truck13	F	299			2.0		24	58	153	
Rail18	M	281	3.67	2.66		1.0	72	34	508	3.85
Truck18	V	258			3.0		22	59	132	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Estimate
Neject This
needed

Rail: TOFC - Trailer-on-Flatcar, M - Mixed Freight
Truck: V - Van, F - Flatbed

- <u>The Greater Frontal Area and Undercarriage Space of the Rail TOFC Has a Negative Impact on Fuel Efficiency on the 251-Mile Rail Route</u>. The rail TOFC has better fuel efficiency than the truck van trailer in scenario 21, however its fuel efficiency is much less than half that of the rail mixed freights in scenarios 13 and 18. The lower fuel efficiency of the rail TOFC may be attributed to a higher horsepower per trailing ton of 3.1, and a high average speed of 56 mph used for this time sensitive freight, versus 37 and 34 mph for the mixed freight. Even with the 60 miles per hour truck van trailer average speed, the highest average truck speed of the study, this truck still attained 137 ton-miles per gallon. Typically, a one mile per hour increase in speed equals a .1 mile per gallon fuel increase. Therefore, one might expect decreased fuel efficiency. However, this effect may have been offset by an easier route terrain as shown by the 1.0 truck terrain severity rating. The rail grade and curvature severity ratings of 1.25 and 1.10, respectively, are the lowest of the study.

- <u>The Truck Flatbed Trailer and Truck Van Trailer are Considerably Less Fuel Efficient than the Rail Mixed Freight on the 261-Mile Rail Route</u>. In scenario 13, the fuel efficiency of the rail mixed freight compares favorably with the truck flatbed trailer. This is reflected in the 5.51 times fuel efficiency of rail. The fuel efficiency value of 843 ton-miles per gallon is the highest obtained in this study. Rail achieves this advantage over relatively easy track terrain as illustrated by grade and curvature ratings of 1.50 and 1.65. The rail horsepower per trailing ton is 0.7, which is quite low, and the average speed is 37 miles per hour. The commodity analyzed is steel products. This lading was hauled by a rail gondola and a truck flatbed trailer.

- <u>The Truck Trailers are Also Less Fuel Efficient than the Rail Mixed Freight on the 281-Mile Rail Route</u>. In scenario 18, the rail mixed freight has a fuel efficiency value of 508 ton-miles per gallon or 3.85 times that of the truck van trailer traversing the same route. The rail achieves this fuel efficiency despite a 3.67 rail grade severity rating, the highest of the study, and a 2.66 rail curvature rating. The horsepower per trailing ton is a low 1.0, and the average speed of 34 miles per hour is typical for mixed freight. The truck van trailer averages 59 miles per hour and carries 22 tons of payload. The route is moderately difficult for trucks as the 3.0 terrain severity rating indicates.

Exhibit 6-4 shows comparative fuel efficiencies over a 343-mile rail route with different equipment types. Three different scenarios were simulated on this route.

EXHIBIT 6-4
FUEL EFFICIENCY COMPARISON FOR MEDIUM SHORT ROUTES WITH MULTIPLE SCENARIOS PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DISTANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail03	M/A	343	1.50	2.50		0.9	43	43	499	5.61
Rail01	M	343	1.50	2.50		1.1	43	43	471	2.82
Rail02	M	343	1.50	2.50		1.6	43	43	414	2.54
Truck03	A	355			1.5		15	55	89	
Truck01	F	355			1.5		24	55	167	
Truck02	V	355			1.5		24	55	163	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: M/A - Mixed Freight with Autos, M - Mixed Freight
Truck: A - Auto Hauler, F - Flatbed, V - Van

- The Low Payload and Fuel Efficiency of the Truck Auto Hauler Trailer Contributes to a Relatively Higher Rail Fuel Efficiency for the 343-Mile Rail Route. Scenarios 01, 02 and 03 achieve rail mixed freight fuel efficiencies ranging from 414 to 499 ton-miles per gallon. These efficiencies translate to a 2.54 and 2.82 fuel efficiency ratio for scenarios 01 and 02 and a 5.61 fuel efficiency ratio in favor of rail for scenario 03. The 5.61 ratio in Rail03 is high due to the relatively low fuel efficiency of the truck auto hauler trailer. This trailer has poor aerodynamics due to the spacing of vehicles on it. Thus, the engine must work harder to travel the same speed. This is further evidenced by the truck auto hauler trailer's higher average engine speed and engine load (see Appendix D, Exhibit D-5). In addition, the truck auto hauler trailer carries 15 tons of payload, the lowest truck payload of the study. The rail horsepower per trailing ton is relatively low, 0.9 for the rail mixed freight with autos and 1.1 and 1.6 for the other rail mixed freight scenarios. The terrain appears fairly easy for both rail and truck, although the rail curvature rating of 2.50 is moderate. The average speed of 43 miles per hour is not atypical for rail mixed freight and the 55 miles per hour is slightly low for the truck trailers. The truck flatbed trailer in scenario 01 achieves 167 ton-miles per gallon, the highest truck fuel efficiency of the study. This truck carries a heavy payload weight of 24 tons.

6.2.2 Comparisons on Medium Distance Routes Ranging from 387 to 604 Miles

Five routes fall into the medium distance category. They encompass the scenarios numbered 15, 17, 19, 20, 22 and the two rail scenarios, 23 and 24, which are combined and compared to truck scenario 23. The results for these scenarios can be found in Exhibits 6-5, 6-6 and 6-7. The rail mixed freight trains achieve the highest fuel efficiency among all the equipment types. Exhibit 6-5 summarizes the results for the three routes in which one scenario per route was simulated. The fuel efficiency results for each route are discussed below.

EXHIBIT 6-5
FUEL EFFICIENCY COMPARISON FOR MEDIUM DISTANCE ROUTES WITH ONE SCENARIO PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail22	TOFC	387	2.25	1.40		5.7	40	62	196	1.40
Truck22	V	429			3.5		22	56	140	
Rail17	M	426	2.26	2.11		0.6	70	37	654	4.48
Truck17	F	462			1.0		22	60	146	
Rail15	M/A	579	2.37	3.53		0.9	28	34	279	3.32
Truck15	A	449			5.0		15	56	84	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: TOFC - Trailer-on-Flatcar, M - Mixed Freight
M/A - Mixed Freight with Autos
Truck: V - Van, F - Flatbed, A - Auto Hauler

- <u>A Low Rail TOFC Lading Weight, High Horsepower per Trailing Ton Ratio, and High Average Speed Contribute to the Reduction of the Rail Fuel Efficiency Advantage on the 387-Mile Rail Route</u>. The rail fuel efficiency advantage over truck of 1.40 in scenario 22 is the lowest of the study. The 5.7 horsepower per trailing ton ratio in this scenario is the highest in the study and contributes to the lower fuel efficiency advantage.

Again, as in scenario 21, this may be time sensitive freight which requires more power to enable the train to travel faster. The 62 miles per hour speed is greater than the corresponding truck speed of 56 miles per hour, and is the highest speed of any equipment type in the study. The high speed and poor aerodynamics of rail TOFC also factors into the lower fuel efficiency. The lading weight for the rail TOFC carrying beverages is also relatively low at 40 tons carried in two trailers. The rail terrain is not too difficult as the 2.25 and 1.40 grade and severity ratings attest. The truck van trailer traverses terrain with a 3.5 rating and hauls a 22 ton payload weight.

- <u>The Rail Mixed Freight on the 426-Mile Rail Route Has a Low Horsepower per Trailing Ton Ratio and Achieves Very High Fuel Efficiency Compared with Truckload Service</u>. The rail mixed freight of Exhibit 6-5 illustrates high fuel efficiency of 654 ton-miles per gallon. This results in a fuel efficiency 4.48 times that of truckload service. The 0.6 horsepower per trailing ton value of Rail17 is the lowest of the study. The terrain of Rail17 is almost moderate in difficulty as the 2.26 and 2.11 grade and curvature severity ratings attest. The truck flatbed trailer achieves a typical 146 ton-miles per gallon over an easy route (1.0 terrain rating). This trailer hauls 22 tons of sawmill products.

- <u>The Low Fuel Efficiency of the Truck Auto Hauler Contributes to Higher Rail Fuel Efficiency on the 579-Mile Rail Route</u>. Examining the third route in Exhibit 6-5 reveals rail fuel efficiencies considerably above their truck counterparts. The rail/truck comparative fuel efficiencies are attributable to a number of factors. Rail15's aerodynamics are adversely affected because it carries autos in its consist. This contributes to its fuel efficiency of 279 ton-miles per gallon, the lowest of any rail mixed freight of this study. The truck auto hauler's low fuel efficiency also affects the 3.32 fuel efficiency ratio advantage realized by the rail mixed freight with autos. The truck auto hauler also traverses terrain with the maximum severity rating of 5.0. In addition to aerodynamic problems, the truck auto hauler carries 15 tons of payload which is considerably less weight than the payload of other truck trailers. The rail mixed freight with autos travels a rather slow 34 miles per hour.

Exhibit 6-6 summarizes the fuel efficiency results for the 604-mile rail route, over which two scenarios for rail and truck were executed. On this route the rail mixed freight achieves better fuel efficiency than rail TOFC. Both equipment types have improved fuel efficiency relative to truckload service.

EXHIBIT 6-6
FUEL EFFICIENCY COMPARISON FOR MEDIUM DISTANCE ROUTES WITH TWO SCENARIOS PER ROUTE

SCEN-ARIO EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail20 M	604	3.07	2.08		1.2	72	33	688	5.25
Rail19 TOFC	604	3.07	2.08		3.7	40	38	280	1.84
Truck20 V	569			1.0		20	60	131	
Truck19 V	569			1.0		24	60	152	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: M - Mixed Freight, TOFC - Trailer-on-Flatcar
Truck: V - Van

- A Rail TOFC Higher Horsepower per Trailing Ton Ratio and Higher Average Speed Reduce Fuel Efficiency Relative to the More Energy Efficient Rail Mixed Freight on the 604-Mile Rail Route. The rail TOFC in scenario 19 is outmatched in ton-miles per gallon by the rail mixed freight in scenario 20. The rail TOFC efficiency of 280 ton-miles per gallon is consistent with previous rail TOFC movements and is considerably lower than the 688 ton-miles per gallon of the rail mixed freight. The rail grade severity of 3.07 is high whereas the truck terrain severity rating is the minimum value of 1.0. The truck van trailers assumed on this 569-mile route indicate that it is in the best interest of truck fuel efficiency to carry as much payload weight as possible. Both truck van trailers travel about the same speed, but even though the truck van trailer in Truck19 consumes 3 gallons more fuel, it carries 4 tons more commodity weight and achieves a fuel efficiency 16 percent greater than Truck20 (152 versus 131 ton-miles per gallon). It is interesting to note that in both of these routes the rail average speed is at least 25 percent lower than the corresponding truck average speed.

Exhibit 6-7 presents a summation of a route with two rail scenarios which are combined to form one composite rail trip. This is due to the fact that the train movement was accomplished in two legs while the truck moved directly from origin to destination. The combined train values are weighted average calculations of the rail mixed freights of scenarios 23 and 24.

EXHIBIT 6-7
FUEL EFFICIENCY COMPARISON FOR MEDIUM DISTANCE ROUTES WITH TWO RAIL SCENARIOS COMBINED

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail23	M	462	2.00	1.10		1.5	70	53	767	5.44
Rail24	M	126	1.90	1.40		2.2	70	55	608	4.31
Combined		588	1.98	1.16					740	5.25
Truck23	F	615			2.5		22	57	141	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: M - Mixed Freight
Truck: F - Flatbed

- <u>The Rail Mixed Freight is Considerably More Fuel Efficient than the Truck Flatbed Trailer on the Combined 588-Mile Rail Route</u>. The fuel efficiency of the rail mixed freight compares favorably with the truck flatbed trailer as indicated in the 5.25 times fuel efficiency of rail. Rail achieves this advantage over terrain which exhibits more difficult grades than curvature as illustrated by weighted average grade and curvature ratings of 1.98 and 1.16 respectively. The combined rail route is heavily influenced by Rail23 because it encompasses 462 of the 588 miles. It has a 1.5 horsepower per trailing ton ratio and a high average speed for rail mixed freight of 53.09 miles per hour. In Rail24 the rail horsepower per trailing ton is 2.2 and the average speed of 55 miles per hour is the highest for rail mixed freight in this study. A truck flatbed with open frame and a rail box car are used to carry the commodity, sawmill products.

6.2.3 Comparisons on Medium Long Routes Ranging from 707 to 1,030 Miles

The routes ranging from 707 to 1,030 miles comprise the medium long routes. Rail fuel efficiency ranges from 1.56 to

3.28 times more fuel efficient than truckload service on these routes. The following analysis is organized into two sections depending on whether one or three scenarios were simulated for each route.

Exhibit 6-8 compares fuel efficiency of intermodal trains with truckload service on three routes with one rail and truck scenario per route. Scenarios 16, 30 and 32 carry grain products, containerized freight and beverages respectively. An assessment of the results for each route is presented below.

EXHIBIT 6-8
FUEL EFFICIENCY COMPARISON FOR MEDIUM LONG ROUTES WITH ONE SCENARIO PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail16	TOFC	707	2.82	1.74		3.1	48	39	240	1.63
Truck16	FS	720			2.0		22	60	147	
Rail30	DSTK	778	3.38	2.03		2.8	150	46	243	2.51
Truck30	C	720			3.0		15	58	97	
Rail32	TOFC	961	1.61	1.64		2.8	30	50	265	1.84
Truck32	V	996			1.0		22	60	144	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: TOFC - Trailer-on-Flatcar, DSTK - Double-stack
Truck: FS - Flatbed with Sides, C - Container, V - Van

- Even Though the Rail TOFC has a Relatively High Horsepower per Trailing Ton Ratio, it has Superior Fuel Efficiency When Compared with the Truck Flatbed Trailer on the 707-Mile Rail Route. Rail TOFC fuel efficiency has a 1.63 fuel efficiency ratio over the corresponding truck flatbed with sides trailer. The horsepower per trailing ton ratio of 3.1 is high, but is not related to above average speed as the 39 miles per hour value indicates. Rather, it may be used to assist the train in negotiating some difficult grades. It should be noted that the grade severity rating accounts for grade steepness and frequency. Thus, although the grade severity rating is 2.82, this does not mean that there may not be some heavy grades. The truck flatbed with sides trailer used for hauling grain in this scenario is covered with a tarp and is not equipped with special aerodynamic aids. This is the only long distance scenario that uses the truck flatbed with sides trailer. The truck probably averages a higher speed of

60 miles per hour due to the relatively easy terrain as evidenced by the 2.0 truck terrain severity rating.

- <u>The Rail Double-stack is 2.51 Times More Fuel Efficient than the Truck Container Trailer on the 778-Mile Rail Route</u>. The rail double-stack has a moderate horsepower per trailing ton value of 2.8 and averages 46 miles per hour. The truck container trailer carries a light payload of 15 tons which contributes to increasing the rail/truck fuel efficiency ratio. The fuel efficiency values of the rail and truck, 243 and 97 ton-miles per gallon, are relatively low compared to other scenarios in this study. The containers moved by each mode of transportation have ribbed sides which are not conducive to good fuel efficiency. In addition, the terrain each traverses is moderately difficult as the 3.38 rail grade and 2.03 rail curvature ratings, and 3.0 truck terrain severity rating illustrate.

- <u>A High Rail TOFC Average Speed Contributes to the Reduction of the Rail Advantage over Truck on the 961-Mile Rail Route</u>. The TOFC scenario 32 achieves fuel efficiency 1.84 times that of the truck van trailer. The 50 miles per hour average TOFC speed, higher than most other TOFC runs in this study contributes to the lower rail fuel efficiency. The easy truck terrain probably accounts for the high 60 miles per hour average truck speed. The rail terrain is fairly easy as the values indicate.

Exhibit 6-9 presents results for one medium long distance route that is 1,007 rail miles in length. Two rail and two truck operating scenarios were simulated for this route.

EXHIBIT 6-9
FUEL EFFICIENCY COMPARISON FOR MEDIUM LONG ROUTES WITH MULTIPLE SCENARIOS PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail11	M	1,007	1.53	1.50		2.0	68	51	486	3.28
Rail10	TOFC	1,007	1.53	1.50		2.9	40	51	209	1.56
Truck11	V	1,030			1.5		24	59	148	
Truck10	V	1,030			1.5		21	59	134	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: M - Mixed Freight, TOFC -Trailer-on-Flatcar
Truck: V - Van

- <u>A Heavy Truck Payload Weight Hauled Over a Long Distance Brings Truckload Service Closer to Rail Fuel Efficiency Levels on the 1,007-Mile Rail Route</u>. In Rail10, the horsepower per trailing ton ratio of 2.9 and fairly high speed of 51 miles per hour contributes to a fuel efficiency value of 209 ton-miles per gallon, the third lowest rail efficiency of the study. The truck van trailer of scenario 10 achieves 134 ton-miles per gallon. The difference between Rail10 and Truck10 is one of the smallest differences between truck and rail in this study, as reflected in the 1.56 fuel efficiency ratio. The best fuel efficiency for the 1,007-mile rail route is obtained by the rail mixed freight. Even when compared with the truck van trailer with higher payload weight and fuel efficiency, the mixed train is superior by 3.28 to 1. It is interesting to note that while both truck scenarios use van trailers, the better fuel efficiency is obtained with the truck van trailer carrying the heavier payload. The route traversed is easy as the approximately 1.5 terrain ratings for both modes indicates.

Exhibit 6-10 summarizes one medium long route made up of two rail scenarios, Rail12 and Rail14, combined. This combination is due to the fact that the rail freight movement was accomplished in two legs while the truck freight was moved in one unbroken trip. This route is 840 rail miles long and evaluates rail TOFC versus a truck van trailer. It should be noted that the two rail scenario configurations are identical (i.e. same number of cars, same power units), thus a weighted average of the two is the same as executing just one train.

EXHIBIT 6-10
FUEL EFFICIENCY COMPARISON FOR MEDIUM LONG ROUTES WITH TWO RAIL SCENARIOS COMBINED

SCENARIO EQUIP. TYPE	DISTANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail12 TOFC	261	1.50	1.65		2.0	40	44	227	1.61
Rail14 TOFC	579	2.37	3.53		2.0	40	40	251	1.78
Combined	840	2.10	2.95		2.0		42	244	1.73
Truck12 V	715			3.0		22	58	141	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: TOFC - Trailer-on-Flatcar
Truck: V - Van

- A Low Rail TOFC Horsepower per Trailing Ton Ratio and Low Average Speed Contribute to Rail Fuel Efficiency Greater than Truckload Service. The rail TOFC horsepower per trailing ton value of 2.0 is the lowest for this equipment type in this study. The 42 miles per hour combined speed is also in the lower range for rail TOFC. The resulting 244 ton-miles per gallon compares favorably to the 141 ton-miles per gallon obtained by the truck van trailer. The rail track profile indicates moderate curvature of 2.95 and less than moderate grades as the 2.10 rating attests.

6.2.4 Comparisons on Long Distance Routes Over 1,300 Miles

Five scenarios make up the long distance range for the study. The fuel efficiency results are examined in three sections; fuel efficiency comparison for long distance routes with 1) one scenario per route, 2) with three scenarios per route and 3) with two combined rail scenarios per route.

Exhibit 6-11 examines three routes which are 1,799 miles and above in length. The fuel efficiency for rail on these routes varies from 206 to 465 ton-miles per gallon. The performance of rail vs. truckload service is examined below separately for each route.

- Rail is More Fuel Efficient in Auto Haulage over the 1,799-Mile Rail Route. The haulage of automobiles by rail mixed freight in scenario 28 detracts from the aerodynamic performance of this train, but rail still achieves fuel efficiency 2.40 times that of the truck

EXHIBIT 6-11
FUEL EFFICIENCY COMPARISON FOR LONG DISTANCE ROUTES WITH ONE SCENARIO PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail28	A	1,799	2.82	1.71		2.1	24	46	206	2.40
Truck28	A	1,608			5.0		15	56	86	
Rail29	DSTK	1,801	2.78	1.71		2.8	150	51	304	3.04
Truck29	C	1,608			5.0		15	57	100	
Rail31	M	1,856	2.20	1.77		2.7	62	49	465	2.96
Truck31	V	1,674			1.0		24	58	157	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: A - Unit Auto, DSTK - Double-stack, M - Mixed Freight
Truck: A - Auto Hauler, C - Container, V - Van

auto hauler in this scenario. Rail track severity is moderate to easy as evidenced by the rail grade severity of 2.82 and the rail curvature severity of 1.71. Truckload service achieves very low fuel efficiency on this route due to the poor aerodynamics of the truck auto hauler and the low payload of 15 tons. Another contributing factor to poor truck fuel efficiency is the topography. The truck terrain severity rating of 5.0 indicates difficult terrain. The 2.1 horsepower per trailing ton ratio is higher than most rail mixed freight. The speeds for both modes, 46 miles per hour for rail and 56 for truck, are typical.

- <u>The High Lading of the Rail Double-stack is More Fuel Efficient Hauling Containerized Freight Over the 1,800-Mile Rail Route</u>. In scenario 29, the rail double-stack moves at a fairly high rate of speed, 51 miles per hour, and travels over moderate grades and fairly easy curves. The rail double-stack car carries a very high lading weight of 150 tons in ten loaded containers, compared with one truck container trailer payload of 15 tons. The higher rail lading, the poor aerodynamic characteristics of the truck container, and the difficult truck terrain (5.0 rating) contribute to a rail fuel efficiency 3.04 times that of truckload service. The 2.8 horsepower per trailing ton ratio allows the fairly high rail average speed of 51 miles per hour.

- <u>Rail Mixed Freight is More Fuel Efficient than the Truck Van Trailer with Good Aerodynamics on the 1,856-Mile Rail Route</u>. The truck van trailer equipped with aerodynamic aids in scenario 31 achieves very good fuel efficiency of 157 ton-miles per gallon. This truck travels over easy terrain and carries a 24 ton payload. This is an 82 percent increase in ton-miles per gallon over the truck auto hauler in Truck28, and a 57 percent increase over the truck container in Truck29. The rail mixed freight moves over relatively easy terrain, travels rather fast for this equipment type at 49 miles per hour and has a 2.7 hp per trailing ton ratio. Despite the good performance by the truck van trailer, the rail mixed freight is 2.96 times more fuel efficient.

Exhibit 6-12 summarizes six scenarios executed over one long distance rail route 1,891 miles in length. On this route the rail mixed freight achieves fuel efficiency over four times greater than truckload service. Additional observations are presented below.

EXHIBIT 6-12
FUEL EFFICIENCY COMPARISON FOR LONG DISTANCE ROUTES WITH THREE SCENARIOS PER ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail26	M	1,891	2.57	1.62		1.5	96	41	676	4.25
Rail27	DSTK	1,891	2.57	1.62		2.3	150	49	350	3.43
Rail25	TOFC	1,891	2.57	1.62		3.8	30	51	229	1.72
Truck26	F	1,910			2.5		24	58	159	
Truck27	C	1,910			2.0		15	59	102	
Truck25	F	1,910			2.0		22	58	133	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: M - Mixed Freight, DSTK - Double-stack,
TOFC - Trailer-on-Flatcar
Truck: F - Flatbed, C - Container

- A High Rail TOFC Horsepower to Trailing Ton Ratio Contributes to a Lower Rail Advantage Over Truck Service on the 1,891-Mile Rail Route. The rail mixed freight and rail double-stack compare favorably to the truck flatbed trailer and truck container trailer. The rail TOFC also experiences better fuel efficiency than the corresponding truck flatbed trailer, but the 1.72 to 1 fuel efficiency factor is not as great as in previous routes. This may be due to the rail TOFC's rather high horsepower to trailing ton ratio of 3.8 and somewhat high speed of 51 mph. The rail executions are over moderate grades and rather easy curvature and the average speeds are standard for these equipment types. The trucks travel over moderate to easy terrain on this route.

Exhibit 6-13 summarizes the results of three rail combinations over one 2,162-mile rail route. Three rail and truck equipment types are evaluated. These include rail TOFC, double-stack and mixed freight, and truck van, container and flatbed trailers.

- Rail TOFC Service is More than Twice as Fuel Efficient as Truckload Service on the 2,162-Mile Rail Route. In Rail04, rail TOFC has a 2.7 hp per trailing ton ratio and travels 42 miles per hour. Even though Rail07 has a 2.2 hp per trailing ton ratio it travels at a much higher average speed, 54 miles per hour. This may possibly be due to the easier 1.35 grade severity of

Rail07. Rail curvature data was not provided by this railroad. The weighted average fuel efficiency value of 327 ton-miles per gallon is the highest rail TOFC value of the study, and is 2.14 times more efficient than Truck04. The truck van trailer has a fuel efficiency of 153 ton-miles per gallon. The 24 ton payload weight contributes to this higher truck efficiency value.

EXHIBIT 6-13
FUEL EFFICIENCY COMPARISON FOR LONG DISTANCE ROUTES WITH TWO RAIL SCENARIOS COMBINED PER ROUTE

SCENARIO	EQUIP. TYPE	DISTANCE (MILES)*	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail04	TOFC	829	2.16	Data Not Available		2.7	51	42	281	1.84
Rail07	TOFC	1,333	1.35			2.2	51	54	355	2.32
Combined		2,162	1.66						327	2.14
Truck04	V	2,093			3.0		24	58	153	
Rail05	DSTK	829	2.16	Data Not Available		2.7	210	41	281	2.13
Rail08	DSTK	1,333	1.35			2.7	210	54	367	2.78
Combined		2,162	1.66						334	2.53
Truck05	C	2,093			2.5		21	58	132	
Rail06	M	829	2.16	Data Not Available		2.1	75	40	450	2.88
Rail09	M	1,333	1.35			1.0	75	50	805	5.16
Combined		2,162	1.66						669	4.29
Truck06	F	2,093			3.0		24	58	156	

* Rail distance shown is line-haul distance only. Not shown are 60 miles of rail switching or 60 miles of truck drayage, which were included in the ton-mile per gallon calculations. The fuel efficiency calculation took into account fuel used for these operations and terminal operations.

Rail: TOFC - Trailer-on-Flatcar, DSTK - Double-stack,
M - Mixed Freight
Truck: V - Van, C - Container, F - Flatbed

- <u>Rail Double-stack Service is More than Twice as Fuel Efficient as Truckload Service on the 2,162-Mile Rail Route</u>. The rail double-stack of Rail05 and Rail08 are powered at a level similar to the rail TOFC of Rail04 and Rail07. This train achieves the same average speed, and has a slightly higher ton-miles per gallon of 334. The fuel efficiency ratio of 2.53 is greater than the rail TOFC because the truck container trailer of Truck05 has poor aerodynamics even with the use of aerodynamic aids, and carries several tons less commodity than the trailers in Truck04 and Truck06.

- Rail Mixed Freight Achieves a 4.29 Fuel Efficiency Ratio Over the Truck Flatbed Trailer on the 2,162-Mile Rail Route. The truck flatbed trailer of Truck 09 has a relatively high fuel efficiency of 156 ton-miles per gallon, however, it is below that of the corresponding rail scenario. The rail mixed freight, with its low horsepower to trailing ton ratio of 2.1 and 1.0 and more favorable aerodynamics has the highest fuel efficiency of the simulations for this route. The rail mixed freight travels at 40 and 50 miles per hour for Rail06 and Rail09 respectively.

6.3 RAIL VS. TRUCK FUEL EFFICIENCY IN REGIONAL/LOCAL SCENARIOS

Eleven scenarios for regional/local service are analyzed. Many of the same factors that impact fuel efficiency in Class 1 rail and over-the-road truckload service also affect regional/local service. These factors include the lading or payload weight, equipment type, average speed, terrain and other route and vehicle characteristics. The discussion of the eleven scenarios is organized according to the three route lengths of 22, 54 and 74 miles respectively. Rail is more efficient in all of the routes compared.

6.3.1 Comparisons on the 22-Mile Rail Route

The rail scenarios achieve from 5.93 to 9 times more fuel efficiency than the trucks on the 22-mile regional/local route. This high fuel efficiency performance is partly due to the slight downhill slope of the route. Exhibit 6-14 summarizes the fuel efficiency of rail vs. truck for the four scenarios. As shown, the truck travels 4 fewer miles on this route. Factors contributing to the high efficiency of the rail include low horsepower per trailing ton, low rail speed and the favorable aerodynamics of rail mixed freight trains.

EXHIBIT 6-14
FUEL EFFICIENCY COMPARISON FOR THE 22-MILE REGIONAL/LOCAL ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail43	M	22	1.56	1.51		1.0	95	14	1,179	9.00
Rail42	M	22	1.56	1.51		1.0	74	14	1,086	8.29
Rail40	M	22	1.56	1.51		2.5	99	14	1,104	7.77
Rail41	M	22	1.56	1.51		2.5	77	14	890	5.93
Truck43	V	18			1.0		21	59	131	
Truck42	V	18			1.0		21	59	131	
Truck40	FS	18			1.0		22	58	142	
Truck41	F	18			1.0		24	59	150	

Rail: M - Mixed Freight
Truck: V - Van, FS - Flatbed with Sides, F - Flatbed

- Low Horsepower per Trailing Ton Contributes to Rail Fuel Efficiency on this Route. The hp per trailing ton in these scenarios ranges from 1.0 to 2.5. This comparatively low power level contributes to good fuel efficiency. The trucks are all powered by a Cummins F-350 engine. This advanced truck engine has the requisite power to haul the payloads and affects truck fuel efficiency.

- Low Average Rail Speed Contributes to Rail Fuel Efficiency on this Route. The low average rail speed of 14 miles per hour also contributes to high rail fuel efficiency. A reduction in speed will reduce fuel consumed and favorably affect fuel efficiency. This relationship also applies to trucks. In the scenarios on this route, the truck average speed is approximately 59 miles per hour.

- Low Grade and Curvature Severity is a Factor in the Rail Fuel Efficiency on this Route. The rail grade severity of 1.56 is the lowest numeric rating of any of the regional/local scenarios, whereas the curvature severity of 1.51 is a middle value. These low terrain indicators contribute to the high rail fuel efficiency.[1] The truck terrain severity rating of 1.0 is the lowest possible value indicating a relatively flat terrain.

- The Rail Mixed Freight Trains on this Route are Superior in Fuel Efficiency to the Truck Van Trailers and Truck Flatbed Trailers. The rail mixed freights operating on this regional/local route have exceptionally high fuel efficiencies relative to other study scenarios. Here rail achieves from 890 to 1,179 ton-miles per gallon. The aerodynamics of the rail mixed freight trains is a factor in the high rail fuel efficiency. It is interesting to note the truck flatbed trailer of Truck41 achieves a fuel efficiency over 5 percent greater than Truck40, the truck flatbed trailer with sides. The truck van trailer consumes almost the same amount of fuel as the truck flatbed trailer, however it carries 3 tons less payload weight. The trucks on this route have fuel efficiencies ranging from 131 to 150 ton-miles per gallon, which is in the typical range relative to the other truck scenarios in this study.

---

[1] A description of the method for evaluating rail route severity is contained in Appendix E. A description of the method for evaluating truck route severity is contained in Appendix F.

6.3.2 Comparisons on the 54-Mile Regional/Local Route

On the 54-mile regional/local rail route, rail is from 4.46 to 5.21 times more fuel efficient than truckload service. The comparison of fuel efficiency results is presented in Exhibit 6-15. As shown, the truck route is one mile shorter than the rail route.

EXHIBIT 6-15
FUEL EFFICIENCY COMPARISON FOR THE 54-MILE REGIONAL/LOCAL ROUTE

SCENARIO	EQUIP. TYPE	DISTANCE (MILES)	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail37	M	54	2.80	1.93		2.1	90	22	682	5.21
Rail38	M	54	2.80	1.93		2.1	100	22	641	4.75
Rail39	M	54	2.80	1.93		2.1	75	22	625	4.46
Truck37	V	53			5.0		22	53	131	
Truck38	FS	53			5.0		22	53	135	
Truck39	V	53			5.0		24	53	140	

Rail: M - Mixed Freight
Truck: V -Van, FS - Flatbed with Sides

This rail route has heavier grades and curvature, as evidenced by ratings of 2.80 and 1.93 respectively, compared to the 22-mile route. Also, rail operates at a faster speed on this route possibly due to better track conditions. The rail horsepower per trailing ton is 2.1. Factors contributing to the difference in fuel efficiency include rail lading weight, low rail speed, favorable aerodynamics and the amount of truck braking. Each is discussed below.

- High Carload Lading Weight Contributes to Rail Fuel Efficiency on this Route. The rail box cars used to haul clay and canned goods and the covered hopper used to haul grain products have high lading weights of 90, 100 and 75 tons respectively for these relatively dense commodities. In comparison, the truck payloads are 22 and 24 tons. Although these truck payload weights are good, they are significantly less than rail carrying capabilities, particularly on the rail mixed freight trains.

- Low Average Rail Speed Contributes to Rail Fuel Efficiency on this Route. The low average rail speed of 22 miles per hour compared to the truck average speed of 53 miles per hour is a factor in rail fuel efficiency on this route.

- The Rail Mixed Freight Trains on this Route are Superior in Fuel Efficiency to the Truck Van Trailers and Truck Flatbed with Sides Trailer. The rail mixed freights operating on this route have fuel efficiencies ranging from 625 to 682 ton-miles per gallon. Two of the three truck scenarios are truck van trailers carrying different cargo weights. The truck van trailer with the greater commodity weight demonstrates a fuel efficiency of 140 ton-miles per gallon compared to 131 ton-miles per gallon for the truck van trailer with the lower weight. The truck flatbed with sides trailer carries 2 tons less commodity weight than the heaviest truck van trailer and has a fuel efficiency of 135 ton-miles per gallon, a value between the other two scenarios in this group.

- A High Amount of Truck Braking Reduces Truck Fuel Efficiency on this Route. The truck route for scenarios 37-39 requires a greater amount of time on the brakes relative to the other regional/local scenarios. As calculated by the Cummins VMS, four percent of the total driving time is spent braking. This is reflected in the truck terrain severity rating of 5.0, the highest numeric rating. This indicates relatively steep grades which contributes to reduced truck fuel efficiency.

6.3.3 Comparisons on the 74-Mile Regional/Local Route

The longest route in the regional/local service scenarios is 74 miles for both rail and truck. As shown in Exhibit 6-16, rail service ranges from 4.03 to 4.51 times more fuel efficient than truckload service. Factors contributing to the difference in rail vs. truck fuel efficiency include terrain, low rail horsepower per trailing ton ratios and favorable aerodynamics of the rail mixed freights.

EXHIBIT 6-16
FUEL EFFICIENCY COMPARISON FOR THE 74-MILE REGIONAL/LOCAL ROUTE

SCEN-ARIO	EQUIP. TYPE	DIS-TANCE (MILES)	RAIL GRADE SEVERITY	RAIL CURVATURE SEVERITY	TRUCK TERRAIN SEVERITY RATING	HP PER TRLNG TON	LADING/ PAYLOAD WEIGHT (TONS)	AVG SPEED (MPH)	FUEL EFFIC. (FE) (TMi/G)	RAIL/ TRUCK FE RATIO
Rail33	M	74	1.75	1.21		1.3	98	36	668	4.51
Rail35	M	74	1.75	1.21		1.3	70	36	635	4.29
Rail36	M	74	1.75	1.21		1.3	77	36	619	4.30
Rail34	M	74	1.75	1.21		1.3	69	36	596	4.03
Truck33	FS	74			1.0		22	59	148	
Truck35	F	74			1.0		23	60	148	
Truck36	D	74			1.0		22	60	144	
Truck34	F	74			1.0		23	60	148	

Rail: M - Mixed Freight
Truck: FS - Flatbed with Sides, F - Flatbed, D - Dump Trailer

- <u>Rail is More Efficient than Truckload Service Despite the Relatively Flat 74-Mile Truck Route</u>. The 74-mile route is a flat route for truckload service as shown by its 1.0 truck terrain severity rating; it requires practically no braking for grades, relatively few gear shifts and permits a high average truck speed (60 miles per hour). Despite these advantages, rail is more fuel efficient. The rail route is characterized by light grades (rating of 1.75) and light curvature (rating of 1.21).

- <u>A Low HP per Ton Ratio Contributes to Rail Fuel Efficiency on this Route</u>. The rail mixed freight on this regional railroad route is the largest train (90 cars with 5,650 trailing tons) among these scenarios. The low horsepower per trailing ton ratio of 1.3 reflects the large train and comparatively level grade. This contributes to rail fuel efficiency.

- <u>The Rail Mixed Freight Trains on this Route are Superior in Fuel Efficiency to the Truck Flatbed Trailers, Truck Flatbed with Sides Trailer and Truck Dump Trailer</u>. The rail mixed freights operating on this route have fuel efficiencies ranging from 596 to 668 ton-miles per gallon. Four truck service scenarios are analyzed for the 74-mile distance. The truck flatbed trailers in Truck34 and Truck35 have equal fuel efficiency since their payload and gross vehicle weights are the same. The truck flatbed with sides trailer also has the same fuel efficiency even though its commodity weight is 1 ton less than the other truck flatbed trailers. The truck dump trailer consumes more fuel than the truck flatbed with sides trailer; it has lower fuel efficiency even though it carries the same commodity weight and has a lower gross vehicle weight. Poor aerodynamics contributes to the decreased fuel efficiency. Even though the truck dump trailer utilizes aerodynamic aids and has round corners and smooth sides, its increased frontal area results in greater wind resistance and a consequent loss in fuel efficiency.

* * * * *

In summary, rail achieved higher ton-miles per gallon than truckload service in all freight transportation scenarios. Rail achieved from 1.40 to 9.00 times higher ton-miles per gallon than truck. Rail mixed freight achieved the highest ton-miles per gallon of all equipment types. The truck flatbed trailer achieved the best fuel efficiency for all the truck types. There are many factors which affect fuel efficiency, including equipment type, average speed, terrain, lading or payload weight and horsepower. Because of the interactions among the factors, each scenario is unique and must be evaluated individually. The next chapter presents a summary analysis of the rail vs. truck fuel efficiency findings.

7.0 RAIL VS. TRUCK FUEL EFFICIENCY FINDINGS

Rail service demonstrated higher ton-miles per gallon than truck under all the simulated conditions in this study. As a result, it is estimated that substantial fuel could be saved with rail use in the scenarios and routes simulated. Specific findings concerning ton-miles per gallon and the gallons of fuel that could be saved are presented in this chapter in three sections as follows:

- Rail vs. truck ton-miles per gallon
- Amount of fuel savings with rail use
- Effect of rail circuity on fuel consumption.

Each is discussed below.

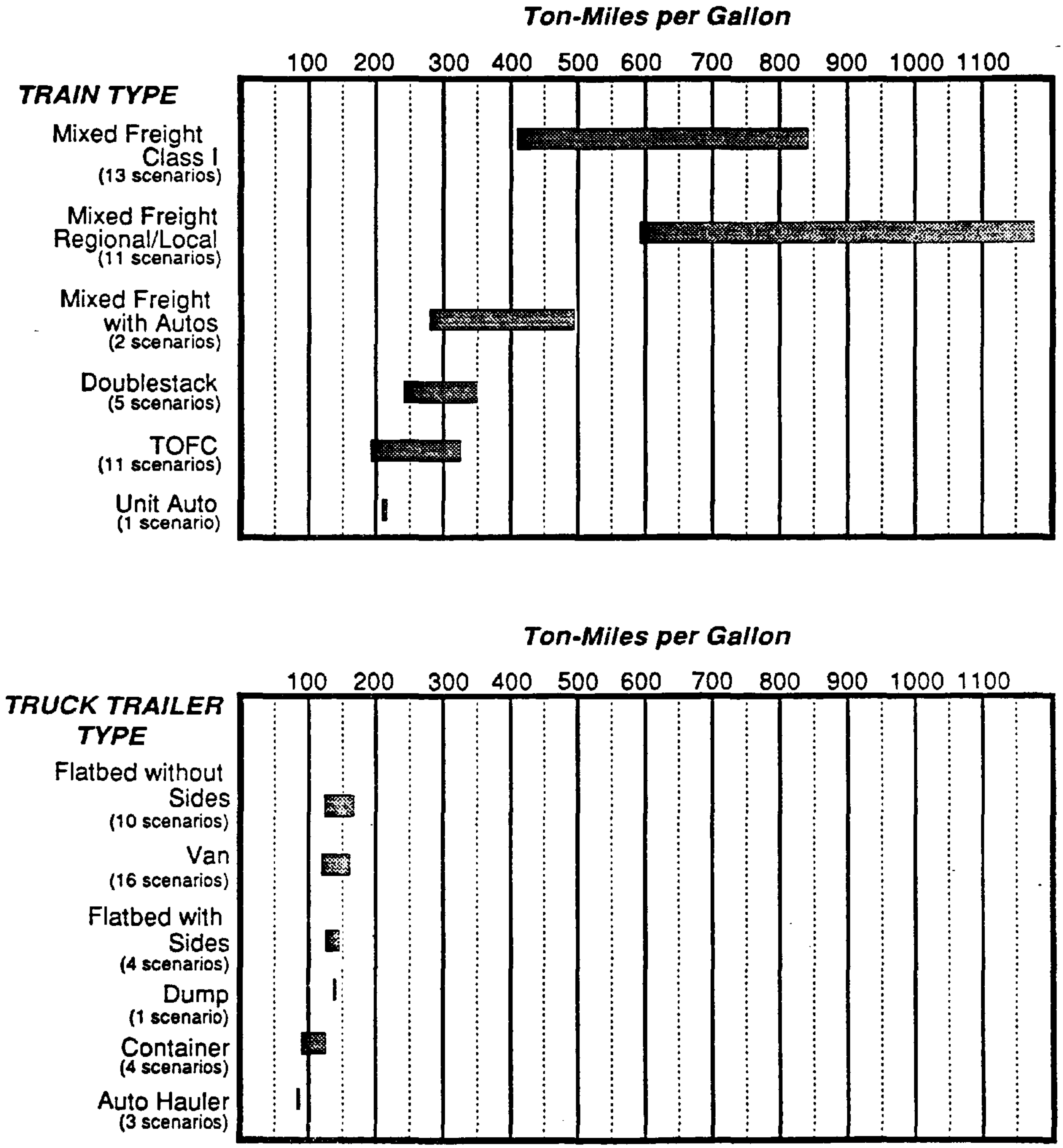
7.1 RAIL VS. TRUCK TON-MILES PER GALLON

Rail achieved higher ton-miles per gallon than truck in all scenarios examined and the difference in fuel efficiency was substantial; rail achieved from 1.40 to 9.00 times higher ton-miles per gallon than truck, depending on the scenario. The ranges of fuel efficiency findings are summarized in Exhibit 7-1. Key factors affecting fuel efficiency include the equipment's aerodynamic resistance characteristics, average speed, terrain, lading and payload weights, rail horsepower per trailing ton and truck engine size. Key observations are:

- The Study Findings Represent Specific Operating Scenarios and are Not Generalized to All Freight Service. Due to the variety of freight services today and the significant effect of terrain and operating variables on fuel efficiency, each comparative scenario should be analyzed separately and not averaged together. The scenarios in this study are presented as examples of types of freight service; they are not representative of all available service.

- Rail Ton-Mile Ranges are Considerably Larger than the Truck Ranges. As shown in Exhibit 7-1, there is a wide range of values for most train types while the truck ton-mile ranges are comparatively narrow. Compared to truck scenarios, the rail scenarios use varying horsepower per trailing ton and varying speeds and a variety of locomotives, while only one truck engine, the Cummins 350, was selected for all truck simulations. These factors contribute to the range differences. While basically the same, the three TPS models utilized by the study participants may possess some minor variations. However, strong efforts were

EXHIBIT 7-1
RANGE OF TRAIN AND TRUCK FUEL EFFICIENCY IN TON-MILES PER GALLON (ALL SCENARIOS)



made to assure that consistent variable values were assumed in all cases. For example, the same railcar and locomotive frontal areas were assumed for each model execution. Thus, differences attributable to the models were minimized as much as possible. The Cummins VMS simulates Cummins truck engines only, and the 350 was selected as best meeting the requirements of all the study scenarios.

- Rail Mixed Freight Achieved the Highest Level of Ton-Miles per Gallon. The rail mixed freight trains achieved both the highest level and the widest range in ton-miles per gallon. The highest ton-mile per gallon values were obtained using trains with lower average speeds. In addition, lower horsepower per trailing ton and favorable aerodynamics are also factors in rail mixed freight fuel efficiency.

- Rail Scenarios With Low Horsepower Per Trailing Ton Achieved the Highest Ton-Miles per Gallon. As shown in Exhibit 7-2, those rail scenarios with the lowest horsepower per trailing ton ratios achieved the highest ton-miles per gallon. In this study, horsepower per trailing ton ranges from 0.7 to 5.7, with all but one rail scenario falling between 0.7 and 3.8. The one train having a 5.7 horsepower per trailing ton ratio achieved the lowest rail fuel efficiency value of 196 ton-miles per gallon.

EXHIBIT 7-2
FUEL EFFICIENCY BY LEVEL OF RAIL HORSEPOWER PER TRAILING TON

RAIL HP PER TRAILING TON RANGE	FUEL EFFICIENCY RANGE (TMi/G)
.6 to 1.7	279 - 1,179
1.8 to 2.7	206 - 1,104
2.8 to 3.8	209 - 304
5.7	196

Fuel efficiency performance in Class I/over-the-road and regional/local service varies. The following paragraphs describe the fuel efficiency findings separately for each of these service segments.

7.1.1 Rail Achieves Higher Ton-Miles per Gallon than Truck in Every Equipment Category For Class I Service.

Exhibit 7-3 summarizes the rail and truck equipment types in the Class I/over-the-road scenarios and their corresponding ranges of fuel efficiency. The train types are shown opposite the trucks that they were compared with. As shown, a larger variety of equipment types is included in these longer distance scenarios than in the regional/local scenarios. Specific observations are:

EXHIBIT 7-3
FUEL EFFICIENCY BY EQUIPMENT TYPE
FOR CLASS I/OVER-THE-ROAD SERVICE

TRAIN TYPE	FUEL EFFICIENCY RANGE (TMI/G)	TRUCK TYPE	FUEL EFFICIENCY RANGE (TMI/G)	RAIL TO TRUCK FE RATIO RANGE
Mixed Freight	471 - 843	Flatbed Trailer - Without Sides	141 - 167	2.82 - 5.51
	414 - 688	Van Trailer	131 - 163	2.96 - 5.25
Mixed Freight with Autos	279 - 499	Auto Hauler	84 - 89	3.32 - 5.61
Double-stack	243 - 350	Container Trailer	97 - 132	2.51 - 3.43
TOFC	229	Flatbed Trailer - Without Sides	133	1.72
	240	- With Sides	147	1.63
	196 - 327	Van Trailer	134 - 153	1.40 - 2.14
Unit Auto	206	Auto Hauler	86	2.40

Rail: TOFC - Trailer-on-Flatcar

- The Rail Mixed Freight Achieves the Highest Ton-Miles per Gallon of All Equipment Types on the Long Distance Hauls. The rail mixed freight equipment achieves the highest Class I fuel efficiency of 843 ton-miles per gallon on a 261-mile rail haul (Rail13). This rail mixed freight also achieves a fuel efficiency ratio of 5.51, the second highest ratio of rail to truck ton-miles per gallon in the Class I service category.

- <u>Mixed Freight with Autos Achieves the Second Highest Ton-Miles per Gallon on the Long Distance Routes</u>. The two rail mixed freight with autos scenarios obtained 279 and 499 ton-miles per gallon. This train type does not perform as well as rail mixed freight without autos. The presence of auto cars in the mixed freight consist contributes to worsening the overall train fuel efficiency due to poor aerodynamics of the rail autoracks.

- <u>Rail Double-stack and TOFC Achieve the Third and Fourth Highest Ton-Miles per Gallon on the Long Distance Routes</u>. Rail double-stack fuel efficiency ranges from 243 to 350 ton-miles per gallon while rail TOFC ranges from 196 to 327 ton-miles per gallon. The lower aerodynamic drag of rail double-stack compared to rail TOFC contributes to its better efficiency. Double-stack containers have no wheels and thus have less tare weight per container than trailers. The lowest rail to truck fuel efficiency ratio, 1.40, is achieved by the TOFC. Double-stack competes directly with truck container trailers and has fuel efficiency ratios ranging from 2.51 to 3.43.

- <u>The Truck Flatbed Without Sides Trailer Achieves the Highest Ton-Miles per Gallon of the Truck Trailers</u>. The truck flatbed without sides trailer achieves a high of 167 ton-miles per gallon. The truck van trailer achieves the next highest truck fuel efficiency of 163 ton-miles per gallon.

- <u>The Truck Auto Hauler Trailer is the Poorest Performer of Any Vehicle Type in the Long Distance Scenarios</u>. The truck auto hauler trailer achieves the lowest ton-miles per gallon of all the equipment types. The truck container trailer achieves the next lowest ton-miles per gallon. Both trucks have undesirable aerodynamic features. These include the open frame of the truck auto hauler trailer and the square shape and ribbed sides of the truck container trailer.

In view of the high ton-miles per gallon achieved by rail relative to truck in all scenarios, it should be expected that considerable fuel savings could be attained by using rail. The next section quantifies the gallons of fuel that are saved.

7.1.2 Rail Achieves Higher Ton-Miles per Gallon than Truck in Every Equipment Category For Regional/Local Service.

Exhibit 7-4 summarizes the fuel efficiency of different equipment types simulated on the regional/local routes. On these routes, mixed freight trains were assumed exclusively. This

EXHIBIT 7-4
FUEL EFFICIENCY BY EQUIPMENT TYPE FOR REGIONAL/LOCAL SERVICE

TRAIN TYPE	FUEL EFFICIENCY RANGE (TMI/G)	TRUCK TYPE	FUEL EFFICIENCY RANGE (TMI/G)	RAIL TO TRUCK FE RATIO RANGE
Mixed Freight		Flatbed Trailer		
	596 - 890	- Without Sides	148 - 150	4.03 - 5.93
	641 - 1,104	- With Sides	135 - 148	4.51 - 7.77
	625 - 1,179	Van Trailer	131 - 140	4.46 - 9.00
	619	Dump Trailer	144	4.30

train type demonstrated higher ton-miles per gallon than any other equipment type on the regional/local routes.

The regional/local commodities include corn, plywood, pulpwood, wood chips, clay, grain products, canned goods, steel products, miscellaneous food products and chemicals. High ton-miles per gallon in comparison with truck results to a large extent from the ability of the railcars (covered hoppers, box cars and flatcars) to carry from 69 to 100 tons of commodity in these scenarios, whereas the trucks carry from 21 to 24 ton payloads. Additional observations are:

- <u>The Rail Mixed Freight Achieved the Highest Ton-Miles per Gallon on Regional/Local Routes</u>. The rail mixed freight ton-miles per gallon range shows better fuel efficiency than the competing truckload service. Including all the truck equipment types in Exhibit 7-4, the rail mixed freight ranged from 4.03 to 9.00 times greater fuel efficiency than truck. Rail mixed freight carrying 95 tons of chemical products obtained the highest fuel efficiency value - 1,179 ton-miles per gallon. Low horsepower per trailing ton, low average speeds and heavy rail lading contributed to the high fuel efficiency values over the regional/local routes.

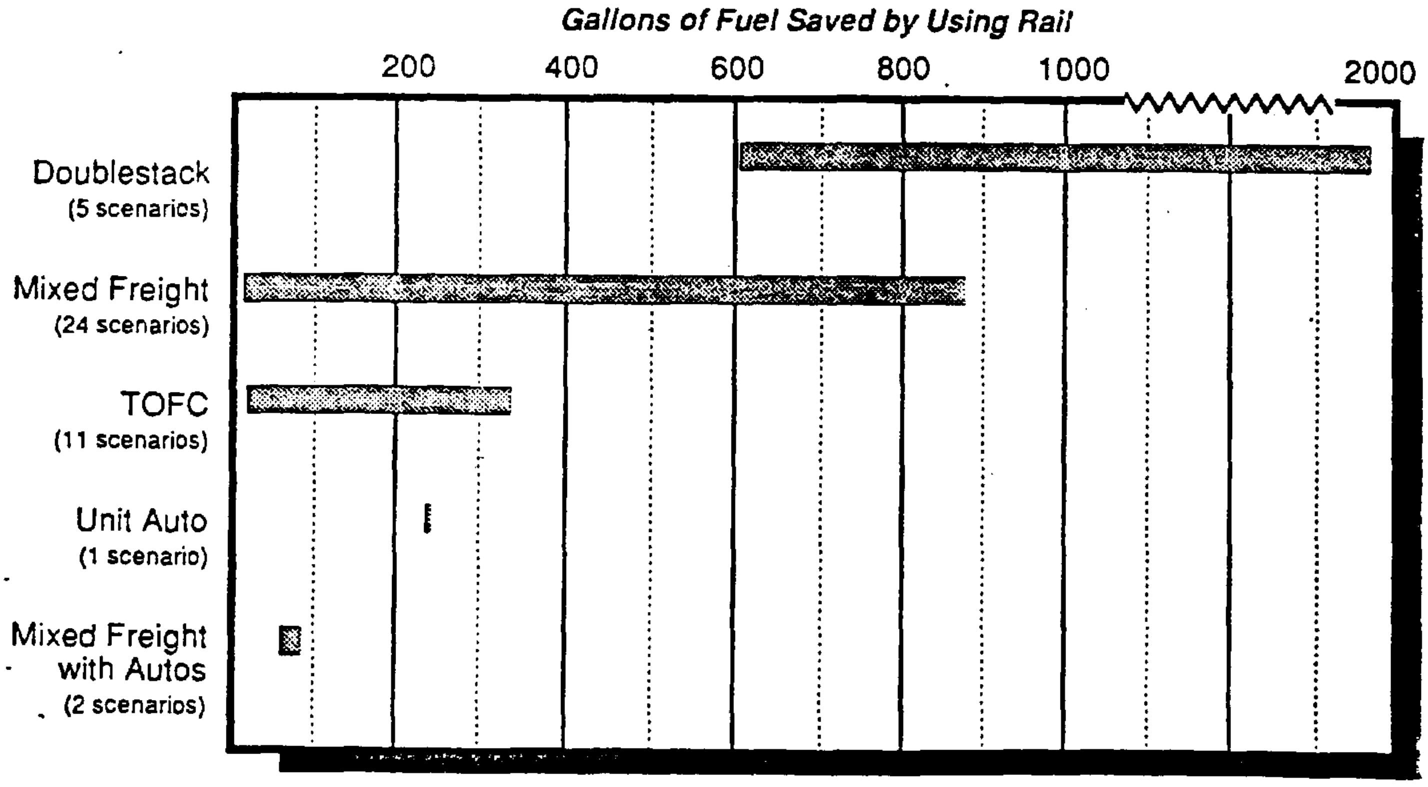
- <u>The Truck Flatbed Without Sides Trailer Achieved the Highest Truck Ton-Miles per Gallon on the Regional/Local Routes</u>. The truck flatbed without sides trailer achieved a high of 150 ton-miles per gallon over the regional/local route, however this performance is considerably below that of the rail mixed freight. On the regional/local routes the truck trailers performed within a narrow range of efficiency - every value is between 131 and 150 ton-miles per gallon. The truck trailers carrying miscellaneous food and chemical products, the lightest payloads at 21 tons, obtained 131 ton-miles per gallon. 150 ton-miles per gallon was obtained with a truck trailer carrying the highest payload, 24 tons of steel products.

7.2 AMOUNT OF FUEL SAVINGS WITH RAIL USE

The ranges of gallons saved by train type are shown in Exhibit 7-5. As illustrated, with use of rail in these scenarios, from less than 100 to almost 2,000 gallons of fuel are estimated to be saved comparing one railcar's lading with an equivalent number of trucks necessary to carry the load. The gallons of fuel savings achieved through the use of rail on these routes is affected by the lading weight, distance, aerodynamics, average speed and terrain.

If trucks were to carry an equivalent number of trailers or containers moved on a dedicated TOFC or double-stack train, the savings using rail would be far greater. For example, in scenario 10 a TOFC railcar saves 104 gallons of fuel compared to truck. For a 34 car TOFC unit train carrying 1,360 tons of commodity, this translates to a savings of 3,536 gallons.

EXHIBIT 7-5
RANGE IN GALLONS OF FUEL SAVED BY USING RAIL



In scenario 30, a 26 car double-stack unit train carrying 3,900 tons of commodity over a 778-mile route saves 15,652 gallons of fuel compared to the fuel required by trucks to carry the equivalent lading.

Factors affecting gallons of fuel are discussed below.

- The Longer the Route Distance the Greater the Rail Fuel Savings. Distance travelled contributes substantially to the number of gallons saved while it has little effect on ton-miles per gallon. Thus, the most fuel efficient scenario in terms of ton-miles per gallon does not automatically achieve the highest savings in gallons of fuel.

Distance is an important contributor to fuel savings; thus, the regional/local scenarios can be expected to differ substantially from the Class I/over-the-road scenarios. Fuel savings for scenarios in both service segments are discussed below.

7.2.1 Rail Fuel Savings are Substantial for Class I/Over-the-Road Service

Class I scenario rail fuel savings range from 11 to 1,965 gallons. The rail scenarios include rail TOFC, rail COFC, rail mixed freight with and without autos and rail unit auto. The truck scenarios include truck flatbeds with sides, truck flatbeds without sides, truck van, truck auto haulers and truck containers. The number of gallons of fuel saved using rail for each of the Class I scenarios is shown in Exhibit 7-6. Supporting detail of the gallons consumed by rail and truck for each scenario are presented in Exhibits 7-7 and 7-8 respectively. The number of trucks required to carry an equivalent amount of lading carried on the railcar is calculated by dividing the rail lading by the truck payload.

EXHIBIT 7-6
RAIL FUEL SAVINGS FOR LONG HAUL SERVICE

SCENARIO	TRUCK FUEL CONSUMED (GALLONS)	RAIL FUEL CONSUMED (GALLONS)	FUEL SAVED USING RAIL (GALLONS)
01	92	37	55
02	93	42	51
03	172	35	137
04	699	361	338
05	3,320	1,462	1,858
06	1,008	278	730
07	*	*	*
08	*	*	*
09	*	*	*
10	308	204	104
11	473	149	324
12	203	159	44
13	184	36	148
14	*	*	*
15	150	64	86
16	235	153	82
17	223	52	171
18	141	48	93
19	150	95	55
20	313	69	244
21	69	58	11
22	122	91	31
23	305	69	236
24	*	*	*
25	430	255	175
26	1,152	277	875
27	2,800	835	1,965
28	450	216	234
29	2,410	917	1,493
30	1,120	518	602
31	663	255	408
32	208	115	93

* In several scenarios, a Class I rail route was separated into two shorter routes. This occurred when the train consist was changed at a midpoint in the Class I route. For these scenarios however, the corresponding truck did not require any configuration change and was kept as only one route. Thus, the truck scenarios - Truck07, 08, 09, 14, and 24 - do not exist and are intentionally omitted.

EXHIBIT 7-7
RAIL FUEL CONSUMPTION FOR LONG HAUL SERVICE

SCENARIO/ EQUIP. TYPE	COMMODITY CARRIED	TOTAL RAIL FUEL (GALLONS)*	PERCENT OF G.W. FOR COMMODITY	RAIL COMMODITY FUEL CONSUMED (GALLONS)**
Rail01 M	LUMBER	2,017	1.46	37
Rail02 M	CANNED GDS	1,032	3.32	42
Rail03 M/A	AUTOS	2,137	1.27	35
Rail04 TOFC	CANNED GDS	5,833	2.41	161
Rail05 DSTK	IMP ELECTR	8,152	6.87	664
Rail06 M	PLYWOOD	6,293	2.23	148
Rail07 TOFC	CANNED GDS	8,649	2.07	200
Rail08 DSTK	IMP ELECTR	10,104	6.87	798
Rail09 M	PLYWOOD	10,505	1.16	130
Rail10 TOFC	MI FOOD PRO	5,288	3.46	204
Rail11 M	CANNED GDS	7,481	1.89	149
Rail12 TOFC	BEVERAGES	2,010	1.78	57
Rail13 M	STEEL PROD	1,967	1.44	36
Rail14 TOFC	BEVERAGES	4,537	1.78	102
Rail15 M/A	AUTOS	4,624	1.22	64
Rail16 TOFC	GRAIN	5,644	2.35	153
Rail17 M	SAWMLL PRO	4,438	1.00	52
Rail18 M	MI FD PROD	2,489	1.64	48
Rail19 TOFC	CANNED FRU	2,937	2.52	95
Rail20 M	PLASTC MATL	4,982	1.24	69
Rail21 TOFC	BEVERAGES	1,713	2.19	58
Rail22 TOFC	BEVERAGES	1,920	3.68	91
Rail23 M	SAWMLL PROD	4,195	0.96	48
Rail24 M	SAWMLL PROD	978	1.41	21
Rail25 TOFC	PREFB WOOD	12,067	1.95	255
Rail26 M	LUMBER	15,384	1.75	277
Rail27 DSTK	CTR FREIGT	17,826	4.11	835
Rail28 AUTO	AUTOS	13,654	1.53	216
Rail29 DSTK	CTR FREIGT	24,036	3.38	917
Rail30 DSTK	CTR FREIGT	12,571	3.30	518
Rail31 M	CANNED VEG	15,071	1.64	255
Rail32 TOFC	BEVERAGES	5,249	1.81	115

* Includes fuel required for rail and truck terminal operations.

** Includes fuel required for rail switching and truck drayage.

EXHIBIT 7-8
TRUCK FUEL CONSUMPTION FOR LONG HAUL SERVICE

SCENARIO/ EQUIP. TYPE		COMMODITY CARRIED	VMS FUEL (GALLONS)	# OF TRUCKS REQUIRED	TRUCK COMM.FUEL CONSUMED (GAL)
Truck01	F	LUMBER	51	1.80	92
Truck02	V	CANNED GDS	52	1.79	93
Truck03	A	AUTOS	60	2.87	172
Truck04	V	CANNED GDS	328	2.13	699
Truck05	C	IMP ELECTR	332	10.00	3,320
Truck06	F	PLYWOOD	322	3.13	1,008
Truck10	V	MI FOOD PRO	162	1.90	308
Truck11	V	CANNED GDS	167	2.83	473
Truck12	V	BEVERAGES	111	1.82	203
Truck13	F	STEEL PROD	47	3.92	184
Truck15	A	AUTOS	80	1.87	150
Truck16	FS	GRAIN	108	2.18	235
Truck17	F	SAWMLL PRO	70	3.18	223
Truck18	V	MI FD PROD	41	3.43	141
Truck19	V	CANNED FRU	90	1.67	150
Truck20	V	PLASTC MATL	87	3.60	313
Truck21	V	BEVERAGES	38	1.82	69
Truck22	V	BEVERAGES	67	1.82	122
Truck23	F	SAWMLL PROD	96	3.18	305
Truck25	F	PREFB WOOD	316	1.36	430
Truck26	F	LUMBER	288	4.00	1,152
Truck27	C	CTR FREIGT	280	10.00	2,800
Truck28	A	AUTOS	281	1.60	450
Truck29	C	CTR FREIGT	241	10.00	2,410
Truck30	C	CTR FREIGT	112	10.00	1,120
Truck31	V	CANNED VEG	257	2.58	663
Truck32	V	BEVERAGES	153	1.36	208

* Scenario numbers 07, 08, 09, 14 and 24 are intentionally omitted. See note at the bottom of Exhibit 7-6.

7.2.2 Rail Fuel Savings are Modest for Regional/Local Service

The fuel savings achieved using rail in the regional/local scenarios ranges from 7 to 38 gallons. Exhibit 7-9 summarizes the fuel saved; and supporting detail of the fuel use by mode is presented in Exhibits 7-10 and 7-11. The rail scenarios are all mixed freight trains, while the truck scenarios include truck flatbed with sides trailers, truck flatbed without sides trailers, truck dump trailers and truck van trailers.

EXHIBIT 7-9
RAIL FUEL SAVINGS FOR REGIONAL/LOCAL SERVICE

SCENARIO	RAIL FUEL CONSUMED (GAL.)	TRUCK FUEL CONSUMED (GAL.)	FUEL SAVED USING RAIL (GAL.)
33	11	49	38
34	9	35	26
35	8	35	27
36	9	40	31
37	7	36	29
38	9	39	30
39	7	28	21
40	2	13	11
41	2	9	7
42	2	10	8
43	2	13	11

EXHIBIT 7-10
RAIL FUEL CONSUMPTION FOR REGIONAL/LOCAL SERVICE

SCENARIO/ EQPMT TYPE		COMMODITY	TOTAL RAIL FUEL (GAL)*	COMMODITY PERCENT OF GROSS TRAIN WT.	RAIL COMMODITY FUEL CONSUMED (GAL.)**
33	M	CORN	516	2.11	11
34	M	PLYWOOD	516	1.66	9
35	M	PULPWOOD	516	1.58	8
36	M	CHIPS	516	1.79	9
37	M	CLAY	329	2.19	7
38	M	GRAIN	329	2.59	9
39	M	CANNED GDS	329	1.99	7
40	M	GRAIN	15	13.35	2
41	M	STEEL PROD	15	12.88	2
42	M	MISC FOOD	27	5.64	2
43	M	CHEMICAL	27	6.67	2

Rail: M - Mixed Freight

EXHIBIT 7-11
TRUCK FUEL CONSUMPTION FOR REGIONAL/LOCAL SERVICE

SCENARIO / EQPMT TYPE		COMMODITY	VMS FUEL PER TRUCK (GAL.)	NO.OF TRUCKS REQUIRED	TRUCK COMM.FUEL CONSUMED (GAL)
33	FS	CORN	11.0	4.45	49
34	F	PLYWOOD	11.5	3.00	35
35	F	PULPWOOD	11.5	3.04	35
36	D	WOOD CHIPS	11.3	3.50	40
37	V	CLAY	8.9	4.09	36
38	FS	GRAIN PROD	8.6	4.55	39
39	V	CANNED GDS	9.1	3.13	28
40	FS	GRAIN PROD	2.8	4.50	13
41	F	STEEL PROD	2.9	3.21	9
42	V	MISC FOOD	2.9	3.52	10
43	V	CHEMICAL	2.9	4.52	13

Truck: V - Van, FS - Flatbed with Sides, F - Flatbed
D - Dump

7.3 EFFECT OF RAIL CIRCUITY ON FUEL CONSUMPTION

This section examines how rail circuity contributes to differences between ton-miles per gallon (fuel efficiency) and gallons of fuel consumed.[1]

The rail to truck fuel efficiency ratios developed in Chapter 6 can be compared to ratios of truck to rail fuel consumption. It might be assumed that if rail is 3 times more fuel efficient than truck service in a particular scenario, then rail would consume 3 times less fuel than the truck. However, this is generally not the case, primarily due to rail circuity. If the railroad distance is longer than the highway distance, then the train must travel more miles and consume more fuel. Thus, in the example, the additional fuel consumption by rail reduces the fuel consumption ratio to less than 3.

Circuity was taken into account in each corridor by comparing the amount of fuel consumed in comparable rail and truck runs. Generally, the more circuitous rail is than truck the greater the expected difference between the ratios. Rail

---

[1] Other factors such as speed changes and terrain may also affect the relationship between fuel efficiency and fuel consumption.

routes are usually longer than competing truck routes. Thus, wherever rail is more circuitous the relative advantage of higher ton-miles per gallon is somewhat offset.

The study results for Class I/over-the-road service and regional/local service contain examples of the effect of circuity on differences between the fuel efficiency and fuel consumption ratios. In Exhibits 7-12 and 7-13 the rail/truck fuel efficiency ratio is obtained by dividing the rail fuel efficiency by the truck fuel efficiency in ton-miles per gallon. The resultant number illustrates how much more fuel efficient one mode is over the other. The truck/rail fuel consumption ratio is calculated by dividing truck fuel usage by rail fuel usage in gallons. Each service segment is discussed below.

7.3.1 Effect of Circuity on Class I Service Fuel Consumption

Exhibit 7-12 summarizes the effect of circuity on Class I service. The Exhibit shows rail distance is without exception longer than truck distance in each of the 27 Class I/over-the-road scenarios. In 14 of the 27 scenarios (operated over 9 different routes) rail is less than 50 miles longer than the truck route. It is typical that truck operators are more concerned about timely delivery than about distance travelled. Thus, if a route is longer but more efficient (e.g. is a better highway or faster than another route) then the longer route may be chosen.

In 5 of the remaining 13 scenarios, (operated over 4 different routes), truck routes are between 74 and 118 miles shorter than rail. The last 8 scenarios executed over 5 different routes are more than 128 miles shorter than rail. Overall, the truck routes are shorter by a more substantial distance than rail.

The effect of circuity on Class I service fuel consumption is more pronounced than on regional/local service fuel consumption. Although there are many scenarios which have close correspondence between fuel efficiency and fuel consumption ratios, there are also several which have great disparity among the ratios. Scenario 15 has a fuel efficiency ratio of 3.32 but only a 2.34 fuel consumption ratio. This may be explained by the fact that rail travels 190 miles longer, or nearly 42 percent further than the 449-mile total truck distance, to arrive at the same destination. Scenario 18 is another example of a significant difference between ratios. The 83-mile circuity of rail compared to truck contributes to the difference between the 3.85 fuel efficiency ratio and the 2.94 fuel consumption ratio. The difference in miles results in rail consuming more fuel to traverse the extra distance.

EXHIBIT 7-12
EFFECT OF RAIL CIRCUITY ON CLASS I SERVICE FUEL CONSUMPTION

SCENARIO/ RAIL EQUIPMENT TYPE	RAIL DISTANCE (MILES)*	TRUCK DISTANCE (MILES)	RAIL DISTANCE LESS TRUCK DISTANCE (MILES)	TRUCK FUEL CONSUMED (GALS)	RAIL FUEL CONSUMED (GALLONS)	FUEL SAVED USING RAIL (GALS)	RAIL/ TRUCK FE RATIO	TRUCK/ RAIL FUEL RATIO (GALS)
01 M	403	355	48	92	37	55	2.82	2.49
02 M	403	355	48	93	42	51	2.54	2.21
03 M/A	403	355	48	172	35	137	5.61	4.91
04 TOFC	2,222	2,093	129	699	361	338	2.14	1.94
05 DSTK	2,222	2,093	129	3,320	1,462	1,858	2.53	2.27
06 M	2,222	2,093	129	1,008	278	730	4.29	3.63
07 TOFC	**	**	**	**	**	**	**	**
08 DSTK	**	**	**	**	**	**	**	**
09 M	**	**	**	**	**	**	**	**
10 TOFC	1,067	1,030	37	308	204	104	1.56	1.51
11 M	1,067	1,030	37	473	149	324	3.28	3.17
12 TOFC	900	715	185	203	159	44	1.73	1.28
13 M	321	299	22	184	36	148	5.51	5.11
14 TOFC	**	**	**	**	**	**	**	**
15 M/A	639	449	190	150	64	86	3.32	2.34
16 TOFC	767	720	47	235	153	82	1.63	1.54
17 M	486	462	24	223	52	171	4.48	4.29
18 M	341	258	83	141	48	93	3.85	2.94
19 TOFC	664	569	95	150	95	55	1.84	1.58
20 M	664	569	95	313	69	244	5.25	4.54
21 TOFC	311	237	74	69	58	11	1.55	1.19
22 TOFC	447	429	18	122	91	31	1.40	1.34
23 M	648	615	33	305	69	236	5.25	4.42
24 M	**	**	**	**	**	**	**	**
25 TOFC	1,951	1,910	41	430	255	175	1.72	1.69
26 M	1,951	1,910	41	1,152	277	875	4.25	4.16
27 DSTK	1,951	1,910	41	2,800	835	1,965	3.43	3.35
28 AUTO	1,859	1,608	251	450	216	234	2.40	2.08
29 DSTK	1,861	1,608	251	2,410	917	1,493	3.04	2.63
30 DSTK	838	720	118	1,120	518	602	2.51	2.16
31 M	1,916	1,674	242	663	255	408	2.96	2.60
32 TOFC	1,021	996	25	208	115	93	1.84	1.81

* Unlike previous tables, this includes an additional 60 miles to account for either rail switching for rail mixed freight or truck drayage for rail intermodal freight.

** Intentionally omitted. See note at the bottom of Exhibit 7-6.

Despite the examples showing disparity, there are more scenarios whose correspondence is very close. In scenario 10, the ratios nearly match. The values include a 1.56 fuel efficiency ratio and 1.51 fuel consumption ratio. Rail is more circuitous by 37 miles in this example so closer correspondence is expected. This is also true in scenario 22 where the ratios differ by less than 0.1 and rail travels 18 miles longer to get to its destination, the closest distance correspondence of the Class I/over-the-road scenarios.

The study also includes scenarios where rail circuity does not explain differences between the fuel efficiency and fuel consumption ratios. In scenarios 28, 29 and 31 rail is over 240 miles more circuitous than truck, yet the ratio values are still relatively close. In these scenarios factors such as average speed, terrain, equipment types and aerodynamics may strongly influence the relationship between the ratios.

7.3.2 Effect of Circuity on Regional/Local Service Fuel Consumption

Exhibit 7-13 summarizes regional/local scenario findings including rail and truck distance travelled, fuel consumed, fuel efficiency ratio and fuel consumption ratio. The exhibit shows minimal distance differences between rail and truck and, for most scenarios, close correspondence between the fuel efficiency and fuel consumption ratios. For example, scenario 33 depicts a 4.51 fuel efficiency ratio and a 4.45 fuel consumption ratio.

Some larger differences can be found. In scenario 43, rail is 9 times more fuel efficient than truck but consumes only 7 times less fuel. This discrepancy may be explained, in part, by the fact that rail travels 4 miles longer than the truck and thus consumes more fuel traveling the extra distance.

EXHIBIT 7-13
EFFECT OF RAIL CIRCUITY ON REGIONAL/LOCAL SERVICE FUEL CONSUMPTION

SCENARIO/ RAIL EQUIPMENT TYPE	RAIL DISTANCE (MILES)	TRUCK DISTANCE (MILES)	RAIL DISTANCE LESS TRUCK DISTANCE (MILES)	TRUCK FUEL CONSUMED (GALS)	RAIL FUEL CONSUMED (GALLONS)	FUEL SAVED USING RAIL (GALS)	RAIL/ TRUCK FE RATIO	TRUCK/ RAIL FUEL RATIO (GALS)
33 M	74	74	0	49	11	38	4.51	4.45
34 M	74	74	0	35	9	26	4.03	4.00
35 M	74	74	0	35	8	27	4.29	4.50
36 M	74	74	0	40	9	31	4.30	4.33
37 M	54	53	1	36	7	29	5.21	5.29
38 M	54	53	1	39	9	30	4.75	4.56
39 M	54	53	1	28	7	21	4.46	4.00
40 M	22	18	4	13	2	11	7.77	7.00
41 M	22	18	4	9	2	7	5.93	5.00
42 M	22	18	4	10	2	8	8.29	5.50
43 M	22	18	4	13	2	11	9.00	7.00

Rail and truck travel the same distance in scenarios 33 through 36, rail travels 1 mile longer in scenarios 37 through 39 and rail travels 4 miles longer than truck in scenarios 40 through 43. This extra distance contributes to the relatively larger differences between the fuel efficiency and fuel consumption ratios in the latter four scenarios.

* * * * *

In summary, even taking into account such factors as circuity and terrain, the superiority of rail fuel efficiency over competing truckload service is fully supported in this study. Rail achieved higher ton-miles per gallon than truck in every scenario. Gallons of fuel saved for all scenarios by using rail ranged from 7 gallons over a 22-mile distance to 1,965 gallons over a 1,891-mile distance. All scenarios were strongly affected by route distance.

APPENDIX A
DESCRIPTION OF TRAIN PERFORMANCE SIMULATOR

APPENDIX A
DESCRIPTION OF TRAIN PERFORMANCE SIMULATOR

This appendix describes the train performance simulator (TPS) and the resistance coefficients that affect train fuel efficiency. The appendix is organized into the following sections:

- Definition of the TPS
- Train resistance
- TPS data requirements
- Other train performance factors
- Interpretation of TPS results.

Each topic is discussed below.

A.1 DEFINITION OF THE TPS

The purpose of a TPS[1] is to predict or replicate the movement of a train along a given track. The results of the TPS executed by Abacus are generated in tables that show the speed, time, distance and fuel consumption. Inputs to the TPS include:

- Route Data. The TPS needs a description of the track over which to run the train.
- Train Data. Information about the train is needed such as locomotive and consist length and car type to determine the aerodynamic forces acting upon them. The car weight and number of axles determine the resistance from friction in the bearings and flanges and from rolling contact.
- Operating Scenario. The TPS can provide for changes in operating conditions such as changes in the consist.

The fundamental mathematical model for a train simulation is based on Newtonian laws of motion. The forces involved are those due to train resistance and other factors including locomotive tractive effort and braking. Train resistance and other train performance factors are discussed below.

---

[1] For further information on the TPS see "User's Manual for the USDOT/TSC Train Performance Simulator, Version 5c," Revised March, 1988, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts 02142.

A.2 TRAIN RESISTANCE

Train resistance is composed of several elements including rolling friction resistance, bearing friction resistance, flange friction resistance and aerodynamic resistance. The resistance equation determines the total resistance force of the railcars and train.

Several resistance equations are available for performing train simulations. The resistance equation used in this study is a modified Canadian National (CN) equation. The CN equation coefficient values and the modifications applied in this study are listed in Exhibit A-1. The modifications were recommended by the participating railroads and based on current empirical research to meet the FRA's objective of accurately representing current train operations.

EXHIBIT A-1
RESISTANCE COEFFICIENTS

TPS Code	Coefficient Name	Definition	CN Equation	Modified CN
F	Rolling friction	Proportional to train weight independent of velocity	0.6	0.75
b	Bearing friction	Proportional to the number of axles, independent of weight and velocity	20	20
f	Flange Friction	Proportional to train weight and velocity	.01	.01
C	Air Drag Coefficient	A function of car size and shape. Proportional to the square of the net velocity in air, independent of weight.	.0005 (Car) .0024 (Locom)	.00255 (Car & Locom)
A	Cross-sectional area	Cross-sectional area in square feet of the end of the railcar.	140 (Car) 120 (Locom)	Varies by car type

In addition to the above, trains are impacted by rolling resistance, grades and curve resistance. The normal factor for grades is 20 pounds per ton per percent of grade, while for curves it is 0.8 pounds per ton per degree of curvature.

A.3 TPS DATA REQUIREMENTS

Advance work on TPS data requirements included the following activities:

- Update Locomotive Files. Abacus Technology identified the 48 locomotives on the TPS and the data elements needed to add new locomotives to the model. Requests were sent to General Electric and General Motors, Electromotive Division to obtain the required specifications of locomotives, introduced in 1985, that represent the latest in locomotive technology from the two U.S. manufacturers.

- Identify Consist Characteristics. Abacus Technology identified the codes and data elements needed to enter a train consist into the TPS. Later, Abacus Technology worked with the railroads in building train consists that reflect appropriate train size, weight, empty/loaded ratio and typical power characteristics for each selected route.

- Identify Train Header Data Requirements. The train header information requires the determination of variables for running the train such as train coasting overspeed in miles per hour, coasting overspeed percent, throttle position, velocity range, rate of energy use, iteration velocity, stall velocity and types of output desired from the model. Appropriate TPS values for these variables were selected.

- Identify Train Operating Characteristics. Other factors were defined such as wind speed, wind direction, the number of locomotives and their codes, the adhesion ratio limit, the maximum speed in miles per hour, the brake pipe pressure, the total number of cars, the number of loaded cars, the number of empty cars, the gross trailing tons, the total lading tons, the car length and number of axles per car.

A.4 OTHER TRAIN PERFORMANCE FACTORS

Other factors can impact train performance and fuel efficiency. Chief among these are tractive effort, braking, acceleration and average run speed. The elapsed time is the time required to complete the train run. This time is dependent upon braking, deceleration, acceleration and the posted speed limits and the route distance. All these factors are calculated by the TPS. A description of the chief train performance factors with comments on how they impact fuel efficiency is presented below.

- <u>Tractive Effort</u>. Tractive effort is the force which a locomotive exerts at the driving wheels to move itself and its trailing consist. It is limited by the power available from the traction motors, by the velocity and by the adhesion characteristics of the wheel-rail interface. The TPS automatically calculates tractive effort based on the locomotive horsepower in the train.

- <u>Braking</u>. When the train needs to be slowed because of a speed restriction or station stop, brakes are applied. This results in a retarding force at the wheel-rail interface of all locomotive and cars in the train which is adhesion limited but which acts as an additional resisting force. The force applied is a function of brake system parameters, time, velocity and weight of lading.

- <u>Acceleration</u>. Acceleration is defined as the rate of change in the train velocity. The TPS requires the train to attempt to accelerate and run at the speed limit whenever possible. Changes in acceleration and deceleration occur due to changes in posted speed limits and on terrain which requires alteration of acceleration such as grades or curves.

- <u>Average Run Speed.</u> Train speed is dictated by posted speed limits. These limits are a function of the track condition, area traffic restrictions, terrain, clearances, weather constraints, tonnage and safe equipment operating speeds.

A.5 INTERPRETATION OF TPS RESULTS

According to the Transportation Systems Center in Cambridge, Massachusetts, comparisons of TPS results with actual rail performance have shown that the TPS reproduces the movement of the train with reasonable accuracy. Results can be thought of as an estimate of the running time over the selected section of track for a train with the specified motive power and consist characteristics and considering the speed restriction and stops imposed. The TPS does not automatically include random delays such as train meets or mechanical failures sometimes incurred by freight trains.

APPENDIX B
DESCRIPTION OF TRUCK VEHICLE MISSION SIMULATOR

APPENDIX B
DESCRIPTION OF TRUCK VEHICLE MISSION SIMULATOR

This appendix describes the Cummins Engine Company Vehicle Mission Simulation (VMS) model for trucks. The description is organized into two sections:

- Background of the VMS
- VMS Operation.

Each is discussed below.

B.1 BACKGROUND OF THE VMS

The simulation of truck operations has always been seen as a tool which would greatly assist the transportation industry. The combination of engineering principles and practice and general management have made vehicle simulation possible today. The VMS model for trucks, developed by the Cummins Engine Company, is an example of such a model. The simulation model allows the user to input specific information and receive a printout of data relating to truck and powertrain performance and operation. The model includes actual route characteristics. It is used to improve decision-making on truck purchases by Cummins customers. The VMS is also used by Cummins for new product development.

When a simulation report is completed, the output is an estimate of performance for the specified truck and powertrain components under ideal operating conditions. The simulation report is used to evaluate truck and powertrain performance based on proposed scenarios.

B.2 VMS OPERATION

The VMS model uses the input described below to simulate the operation of a truck over the specified route. Once the operation of the model is complete it generates a comprehensive report on various output statistics.

B.2.1 Model Inputs

The inputs that are requisite to the running of the VMS model and computing of vehicle performance include descriptions of the engine; the drivetrain consisting of the transmission, axle and tires; the truck configuration; and the route over which the truck will travel. The types of data required for the operation of the VMS include:

- Description of the Engine. To provide a complete description of the engine, the VMS uses data which relates fuel consumption characteristics to various operating speeds and torque outputs, engine inertia, engine temperature and engine altitude correction factors. The user input is the engine model.

- Powertrain Description. To provide a complete description of the powertrain, the VMS uses data relating to gear ratios and power transmission efficiencies of gears in the transmission and rear axle. Other required data includes the revolutions per mile and driveline inertias. The user input includes the transmission, drive axle and axle ratios.

- Vehicle Description. To provide a complete description of the vehicle, the VMS requires user input to include vehicle height and width, cab type and model, trailer type, tires, configuration and use of aerodynamic aids.

- Description of the Route. The VMS uses data which documents all characteristics of the planned route of travel. This includes direction of travel, length of the segment, its altitude, speed limit imposed and type of road surface. The highway to be traversed is the only user input required.

B.2.2 Model Outputs

The outputs that are produced by the VMS model include the following:

- Input Summary. A complete description of the vehicle, engine and drivetrain are provided in the summary report.

- Result Summary. The summary of results from the running of the VMS model include parameters that describe the vehicle's performance. Exhibit B-1 provides a sample of a summary results list.

- Engine Description and Steady State Summary. The engine description includes an output of engine speed, standard torque, engine power, accessory power, installed power and installed specific fuel consumption. A steady state summary report is also generated which shows vehicle speed and upper engine operating range. This is useful to determine startability and gradeability.

EXHIBIT B-1

SAMPLE VMS SIMULATION SUMMARY

```
SIMULATION SUMMARY


  GCW OR GVW (LBS)      78000.

  CRUISE SPEED (MPH)        60

  WIND SPEED (MPH)           0
  WIND DIRECTION (DEG)       0

  TEMPERATURE               77
**********************************************************************

  DISTANCE (MILES)       355.4

  DRIVING TIME(HRS)       6.46

  IDLE TIME(MIN-SEC)      0-26

  AVERAGE SPEED(MPH)      55.0

  FUEL USED (GAL)         52.3

  FUEL MILEAGE(MPG)       6.79

  TIME AT FULL
   THROTTLE(PCT)           1.5

  AVG ENGINE SPEED
   (REVS/MILE)            1714

  ENG LOAD FACTOR(PCT)      47

  TOTAL GEAR SHIFTS         36

  TIME ON BRAKES(MIN)      2.9
```

APPENDIX C
DOCUMENTATION OF RAIL SERVICE SCENARIOS

EXHIBIT C-1
RAIL SERVICE ROUTE CHARACTERISTICS

SERVICE SCENARIO AND EQUIPMENT TYPE		ROUTE DISTANCE (MILES)	GRADE SEVERITY*	CURVATURE SEVERITY*	FREQUENCY OF SPEED LIMIT CHANGES*
Rail01	M	343	1.50	2.50	3.56
Rail02	M	343	1.50	2.50	3.56
Rail03	M/A	343	1.50	2.50	3.56
Rail04	TOFC	829	2.16	**	3.02
Rail05	DSTK	829	2.16	**	3.02
Rail06	M	829	2.16	**	3.02
Rail07	TOFC	1,333	1.35	**	1.64
Rail08	DSTK	1,333	1.35	**	1.64
Rail09	M	1,333	1.35	**	1.64
Rail10	TOFC	1,007	1.53	1.50	2.00
Rail11	M	1,007	1.53	1.50	2.00
Rail12	TOFC	261	1.50	1.65	3.98
Rail13	M	261	1.50	1.65	3.98
Rail14	TOFC	579	2.37	3.53	5.00
Rail15	M/A	579	2.37	3.53	4.76
Rail16	TOFC	707	2.82	1.74	4.18
Rail17	M	426	2.26	2.11	3.28
Rail18	M	281	3.67	2.66	5.00
Rail19	TOFC	604	3.07	2.08	3.32
Rail20	M	604	3.07	2.08	3.35
Rail21	TOFC	251	1.25	1.10	2.88
Rail22	TOFC	387	2.25	1.40	2.32
Rail23	M	462	2.00	1.10	2.21
Rail24	M	126	1.90	1.40	1.00
Rail25	TOFC	1,891	2.57	1.62	2.75
Rail26	M	1,891	2.57	1.62	2.75
Rail27	DSTK	1,891	2.57	1.62	2.75
Rail28	AUTO	1,799	2.82	1.71	2.30
Rail29	DSTK	1,801	2.78	1.71	2.24
Rail30	DSTK	778	3.38	2.03	3.14
Rail31	M	1,856	2.20	1.77	2.02
Rail32	TOFC	961	1.61	1.64	1.71
Rail33	M	74	1.75	1.21	2.97
Rail34	M	74	1.75	1.21	2.97
Rail35	M	74	1.75	1.21	2.97
Rail36	M	74	1.75	1.21	2.97
Rail37	M	54	2.80	1.93	2.21
Rail38	M	54	2.80	1.93	2.21
Rail39	M	54	2.80	1.93	2.21
Rail40	M	22	1.56	1.51	4.46
Rail41	M	22	1.56	1.51	4.46
Rail42	M	22	1.56	1.51	4.46
Rail43	M	22	1.56	1.51	4.46

* See Appendix E for an explanation of the method for evaluating rail route severity.

** Data was not available from the participating railroad.

EXHIBIT C-2
RAIL SERVICE LOCOMOTIVE CHARACTERISTICS

SERVICE SCENARIO AND EQUIPMENT TYPE		TRAIN TYPE	LOCOMOTIVES					LOCOMOTIVE HORSEPOWER[1]
			TYPE	NO.	TYPE	NO.	TOTAL	
Rail01	M	Mixed Freight	GP-9	1	GP40	1	2	4,800
Rail02	M	Mixed Freight	GP40	1			1	3,000
Rail03	M/A	Mixed Freight	GP-9	1	GP40	1	2	4,800
Rail04	TOFC	Intermodal	SD40-2	3			3	9,000
Rail05	DSTK	Double-stack	SD40-2	4			4	12,000
Rail06	M	Mixed Freight	SD40-2	3			3	9,000
Rail07	TOFC	Intermodal	SD40-2	3			3	9,000
Rail08	DSTK	Double-stack	SD40-2	4			4	12,000
Rail09	M	Mixed Freight	SD40-2	3			3	9,000
Rail10	TOFC	Intermodal	SD40-2	2			2	6,000
Rail11	M	Mixed Freight	SD40-2	3			3	9,000
Rail12	TOFC	Intermodal	GP40-2	3			3	9,000
Rail13	M	Mixed Freight	SD40-2	2			2	6,000
Rail14	TOFC	Intermodal	GP40-2	3			3	9,000
Rail15	M/A	Mixed Freight	SD40-2	2			2	6,000
Rail16	TOFC	Intermodal	B36-7	3			3	11,250
Rail17	M	Mixed Freight	SD40-2	1	C40-8	1	2	6,000
Rail18	M	Mixed Freight	SD40-2	1	GP40-2	1	2	6,000
Rail19	TOFC	Intermodal	B36-7	3			3	11,250
Rail20	M	Mixed Freight	SD40-2	3			3	9,000
Rail21	TOFC	Intermodal	B36-7	3			3	11,250
Rail22	TOFC	Intermodal	B36-7	3			3	11,250
Rail23	M	Mixed Freight	B36-7	4			4	15,000
Rail24	M	Mixed Freight	B36-7	4			4	15,000
Rail25	TOFC	Intermodal	SD60	3			3	11,400
Rail26	M	Mixed Freight	SD60	2	SD40	1	3	10,600
Rail27	DSTK	Double-stack	SD60	2	SD40	2	4	13,600
Rail28	AUTO	Solid Auto	SD60	1	SD40	2	3	9,800
Rail29	DSTK	Double-stack	SD60	2	C40-8	3	5	19,600
Rail30	DSTK	Double-stack	SD60	2	C40-8	3	5	19,600
Rail31	M	Mixed Freight	SD60	2	SD40	2	4	13,600
Rail32	TOFC	Intermodal	C36-7	2	SD40	1	3	10,500
Rail33	M	Mixed Freight	GP-9	4			4	7,200
Rail34	M	Mixed Freight	GP-9	4			4	7,200
Rail35	M	Mixed Freight	GP-9	4			4	7,200
Rail36	M	Mixed Freight	GP-9	4			4	7,200
Rail37	M	Mixed Freight	GP-7	2	SD-40	2	4	9,200
Rail38	M	Mixed Freight	GP-7	2	SD-40	2	4	9,200
Rail39	M	Mixed Freight	GP-7	2	SD-40	2	4	9,200
Rail40	M	Mixed Freight	GP-9	1			1	1,800
Rail41	M	Mixed Freight	GP-9	1			1	1,800
Rail42	M	Mixed Freight	GP-9	1			1	1,800
Rail43	M	Mixed Freight	GP-9	1			1	1,800

---

[1] The TPS used for this analysis assigned a horsepower of 1600 rather than 1500 to the GP-7, and a horsepower of 1800 rather than 1750 to the GP-9. These horsepower differences are minimal. If the difference were measurable, a slightly higher level of fuel consumption would be the result. This only applies to the small local service scenarios 33-43.

EXHIBIT C-3
RAIL SERVICE CONSIST CHARACTERISTICS

SERVICE SCENARIO AND EQUIPMENT TYPE	NO. OF CARS	NO. LOADED	NO. EMPTY	TRAILING WEIGHT (TONS)	GROSS WT. (TONS)	HP PER TRAILING TON
Rail01 M	65	65	0	4,420	4,682	1.1
Rail02 M	28	28	0	1,909	2,047	1.6
Rail03 M/A	75	75	0	5,475	5,737	0.9
Rail04 TOFC	36	34	2	3,354	3,978	2.7
Rail05 DSTK	23	12	11	4,421	5,253	2.7
Rail06 M	51	36	15	4,305	4,929	2.1
Rail07 TOFC	46	43	3	4,005	4,629	2.2
Rail08 DSTK	23	12	11	4,421	5,253	2.7
Rail09 M	96	73	23	8,835	9,459	1.0
Rail10 TOFC	34	34	0	2,040	2,456	2.9
Rail11 M	64	42	22	4,550	5,174	2.0
Rail12 TOFC	63	63	0	4,536	4,932	2.0
Rail13 M	88	73	15	8,448	8,832	0.7
Rail14 TOFC	63	63	0	4,536	4,932	2.0
Rail15 M/A	80	74	6	6,400	6,784	0.9
Rail16 TOFC	51	51	0	3,672	4,086	3.1
Rail17 M	119	79	40	9,996	10,380	0.6
Rail18 M	71	51	20	5,964	6,288	1.0
Rail19 TOFC	41	41	0	3,075	3,489	3.7
Rail20 M	82	66	16	7,708	8,284	1.2
Rail21 TOFC	61	61	0	3,599	4,013	3.1
Rail22 TOFC	30	30	0	1,980	2,394	5.7
Rail23 M	120	83	37	10,320	10,872	1.5
Rail24 M	80	67	13	6,800	7,352	2.2
Rail25 TOFC	47	35	12	3,007	3,855	3.8
Rail26 M	93	48	45	7,005	7,476	1.5
Rail27 DSTK	21	21	0	5,819	6,563	2.3
Rail28 AUTO	55	55	0	4,580	5,166	2.1
Rail29 DSTK	26	26	0	6,908	7,963	2.8
Rail30 DSTK	26	26	0	6,908	8,179	2.8
Rail31 M	76	40	36	5,126	6,205	2.7
Rail32 TOFC	49	47	2	3,704	4,152	2.8
Rail33 M	90	70	20	5,650	6,146	1.3
Rail34 M	90	70	20	5,650	6,146	1.3
Rail35 M	90	70	20	5,650	6,146	1.3
Rail36 M	90	70	20	5,650	6,146	1.3
Rail37 M	60	60	0	4,380	5,024	2.1
Rail38 M	60	60	0	4,380	5,024	2.1
Rail39 M	60	60	0	4,380	5,024	2.1
Rail40 M	10	10	0	730	854	2.5
Rail41 M	10	10	0	730	854	2.5
Rail42 M	25	25	0	1,825	1,949	1.0
Rail43 M	25	25	0	1,825	1,949	1.0

EXHIBIT C-4
RAIL SERVICE LOAD CHARACTERISTICS

SERVICE SCENARIO AND EQUIPMENT TYPE		COMMODITY ASSUMED FOR ANALYSIS	CAR TYPE	RAIL LADING (TONS)
Rail01	M	Lumber	TOFC	43
Rail02	M	Canned Food	TOFC	43
Rail03	M/A	Autos	Auto Rack	43
Rail04	TOFC	Canned Food	TOFC	51
Rail05	DSTK	Imported Electronics	Double-stack	210
Rail06	M	Plywood	Box Car	75
Rail07	TOFC	Canned Food	TOFC	51
Rail08	DSTK	Imported Electronics	Double-stack	210
Rail09	M	Plywood	Box Car	75
Rail10	TOFC	Food Products	TOFC	40
Rail11	M	Canned Food	Box Car	68
Rail12	TOFC	Beverages	TOFC	40
Rail13	M	Steel Products	Gondola	94
Rail14	TOFC	Beverages	TOFC	40
Rail15	M/A	Autos	Auto Rack	28
Rail16	TOFC	Grain Products	TOFC	48
Rail17	M	Sawmill Products	Box Car	70
Rail18	M	Food Products	Covered Hopper	72
Rail19	TOFC	Canned Fruit	TOFC	40
Rail20	M	Plastic Materials	Covered Hopper	72
Rail21	TOFC	Beverages	TOFC	40
Rail22	TOFC	Beverages	TOFC	40
Rail23	M	Sawmill Products	Box Car	70
Rail24	M	Sawmill Products	Box Car	70
Rail25	TOFC	Prefab Wood Products	TOFC	30
Rail26	M	Lumber	Flatcar	96
Rail27	DSTK	Containerized Freight	Double-stack	150
Rail28	AUTO	Autos	Auto Rack	24
Rail29	DSTK	Containerized Freight	Double-stack	150
Rail30	DSTK	Containerized Freight	Double-stack	150
Rail31	M	Canned Vegetables	Box Car	62
Rail32	TOFC	Beverages	TOFC	30
Rail33	M	Corn	Covered Hopper	98
Rail34	M	Plywood	Box Car	69
Rail35	M	Pulpwood	Flatcar	70
Rail36	M	Chips	Open Hopper	77
Rail37	M	Clay	Box Car	90
Rail38	M	Grain	Covered Hopper	100
Rail39	M	Canned Goods	Box Car	75
Rail40	M	Grain	Covered Hopper	99
Rail41	M	Steel Products	Flatcar	77
Rail42	M	Misc Food Products	Box Car	74
Rail43	M	Chemical Products	Box Car	95

EXHIBIT C-5
RESULTS OF TRAIN SIMULATION

SERVICE SCENARIO AND EQUIPMENT TYPE		AVERAGE RUNNING SPEED (MPH)	TOTAL RUNNING TIME	FUEL CONSUMED (GALLONS)*
Rail01	M	43	8 Hrs 3 Min	2,008
Rail02	M	43	7 Hrs 16 Min	1,023
Rail03	M/A	43	8 Hrs 19 Min	2,113
Rail04	TOFC	42	19 Hrs 44 Min	5,831
Rail05	DSTK	41	20 Hrs 8 Min	8,150
Rail06	M	40	20 Hrs 35 Min	6,284
Rail07	TOFC	54	24 Hrs 49 Min	8,646
Rail08	DSTK	54	24 Hrs 37 Min	10,102
Rail09	M	50	26 Hrs 35 Min	10,481
Rail10	TOFC	51	19 Hrs 43 Min	5,286
Rail11	M	51	19 Hrs 55 Min	7,457
Rail12	TOFC	44	5 Hrs 52 Min	2,007
Rail13	M	37	7 Hrs 3 Min	1,943
Rail14	TOFC	40	15 Hrs 28 Min	4,534
Rail15	M/A	34	18 Hrs 16 Min	4,600
Rail16	TOFC	39	18 Hrs 8 Min	5,641
Rail17	M	37	11 Hrs 25 Min	4,383
Rail18	M	34	7 Hrs 52 Min	2,465
Rail19	TOFC	38	16 Hrs 4 Min	2,935
Rail20	M	33	18 Hrs 4 Min	4,958
Rail21	TOFC	56	4 Hrs 27 Min	1,710
Rail22	TOFC	62	6 Hrs 13 Min	1,918
Rail23	M	53	8 Hrs 42 Min	4,140
Rail24	M	55	2 Hrs 16 Min	954
Rail25	TOFC	51	37 Hrs 9 Min	12,064
Rail26	M	41	46 Hrs 5 Min	15,360
Rail27	DSTK	49	38 Hrs 31 Min	17,824
Rail28	AUTO	46	39 Hrs 32 Min	13,645
Rail29	DSTK	51	35 Hrs 19 Min	24,034
Rail30	DSTK	46	17 Hrs 2 Min	12,569
Rail31	M	49	37 Hrs 57 Min	15,047
Rail32	TOFC	50	19 Hrs 9 Min	5,246
Rail33	M	36	2 Hrs 2 Min	516
Rail34	M	36	2 Hrs 2 Min	516
Rail35	M	36	2 Hrs 2 Min	516
Rail36	M	36	2 Hrs 2 Min	516
Rail37	M	22	2 Hrs 27 Min	329
Rail38	M	22	2 Hrs 27 Min	329
Rail39	M	22	2 Hrs 27 Min	329
Rail40	M	14	1 Hr 33 Min	15
Rail41	M	14	1 Hr 33 Min	15
Rail42	M	14	1 Hr 34 Min	27
Rail43	M	14	1 Hr 34 Min	27

* Calculated by the TPS.

EXHIBIT C-6
CLASS I SERVICE FUEL EFFICIENCY RESULTS

SERVICE SCENARIO AND EQUIPMENT TYPE		FUEL CONSUMED BY TRAIN (GAL)*	LOAD ASSUMED FOR ANALYSIS	FUEL CONSUMED BY LOAD (GAL)**	FUEL EFFICIENCY (TON-MILES PER GAL)***
Rail01	M	2,017	Lumber	37	471
Rail02	M	1,032	Canned Food	42	414
Rail03	M/A	2,137	Autos	35	499
Rail04	TOFC	5,833	Canned Food	161	281
Rail05	DSTK	8,152	Imported Electronics	664	281
Rail06	M	6,293	Plywood	148	450
Rail07	TOFC	8,649	Canned Food	200	355
Rail08	DSTK	10,104	Imported Electronics	798	367
Rail09	M	10,505	Plywood	130	805
Rail10	TOFC	5,288	Food Products	204	209
Rail11	M	7,481	Canned Food	149	486
Rail12	TOFC	2,010	Beverages	57	227
Rail13	M	1,967	Steel Products	36	843
Rail14	TOFC	4,537	Beverages	102	251
Rail15	M/A	4,624	Autos	64	279
Rail16	TOFC	5,644	Grain Products	153	240
Rail17	M	4,438	Sawmill Products	52	654
Rail18	M	2,489	Food Products	48	508
Rail19	TOFC	2,937	Canned Fruit	95	280
Rail20	M	4,982	Plastic Materials	69	688
Rail21	TOFC	1,713	Beverages	58	213
Rail22	TOFC	1,920	Beverages	91	196
Rail23	M	4,195	Sawmill Products	48	767
Rail24	M	978	Sawmill Products	21	608
Rail25	TOFC	12,067	Prefab Wood Products	255	229
Rail26	M	15,384	Lumber	277	676
Rail27	DSTK	17,826	Containerized Freight	835	350
Rail28	AUTO	13,654	Autos	216	206
Rail29	DSTK	24,036	Containerized Freight	917	304
Rail30	DSTK	12,571	Containerized Freight	518	243
Rail31	M	15,071	Canned Vegetables	255	465
Rail32	TOFC	5,249	Beverages	115	265

* Includes fuel required for rail and truck terminal operations.

** Includes fuel required for district switching and truck drayage.

*** Includes mileage for rail switching or truck drayage in addition to route distance.

EXHIBIT C-7
REGIONAL/LOCAL SERVICE FUEL EFFICIENCY RESULTS

SERVICE SCENARIO AND EQUIPMENT TYPE		FUEL CONSUMED BY TRAIN (GAL)	LOAD ASSUMED FOR ANALYSIS	FUEL CONSUMED BY LOAD (GAL)	FUEL EFFICIENCY (TON-MILES PER GAL)
Rail33	M	516	Corn	11	668
Rail34	M	516	Plywood	9	596
Rail35	M	516	Pulpwood	8	635
Rail36	M	516	Chips	9	619
Rail37	M	329	Clay	7	682
Rail38	M	329	Grain Products	9	641
Rail39	M	329	Canned Goods	7	625
Rail40	M	15	Grain Products	2	1,104
Rail41	M	15	Steel Products	2	890
Rail42	M	27	Misc Food Products	2	1,086
Rail43	M	27	Chemical Products	2	1,179

APPENDIX D
DOCUMENTATION OF TRUCK SERVICE SCENARIOS

EXHIBIT D-1
TRUCK SCENARIO CHARACTERISTICS

SERV. SCEN. AND EQUIPMENT TYPE		TRAILER TYPE	COMMODITY	TRUCK PAYLOAD (TONS)	TRACTOR + TRAILER (TONS)	GVW (TONS)
Truck01	F	FLATBED	LUMBER	24	15.0	39.0
Truck02	V	VAN TRAILER	CANNED GDS	24	15.0	39.0
Truck03	A	AUTO HAUL	AUTOS	15	17.5	32.5
Truck04	V	VAN TRAILER	CANNED GDS	24	15.0	39.0
Truck05	C	CONTAINER	IMP ELECTR	21	16.0	37.0
Truck06	F	FLATBED	PLYWOOD	24	15.0	39.0
Truck10	V	VAN TRAILER	MI FOOD PRO	21	15.0	36.0
Truck11	V	VAN TRAILER	CANNED GDS	24	15.0	39.0
Truck12	V	VAN TRAILER	BEVERAGES	22	15.0	37.0
Truck13	F	FLATBED	STEEL PROD	24	15.0	39.0
Truck15	A	AUTO HAUL	AUTOS	15	17.5	32.5
Truck16	FS	FBD/SIDES	GRAIN	22	16.0	38.0
Truck17	F	FLATBED	SAWMLL PRO	22	15.0	37.0
Truck18	V	VAN TRAILER	MI FD PROD	21	15.0	36.0
Truck19	V	VAN TRAILER	CANNED FRU	24	15.0	39.0
Truck20	V	VAN TRAILER	PLASTC MATL	20	15.0	35.0
Truck21	V	VAN TRAILER	BEVERAGES	22	15.0	37.0
Truck22	V	VAN TRAILER	BEVERAGES	22	15.0	37.0
Truck23	F	FLATBED	SAWMLL PROD	22	15.0	37.0
Truck25	F	FLATBED	PREFB WOOD	22	15.0	37.0
Truck26	F	FLATBED	LUMBER	24	15.0	39.0
Truck27	C	CONTAINER	CTR FREIGT	15	16.0	31.0
Truck28	A	AUTO HAUL	AUTOS	15	17.5	32.5
Truck29	C	CONTAINER	CTR FREIGT	15	16.0	31.0
Truck30	C	CONTAINER	CTR FREIGT	15	16.0	31.0
Truck31	V	VAN TRAILER	CANNED VEG	24	15.0	39.0
Truck32	V	VAN TRAILER	BEVERAGES	22	15.0	37.0
Truck33	FS	FLATBED/SIDES	CORN	22	16.0	38.0
Truck34	F	FLATBED	PLYWOOD	23	15.0	38.0
Truck35	F	FLATBED	PULPWOOD	23	15.0	38.0
Truck36	D	DUMP TRAILR	WOOD CHIPS	22	15.0	37.0
Truck37	V	VAN TRAILER	CLAY	22	15.0	37.0
Truck38	FS	FLATBED/SIDES	GRAIN PROD	22	16.0	38.0
Truck39	V	VAN TRAILER	CANNED GDS	24	15.0	39.0
Truck40	FS	FLATBED/SIDES	GRAIN PROD	22	16.0	38.0
Truck41	F	FLATBED	STEEL PROD	24	15.0	39.0
Truck42	V	VAN TRAILER	MISC FOOD	21	15.0	36.0
Truck43	V	VAN TRAILER	CHEMICAL PROD	21	15.0	36.0

Scenario numbers 07, 08, 09, 14 and 24 are intentionally omitted.

EXHIBIT D-2
TRUCK SCENARIO CHARACTERISTICS

SERV. SCEN. AND EQUIPMENT TYPE		TRAILER TYPE	TRAILER CORNERS/ SIDES	VEHICLE WIDTH/ HEIGHT	AERO-DYNAMIC AIDS*
Truck01	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck02	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck03	A	AUTO HAUL	OPEN FRAME	8'6"/13'6"	NO
Truck04	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck05	C	CONTAINER	SQUARE/RIBBED	8'6"/13'6"	YES
Truck06	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck10	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck11	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck12	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck13	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck15	A	AUTO HAUL	OPEN FRAME	8'6"/13'6"	NO
Truck16	FS	FBD/SIDES	OPEN TOP W/TARP	8'6"/10'	NO
Truck17	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck18	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck19	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck20	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck21	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck22	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck23	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck25	F	FLATBED	OPEN FRAME	8'6"/13'6"	NO
Truck26	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck27	C	CONTAINER	SQUARE/RIBBED	8'6"/13'6"	YES
Truck28	A	AUTO HAUL	OPEN FRAME	8'6"/13'6"	NO
Truck29	C	CONTAINER	SQUARE/RIBBED	8'6"/13'6"	YES
Truck30	C	CONTAINER	SQUARE/RIBBED	8'6"/13'6"	YES
Truck31	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck32	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck33	FS	FLATBED/SIDES	OPEN TOP W/TARP	8'6"/10'	NO
Truck34	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck35	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck36	D	DUMP TRAILR	ROUND/SMOOTH	8'6"/12'	YES
Truck37	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck38	FS	FLATBED/SIDES	OPEN TOP W/TARP	8'6"/10'	NO
Truck39	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck40	FS	FLATBED/SIDES	OPEN TOP W/TARP	8'6"/10'	NO
Truck41	F	FLATBED	OPEN FRAME	8'6"/10'	NO
Truck42	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES
Truck43	V	VAN TRAILER	ROUND/SMOOTH	8'6"/13'6"	YES

* Includes roof deflectors, cab extenders, side skirts and aerodynamic bumper/lights.

Scenario numbers 07, 08, 09, 14 and 24 are intentionally omitted.

EXHIBIT D-3
TRUCK SCENARIO CHARACTERISITICS

SERV. SCEN. AND EQUIPMENT TYPE	DRIVING TIME (HRS/MIN)	DISTANCE (MILES)	AVERAGE SPEED (MPH)	VMS FUEL USED (GAL)	VMS MILES PER GAL
Truck01 F	06hr 29min	355.4	55	51.1	6.95
Truck02 V	06hr 28min	355.4	55	52.3	6.79
Truck03 A	06hr 29min	355.4	55	60.1	5.91
Truck04 V	36hr 10min	2093.1	58	327.8	6.39
Truck05 C	36hr 07min	2093.1	58	332.1	6.30
Truck06 F	36hr 09min	2093.1	58	321.6	6.51
Truck10 V	17hr 29min	1030.2	59	162.1	6.35
Truck11 V	17hr 31min	1030.2	59	167.0	6.17
Truck12 V	12hr 15min	715.0	58	111.3	6.43
Truck13 F	05hr 12min	299.3	58	47.0	6.37
Truck15 A	07hr 59min	448.6	56	80.0	5.61
Truck16 FS	12hr 07min	720.2	60	107.5	6.70
Truck17 F	07hr 44min	462.1	60	69.5	6.65
Truck18 V	04hr 23min	258.1	59	41.0	6.30
Truck19 V	09hr 33min	569.1	60	89.8	6.34
Truck20 V	09hr 32min	569.1	60	86.8	6.56
Truck21 V	03hr 56min	236.6	60	38.1	6.21
Truck22 V	07hr 37min	428.6	56	67.3	6.37
Truck23 F	10hr 43min	615.1	57	95.7	6.43
Truck25 F	32hr 56min	1909.8	58	315.7	6.06
Truck26 F	32hr 52min	1909.8	58	288.1	6.66
Truck27 C	32hr 31min	1909.8	59	280.1	6.84
Truck28 A	28hr 37min	1607.8	56	281.3	5.73
Truck29 C	28hr 28min	1607.8	57	241.1	6.68
Truck30 C	12hr 31min	719.7	58	111.7	6.44
Truck31 V	29hr 02min	1674.0	58	256.8	6.54
Truck32 V	16hr 38min	995.8	60	152.7	6.52
Truck33 FS	01hr 14min	73.8	59	11.0	6.70
Truck34 F	01hr 14min	73.8	60	11.5	6.44
Truck35 F	01hr 14min	73.8	60	11.5	6.44
Truck36 D	01hr 14min	73.8	60	11.3	6.54
Truck37 V	01hr 00min	52.9	53	8.9	5.94
Truck38 FS	01hr 00min	52.9	53	8.6	6.14
Truck39 V	01hr 00min	52.9	53	9.1	5.80
Truck40 FS	00hr 18min	18.1	58	2.8	6.49
Truck41 F	00hr 18min	18.1	59	2.9	6.16
Truck42 V	00hr 18min	18.1	59	2.9	6.19
Truck43 V	00hr 18min	18.1	59	2.9	6.19

Scenario numbers 07, 08, 09, 14 and 24 are intentionally omitted.

EXHIBIT D-4
TRUCK SCENARIO CHARACTERISTICS

SERV. SCEN. AND EQUIPMENT TYPE	RAIL LADING (TONS)	TRUCK PAYLOAD (TONS)	# OF TRUCKS REQUIRED	FUEL EFFICIENCY (TMi/G)
Truck01 F	43	24	1.80	167
Truck02 V	43	24	1.79	163
Truck03 A	43	15	2.87	89
Truck04 V	51	24	2.13	153
Truck05 C	210	21	10.00	132
Truck06 F	75	24	3.13	156
Truck10 V	40	21	1.90	133
Truck11 V	68	24	2.83	148
Truck12 V	40	22	1.82	141
Truck13 F	94	24	3.92	153
Truck15 A	28	15	1.87	84
Truck16 FS	48	22	2.18	147
Truck17 F	70	22	3.18	146
Truck18 V	72	21	3.43	132
Truck19 V	40	24	1.67	152
Truck20 V	72	20	3.60	131
Truck21 V	40	22	1.82	137
Truck22 V	40	22	1.82	140
Truck23 F	70	22	3.18	141
Truck25 F	30	22	1.36	133
Truck26 F	96	24	4.00	159
Truck27 C	150	15	10.00	102
Truck28 A	24	15	1.60	86
Truck29 C	150	15	10.00	100
Truck30 C	150	15	10.00	97
Truck31 V	62	24	2.58	156
Truck32 V	30	22	1.36	143
Truck33 FS	98	22	4.45	148
Truck34 F	69	23	3.00	148
Truck35 F	70	23	3.04	148
Truck36 D	77	22	3.50	144
Truck37 V	90	22	4.09	131
Truck38 FS	100	22	4.55	135
Truck39 V	75	24	3.13	140
Truck40 FS	99	22	4.50	142
Truck41 F	77	24	3.21	150
Truck42 V	74	21	3.52	131
Truck43 V	95	21	4.52	131

Scenario numbers 07, 08, 09, 14 and 24 are intentionally omitted.

EXHIBIT D-5
TRUCK SCENARIO CHARACTERISTICS

SERV. SCEN. AND EQUIPMENT TYPE		TIME AT FULL THROTTLE (PERCENT)	AVERAGE ENGINE SPEED (RPMs)	ENGINE LOAD FACTOR (PERCENT)	TOTAL GEAR SHIFTS	TIME ON BRAKES (MIN)
Truck01	F	1.5	1714	46	36	2.9
Truck02	V	1.5	1714	47	36	2.9
Truck03	A	1.4	1764	54	33	2.8
Truck04	V	16.2	1737	53	239	47.2
Truck05	C	15.5	1733	54	231	38.8
Truck06	F	15.5	1736	52	233	48.9
Truck10	V	5.9	1718	54	110	10.9
Truck11	V	8.2	1719	56	110	11.2
Truck12	V	21.7	1727	53	95	17.7
Truck13	F	9.6	1727	53	73	4.7
Truck15	A	36.2	1793	58	99	12.2
Truck16	FS	9.1	1711	52	21	8.0
Truck17	F	6.4	1706	52	11	.4
Truck18	V	13.8	1722	55	14	6.8
Truck19	V	8.1	1707	55	18	.8
Truck20	V	6.4	1706	53	18	.8
Truck21	V	1.7	1705	56	9	.4
Truck22	V	5.8	1734	51	120	12.0
Truck23	F	4.3	1725	52	120	12.2
Truck25	F	20.1	1741	55	198	26.8
Truck26	F	18.1	1741	51	198	36.6
Truck27	C	12.3	1725	50	144	24.9
Truck28	A	19.3	1804	57	321	74.6
Truck29	C	17.3	1753	49	270	82.4
Truck30	C	20.9	1747	52	74	19.6
Truck31	V	16.1	1753	52	192	3.6
Truck32	V	2.4	1703	53	7	.6
Truck33	FS	1.8	1711	51	7	.1
Truck34	F	1.9	1711	54	7	.1
Truck35	F	1.9	1711	54	7	.1
Truck36	D	1.8	1711	53	7	.1
Truck37	V	15.0	1772	52	27	2.4
Truck38	FS	14.9	1773	50	27	2.4
Truck39	V	16.8	1778	53	30	2.5
Truck40	FS	6.9	1732	52	7	.1
Truck41	F	7.4	1733	55	7	.1
Truck42	V	6.9	1732	55	7	.1
Truck43	V	6.9	1732	55	7	.1

Scenario numbers 07, 08, 09, 14 and 24 are intentionally omitted.

APPENDIX E
METHOD FOR EVALUATING RAIL ROUTE SEVERITY

APPENDIX E
METHOD FOR EVALUATING RAIL ROUTE SEVERITY

This appendix explains the method used to characterize the grades, curvature and frequency of speed limit changes on the railroad routes in this study. This rating method was developed to provide a standard way to evaluate and communicate the characteristics of the different routes. The method can also be helpful in describing the route conditions under which some trains are more fuel efficient than others. The ratings are not used to calculate fuel efficiency.

This appendix is organized into three sections as follows:

- Grade severity
- Curvature severity
- Frequency of speed limit changes.

E.1 GRADE SEVERITY

To rate grade severity, the entire length of track is analyzed in sections of similar grade severity. Then, a weighted average of all track mileage is calculated to give the route an overall grade severity rating.

The analysis proceeds as follows. First, the track is divided into sections that have similar percent grades. Then, the sections are assigned a value based on the scale below. This value is multiplied by the proportion of miles this section represents out of the overall route. The final grade severity rating, as shown in Exhibit E-1, is a sum of the weighted grade severity values.

E.2 CURVATURE SEVERITY

Curvature severity is rated similarly to grade severity. The track is analyzed in segments for frequency and severity of curves. A weighted average is then calculated to provide an overall rating for the route. Exhibit E-2 presents the curvature severity rating table.

EXHIBIT E-1
GRADE SEVERITY RATING

RATING	DESCRIPTION	GRADES VALUES INCLUDED
1.00 - 1.49	Flat, no grade	0 - .1874 %
1.50 - 1.99		.1875 - .3749 %
2.00 - 2.49		.3750 - .5624 %
2.50 - 2.99		.5625 - .7490 %
3.00 - 3.49		.7500 - .9374 %
3.50 - 3.99		.9375 - 1.1249 %
4.00 - 4.49		1.1250 - 1.3124 %
4.50 - 4.99		1.3125 - 1.499 %
5.00	Steep grades	1.500 - + %

EXHIBIT E-2
CURVATURE SEVERITY RATING

RATING	DESCRIPTION	CURVE VALUES INCLUDED
1.00 - 1.49	Straight, no curve	0 - 1.124 degrees
1.50 - 1.99		1.125 - 2.249 degrees
2.00 - 2.49		2.250 - 3.374 degrees
2.50 - 2.99		3.375 - 4.499 degrees
3.00 - 3.49		4.500 - 5.624 degrees
3.50 - 3.99		5.625 - 6.749 degrees
4.00 - 4.49		6.750 - 7.874 degrees
4.50 - 4.99		7.875 - 8.999 degrees
5.00	Frequent curves	9.0+ degrees

E.3 FREQUENCY OF SPEED LIMIT CHANGES

The frequency of speed limit change is rated by totaling the number of speed limit changes and then determining a percent value based on this number divided by the route distance. This value is then assigned a rating corresponding to the schedule below. The frequency of speed limit changes rating is depicted in Exhibit E-3.

EXHIBIT E-3
FREQUENCY OF SPEED LIMIT CHANGES RATING

RATING	DESCRIPTION	NO. OF SPEED CHANGES/ ROUTE DISTANCE
1.00	No speed limit changes	0 - 5.00 percent
1.00 - 1.49		5.01 - 7.49 percent
1.50 - 1.99		7.50 - 9.99 percent
2.00 - 2.49		10.00 - 12.49 percent
2.50 - 2.99		12.50 - 14.99 percent
3.00 - 3.49		15.00 - 17.49 percent
3.50 - 3.99		17.50 - 19.99 percent
4.00 - 4.49		20.00 - 22.49 percent
4.50 - 4.99		22.50 - 24.99 percent
5.00	Frequent speed limit changes	25+ percent.

APPENDIX F
METHOD FOR EVALUATING TRUCK ROUTE SEVERITY

APPENDIX F
METHOD FOR EVALUATING TRUCK ROUTE SEVERITY

This appendix explains the method used to evaluate truck route severity on the truck routes in this study. This rating method was developed to provide a standard way to evaluate and communicate the characteristics of the different routes. The method can also be helpful in describing the route conditions under which some trucks are more fuel efficient than others. The ratings are not used to calculate fuel efficiency.

A scale was developed to rate the truck route characteristics. The scale, shown in Exhibit F-1, was developed based on the Cummins VMS output report, which includes data on the extent of engine utilization. These data, as shown in Exhibit D-5 in Appendix D, include time at full throttle, average engine speed, engine load factor, total gear shifts and time on brakes. It was determined that the amount of time on brakes may be indicative of terrain difficulty. This variable was then divided by route distance to normalize the data for each scenario. The calculated values for each scenario were then used to develop a scale to measure route severity. Route severity is measured in increments of .5 with 0 representing an easy terrain and 5.0 representing a difficult terrain. Exhibit F-2 presents a listing of route severity rating for each truck route.

EXHIBIT F-1
ROUTE SEVERITY RATING

RATING	DESCRIPTION	BRAKING MINUTES/ ROUTE DISTANCE
1.0	EASY TERRAIN	0 - .0055
1.5		.0056 - .0110
2.0		.0111 - .0166
2.5		.0167 - .0222
3.0		.0223 - .0278
3.5		.0279 - .0334
4.0		.0335 - .0390
4.5		.0391 - .0446
5.0	DIFFICULT TERRAIN	.0447+

EXHIBIT F-2
ROUTE SEVERITY CHARACTERISTICS

SERVICE SCENARIO	TIME ON BRAKES (MIN)	ROUTE DISTANCE (MILES)	BRAKING MINUTES/ ROUTE DISTANCE	ROUTE SEVERITY RATING
Truck01	2.9	355.4	.0082	1.5
Truck02	2.9	355.4	.0082	1.5
Truck03	2.8	355.4	.0079	1.5
Truck04	47.2	748.0	.0226	3.0
Truck05	38.8	748.0	.0185	2.5
Truck06	48.9	748.0	.0234	3.0
*				
*				
*				
Truck10	10.9	1,030.2	.0106	1.5
Truck11	11.2	1,030.2	.0109	1.5
Truck12	17.7	715.0	.0248	3.0
Truck13	4.7	299.3	.0157	2.0
*				
Truck15	12.2	448.6	.0272	3.0
Truck16	8.0	720.2	.0111	2.0
Truck17	.4	462.1	.0009	1.0
Truck18	6.8	258.1	.0263	3.0
Truck19	.8	569.1	.0014	1.0
Truck20	.8	569.1	.0014	1.0
Truck21	.4	236.6	.0017	1.0
Truck22	12.0	428.6	.0280	3.5
Truck23	12.2	615.1	.0198	2.5
*				
Truck25	26.8	1909.8	.0140	2.0
Truck26	36.6	1909.8	.0192	2.5
Truck27	24.9	1909.8	.0130	2.0
Truck28	74.6	1607.8	.0464	5.0
Truck29	82.4	1607.8	.0513	5.0
Truck30	19.6	719.7	.0272	3.0
Truck31	3.6	1674.0	.0022	1.0
Truck32	.6	995.8	.0006	1.0
Truck33	.0	73.8	0	1.0
Truck34	.0	73.8	0	1.0
Truck35	.0	73.8	0	1.0
Truck36	.0	73.8	0	1.0
Truck37	2.4	52.9	.0454	5.0
Truck38	2.4	52.9	.0454	5.0
Truck39	2.5	52.9	.0473	5.0
Truck40	.0	18.1	0	1.0
Truck41	.0	18.1	0	1.0
Truck42	.0	18.1	0	1.0
Truck43	.0	18.1	0	1.0

Sscenario numbers 07, 08, 09, 14 and 24 are intentionally omitted.

APPENDIX G
ASSUMPTIONS REGARDING FUEL CONSUMPTION FOR RAIL SWITCHING, RAIL TERMINAL OPERATIONS AND TRUCK DRAYAGE

APPENDIX G
ASSUMPTIONS REGARDING FUEL CONSUMPTION FOR RAIL SWITCHING, RAIL TERMINAL OPERATIONS AND TRUCK DRAYAGE

The TPS train simulation does not include fuel consumed during the activities of rail switching, rail terminal operations and truck drayage. Estimates of fuel consumed during rail intermodal and rail mixed freight terminal operations were added to the total train fuel consumption, and were subsequently allocated per railcar based on the percentage of gross weight of the car and lading. Fuel required for the rail mixed freight switching was added directly to the railcar value obtained after the terminal operations calculation. Fuel required for the rail intermodal truck drayage was calculated for each trailer and container moved. The estimated fuel consumption amounts for each are presented in Exhibit G-1.

EXHIBIT G-1
ESTIMATED FUEL CONSUMPTION

ACTIVITY	TOTAL FUEL CONSUMED PER FREIGHT MOVEMENT
RAILCAR SWITCHING (GENERAL FREIGHT)	7.54 Gals.
TERMINAL OPERATIONS - RAIL (GENERAL FREIGHT)	From 9.4 to 55.2 Gals. (Depending on train size)
TERMINAL OPERATIONS - TRUCK (INTERMODAL FREIGHT)	From 2.0 to 3.0 Gals. (Depending on train size)
TRUCK DRAYAGE (INTERMODAL FREIGHT)	10.34 Gals.

The assumptions supporting each of these fuel consumption figures is presented below.

G.1 RAIL SWITCHING

The distance that the freight must be moved varies by product and by terminal. For the purpose of this study, a standard one-way rail local switching distance of 30 miles and a fuel consumption of 3.77 gallons per railcar is assumed. After adding the switching at the beginning and at the end of the trip, the total gallons consumed is 7.54 gallons per car. The supporting analysis for these assumptions is outlined below.[1]

- Locomotive. The locomotive is assumed to be a GP38, with total weight of 137 tons.
- Train. The train consists of 20 loads (1,800 tons) and 10 empties (300 tons) for a total trailing weight of 2,100 tons.
- Distance. The distance traveled (one-way) is 30 miles at 0 percent grade.
- Speed. The maximum speed traveled is 40 miles per hour.
- Number of Stops. The train makes three 20-minute stops for switching.
- Trip Time. The time consumed in moving is 90 minutes to travel 30 miles. The time consumed in switching is 60 minutes for 3 stops, for a total trip time of 2 1/2 hours.
- Throttle Positions. The average throttle position for moving is throttle # 5. The average throttle position for switching is throttle # 3.
- Total Fuel Consumption[2]. The total fuel consumed for this trip is 111.4 gallons, calculated as follows:

90 min. moving (Avg.throttle #5)	95.7 gals.
60 min. switching(Avg. throttle #3)	15.7 gals.
Total fuel consumed	111.4 gals.

- Fuel Consumption per Car. The fuel consumption for a loaded car with an assumed gross car weight of 76 tons is 7.54 gallons. Calculations are presented in Exhibit G-2.

---

[1] The assumptions for rail switching were developed by Harry Eck, former Superintendent of Locomotive Operations, CSX Railroad.

[2] Fuel consumption figures are taken from Manual No. 506, "Fuel Conservation in Train Operation," published by the Association of American Railroads, December, 1981.

EXHIBIT G-2
CALCULATIONS FOR FUEL CONSUMPTION PER CAR

Step 1.

The Percent of Gross Train Weight for the Loaded Car = $\frac{76 \text{ Tons}}{2,237 \text{ Tons}}$ = .0339 = 3.39

Step 2.

The Amount of Fuel Consumed by the Loaded Car = 111.4 Gal. x .0339 = 3.77 Gals.

Step 3.

Completed Trip Fuel Consumption for Rail Local Switching = 3.77 Gals. x 2 = **7.54 Gals.**

G.2 TERMINAL OPERATIONS - RAIL

Rail terminal operations encompass the railroad switch movements required to classify (block) a general freight train. The number of switch movements to make up a given block could have wide variation. The number of switch movements have been estimated for the purpose of this study based on practical experience.

It is assumed that either a GP-9 or SD-9 locomotive is used to switch the train into four blocks. The amount of fuel consumption is estimated for trains of 40, 80 and 120 cars in Exhibit G-3. These fuel consumption figures were added to fuel consumed in the line-haul and then divided and allocated to each car.

EXHIBIT G-3
ESTIMATED FUEL CONSUMPTION

Number of Freight Cars	Fuel Consumption for Rail Terminal Operations
40	9.4 gals.
80	24.2 gals.
120	55.2 gals.

The assumptions are as follows:

- 40 Car Train. This train requires eight switching moves averaging 3 minutes per move. This totals 24 minutes switching using average throttle position #3 (23.6 Gallons per Hour) for a total of 9.4 gallons of fuel.
- 80 Car Train. This train requires twelve switching moves averaging 4 minutes per move. This totals 48 minutes in average throttle position #3.5 (30.2 GPH) for a total of 24.2 gallons of fuel.
- 120 Car Train. Eighteen switching moves are required for this train averaging 5 minutes per move and totaling 90 minutes using average throttle position #4 (36.8 GPH) for a total of 55.2 gallons of fuel.

G.3 TERMINAL OPERATIONS - INTERMODAL

Energy consumption at the railroad terminal includes the hostling of intermodal trailers and containers from the point where they were dropped by the inbound delivery truck to the track location where they are to be side loaded onto the rail flatcar. The railroads use yard tractors for this purpose that are kept operating almost continuously.

For this study it is assumed that an intermodal train with from 20 to 45 cars requires the expenditure of 2 gallons of fuel for truck hostling, and a train with from 46 to 70 cars requires 3 gallons of fuel as summarized in Exhibit G-4. These fuel consumption figures were added to fuel consumed in the line-haul and then divided and allocated to each car.

EXHIBIT G-4
FUEL CONSUMPTION FOR TERMINAL OPERATIONS

Number of Intermodal Cars	Fuel Consumption for Terminal Operations
20 to 45	2.0 gals.
46 to 70	3.0 gals.

These estimates are based on the following:

- A typical trailer or container is estimated to be moved

600 feet by the rail yard tractor

- Each intermodal railcar is assumed to carry the equivalent of two trailers or containers.
- Because of almost continuous operation and the stop and go nature of rail terminal work, the rail yard tractor is assumed to burn fuel at a rate of 4.0 miles per gallon.

G.4 TRUCK DRAYAGE OF INTERMODAL FREIGHT

Truck drayage is required for intermodal shipments of containers or trailers. Most large-volume railroad terminals use mobile lift transfer of the container or trailer from the truck to the railcar and vice versa. A mobile lift or side loader can place trailers and containers directly on flatcars designated to go to their destination, so there is no further "classification" of the railcars necessary after loading.

The assumption for this study is that 5.17 gallons of fuel are consumed at each end of an intermodal movement for truck drayage of one trailer or container. A completed intermodal freight movement (origin to destination) would include 10.34 gallons of truck diesel fuel per container or trailer hauled. For example, for rail TOFC with two trailers this amounts to 20.68 gallons (10.34 gallons multiplied by two) and for rail double-stack with 10 containers this results in 103.40 gallons (10.34 gallons multiplied by ten). This assumption is based on the following:

- Distance. A one way distance of 30 truck miles is assumed at each end of the freight delivery. For example, a loaded truck would move a trailer 30 miles to the railroad terminal. At the end of the railroad freight movement, a truck would arrive at the railroad terminal, pick up the trailer, and take it to the customer location.
- Rate of Fuel Consumption. The average rate of fuel consumption for truck drayage is estimated at 5.8 miles per gallon. Supporting sources for this estimate are listed in Attachment 1 to this appendix.

Given the above assumptions, the fuel consumption for truck drayage is calculated in Exhibit G-5.

EXHIBIT G-5
CALCULATIONS FOR FUEL CONSUMPTION FOR TRUCK DRAYAGE

Step 1.

The Amount of Fuel Consumed by the Drayage Truck $= \frac{30 \text{ miles}}{5.8 \text{ mpg}} =$ 5.17 Gals.

Step 2.

Completed Trip Fuel Consumption for Truck Drayage = 5.17 Gals. x 2 = **10.34 Gals.**

ATTACHMENT 1
Supporting Sources for the Estimate of Truck Fuel Consumption

The following sources support the estimated truck fuel consumption of 5.8 miles per gallon used in calculating truck drayage:

- A 1987 survey on future truck requirements by the Maintenance Council of the American Trucking Association included the question "What is your current fleet average fuel consumption?" An average of 5.8 mpg was reported based on responses from 150 trucking companies.

- Mr. Vic Suski, an engineer with the American Trucking Association, provided a 1990 average fuel consumption estimate of 5.8 miles per gallon in a telephone discussion. According to Mr. Suski, trucking companies track fuel consumption in different ways and there is no current accurate source of fleetwide average fuel economy. However, the 5.8 mpg estimate is based on reports and articles in the trade press that he has reviewed.

- "Highway Statistics 1988" published by the U.S. Department of Transportation, Federal Highway Administration reports a preliminary estimate of fuel consumption of 5.22 mpg in 1987 for all combination trucks. It is reasonable to assume that with improved technology this figure has increased to 5.8 mpg in 1990. Reference: Highway Statistics 1988, Table VM-1, page 172.

- A fleet average fuel consumption of 5.6 mpg was reported by the Arthur H. Fulton Inc. trucking company of Stephens City, Virginia in the April, 1990 volume of Southern Motor Cargo Magazine. This company operates nationwide with 350 truck tractors and 875 trailers.

- A fleet average fuel efficiency of 6.1 miles per gallon was reported for Freymiller Trucking, Inc. in a January 30, 1990 investment research report by Alex. Brown & Sons Inc. The report suggests that Freymiller's fuel efficiency performance ranks among the leaders in the industry. Part of the improved fuel efficiency may be due to the fact that Freymiller has shortened its tractor trade-in cycle from 36 to 24 months. Freymiller is a long-haul domestic truckload carrier with annual revenues of approximately $80 million.

APPENDIX H
ABSTRACTS OF PREVIOUS FUEL EFFICIENCY STUDIES

Previous Studies of Rail vs. Truck Fuel Efficiency

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
1. TITLE: Changes in Transportation Energy Intensiveness: 1972-1978 PURPOSE: Disseminate preliminary technical information about changes in transportation energy for the time period 1972-1978. SOURCE: Performed by: Department of Transportation (U.S. DOT), Transportation Systems Center (TSC) Author: John K. Pollard Date: May 1980	BTU / PM BTU / TM MPG	Improvements in rail and truck design are reflected in lower percentage change for units indicated.
2. TITLE: Railroads and the Environment: Estimation of fuel Consumption in Rail Transportation Volume II - Freight Service Measurements PURPOSE: Provide a technical basis for the improvement of rail transportation service, efficiency, and productivity. SOURCE: Performed by: Department of Transportation (U.S. DOT), Transportation Systems Center (TSC) Sponsored by: U.S. DOT, Federal Railroad Administration Author: John B. Hopkins; A.T. Newfell Date: September 1977	TM / GALLON	Study recognizes the futility of developing a single number for energy intensiveness. It can be misleading if applied to a specific case differing in some crucial factor. Thus, the study focuses on determining fuel consumption under various circumstances using TM / GALLON.
3. TITLE: Fuel Efficiency Improvement in Rail Freight Transportation PURPOSE: Provide a technical basis for the improvement of transportation service, efficiency, and productivity. SOURCE: Performed by: The Emerson Consultants, Inc. Sponsored by: U.S. DOT, Federal Railroad Administration Author: J.N. Cetinich Date: December 1975	NET TM / GALLON GROSS TM / GALLON TRAILING GROSS TM / GALLON	+ Net TM / GAL is the recommended measure for evaluating corporate effectiveness in diesel fuel + Net TM / GAL encompasses heavier loading of cars, reduction of empty car miles, more fuel efficient train operations, reduction of fuel spillage and distribution losses, and better control of all fuel activities. + Recommended measures for assessing the fuel-effectiveness of railroad operating departments in freight train operations - All three of these measures demand both consistent ton-mile and fuel-consumed data. Most present accounting and fuel control systems do not maintain these data on a current basis and consistent with the time periods for both sets of data

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
4. TITLE: An Improved Truck/Rail Operation Evaluation of a Selected Corridor PURPOSE: Presuming an improved truck/rail transportation service would offer significant opportunities for the future, this study had as its objective the consideration of potential impacts upon trucking companies, shippers, Teamsters, and the highways SOURCE: Performed by: Reebie Associates Sponsored by: U.S. DOT, Federal Highway Administration Author: D.P. Ainsworth; M.J. Keale; C.J. Liba; H.M. Levinson Date: December 1975	GALLONS PER 40 FT. CONTAINER EQVT.	Estimates of railroad fuel consumption are more difficult in that more recent well documented railroad fuel consumption data is simply non-existent. The last time tests were conducted under controlled standards was 1928. This data is still used because it is verifiable, in spite of the fact that it is old and there is no allowance for the aerodynamic effects of variations in frontal sections and openings between cars.
5. TITLE: When It Comes to Fuel-Efficiency, Railroads Lead the Transportation Pack PURPOSE: Article depicts America's railroads as among the leaders in the search for alternative fuels and improved fuel efficiency SOURCE: Performed by: Association of American Railroads, Office of Information and Public Affairs Date: September 1, 1988	TM / GALLON	AAR viewed this as a key measurement to illustrate the 40 percent increase in rail energy efficiency over the past 10 years.
6. TITLE: The Feasibility of a Nationwide Network for Longer Combination Vehicles PURPOSE: Documents analyses of effects on truck traffic and freight distribution costs attributable to (a) the truck size and weight limit and highway user tax changes of the STAA '82 and (b) a hypothetical national highway network for long combination vehicles (LCV) SOURCE: Performed by: U.S. DOT, Transportation Systems Center Sponsored by: U.S. DOT, Office of the Secretary, Office of Economics Author: Domenic J. Maio Date: May 1986	TM / GALLON	Used this measure to illustrate the change in fuel consumption resulting from STAA '82 and the hypothetical LCV network.

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
7. TITLE: An Integrated Transportation Policy for an Era of Rising Expectations PURPOSE: In the 1980's the U.S. freight railroad industry went through a decisive transition as a new economic and regulatory order emerged. Many of the implications and opportunities created by this new order have not yet registered on national transportation policy. This paper assists the government in catching up with the new realities. SOURCE: Performed by: Association of American Railroads Date: August 1989	TM / GALLON MPG	Unit used to show railroads consume 2.76 times less energy per ton of freight carried as compared to trucks. Used to show truck per-mile energy consumption has improved 14% between 1980-1987.
8. TITLE: Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation PURPOSE: This report details the efficiencies of various vehicles and modes for both passengers and freight under various conditions. The potential impacts of alternative energy-conservation options are evaluated, and research needs are identified. SOURCE: Performed by: Transportation Research Board, National Research Council Sponsored by: American Association of State Highway and Transportation Officials Date: 1977	TM / GALLON BTU / [UNIT]-MILE Metric equivalent: MJ / [UNIT]-KM Where [UNIT] is PASSENGER or TON	- When comparing efficiencies of various modes of transportation, it is not enough to compare TM / GALLON. Attention should also be given to such items as trip length; transport time; commodity value, perishability, and fragility; freight density; and manufacturing flow processes. Comparisons should be made only if the data address the same markets and are related to the performance of the same transportation job. Used to denote current energy consumption for rail passenger service. Varies from 1,646 to 3,533 Btu/passenger mile. Used to compare rail efficiency, 675 Btu/TM, to truck efficiency, 2,700 Btu/TM for intercity combination trucks. - Research is needed to obtain more accurate data on fuel use, vehicle-miles traveled, automobile occupancy, and passenger-miles on public transit. - Accuracy of data is frequently unknown since many businesses do not conform to the reporting requirements of regulatory agencies, and estimates themselves may experience a 5-10 percent error. - A high priority needs to be given to developing test procedures for determining fuel economy. Because the real fuel efficiency of commercial vehicles is determined by the fuel consumed relative to the work performed (transport of material and people), the final measure of fuel economy should reflect productivity (i.e. ton-miles, or passenger-mpg of fuel consumed).

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
9. TITLE: An Assessment of the Opportunities for Achieving Energy Efficiencies in Transportation PURPOSE: Examined opportunities for achieving energy efficiencies in the following modes of transportation; truck, rail, air, waterways and pipelines SOURCE: Performed by: University of California: Berkeley, CA Sponsored by: Lawrence Livermore Laboratory: CA Author: W.L. Garrison; O. Michael Bevilacqua Date: October 1976	BTU / TM	Used as a measure of energy intensiveness to compare rail and truck intercity freight energy use. Rail consumes 670 Btu/TM versus 2,800 Btu/ TM for trucks.
10. TITLE: Energy Conservation in Transportation PURPOSE: Presents energy conservation measures in planning and policy, technology and design, and operations and maintenance for various transportation modes. SOURCE: Performed by: System Design Concepts, Inc. Sponsored by: Transportation Research Board, National Research Council Author: Joseph R. Stowers; V. Wesley Boyar Date: December 1985	MPG	Used as a basis of comparison for gasoline and diesel trucks. Diesel two-axle tractors were significantly more efficient than their gasoline counterparts.
11. TITLE: Amtrak Fuel Consumption Study PURPOSE: This report documents a study of fuel consumption on National Railroad Passenger Corporation (Amtrak) trains and is part of an effort to determine effective ways of conserving fuel on the Amtrak system. SOURCE: Performed by: U.S. DOT, Transportation Systems Center Sponsored by: U.S. DOT, Federal Railroad Administration in cooperation with Amtrak Author: John Hitz Date: February 1981	PM / GALLON	Determined average fuel efficiency of trains to be 277 PM/Gallon based on series of 26 test runs conducted on Amtrak trains operating between Boston and New Haven.

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
12. TITLE: The Effect of Fuel Price Increases on Energy Intensiveness of Freight Transport PURPOSE: Examines effect of fuel price increases on energy intensiveness of freight transport. Encompasses water, rail, pipeline, truck and air cargo modes. SOURCE: Performed by: Rand, Santa Monica, CA Sponsored by: National Science Foundation Author: W.E. Mooz Date: December 1971	BTU / TM	Unit is used to determine the effect of a tenfold increase in fuel prices on average modal rates. Rail was calculated to be 750 Btu/TM and trucks 2,400 Btu/TM.
13. TITLE: Fuel Efficiency in Freight Transportation PURPOSE: This study reviews the record of extensive research on barge transportation. SOURCE: Performed by: Economic Sciences Corporation Sponsored by: Water Transportation Association The American Waterways Operators Inc. Author: Samuel Ewer Eastman Date: June 1980	BTU / TM TM / GALLON	Units used to compare different transport modes, but primary emphasis was waterways versus rail. Waterway Btu/TM was 270 compared with 686 Btu/TM for rail. Waterway ton miles moved per gallon was 514 versus 202 TM/Gallon for rail.
14. TITLE: Fuel Conservation from an Operating Standpoint PURPOSE: The articles in this booklet have been assembled in order to acquaint operating officers with the different locomotive operating practices which would aid in conserving fuel SOURCE: Performed by: The Railway Fuel & Operating Officers Association Author: Compiled by H.C. Eck, Member Executive Committee Date: 1980	TM / GALLON	Unit is mentioned in conjunction with the effort to instill the value of saving a gallon of fuel. States, "On American railroads, one gallon of fuel moves one ton of freight 420 miles."

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
15. TITLE: An Investigation of Truck Size and Weight Limits Technical Supplement Volume 3: Truck and Rail Fuel Effects of Truck Size and Weight Limits PURPOSE: 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 SOURCE: Performed by: U.S. DOT, Transportation Systems Center Sponsored by: U.S. DOT, Office of the Secretary of Transportation Author: David Knapton Date: July 1981 Analytical model: Empirical model based in part on Cummins Engine Company Vehicle Mission Simulation	BTU / TM	Used as empirical model to obtain measurements in BTU/TM for rail and truck. Based on the estimates of national total direct and indirect energy consumption, trucking uses 3.5 times as much fuel as rail in direct consumption and 3.1 times as much indirect energy.
16. TITLE: Energy Intensity of Various Transportation Modes PURPOSE: Article (from Transportation Research Record 689) is an overview of existing literature related to the energy intensity of various transportation modes for passenger and freight movement SOURCE: Performed by: Energy and Transportation Division, Aerospace Corporation Sponsored by: Transportation Research Board; National Academy of Sciences Author: Ram K. Mittal Date: 1978	KJ / [UNIT]-KM where [UNIT] is SEAT and PASSENGER JOULES / KG-KM	Used as unit of measure for rail transit systems but did not indicate any values for trucks. Used as basis of comparison for intercity truck, 1806 J/kg-km, and intercity freight trains, 540 J/kg-km.
17. TITLE: Debunking the Rail Energy Efficiency Myth PURPOSE: Discredit use of ton-miles per gallon as unit of efficiency and propose alternative energy efficiency unit. SOURCE: Performed by: American Trucking Associations, Inc Date: August 1974	TM / GALLON	- States that fuel consumption per ton-mile varies with the gross weight involved not the carried load, all other things being equal. However, in transportation things are rarely equal. Among the things that are seldom equal are the terrain over which shipments move, the mileage between given points by different carriers and forms of transport, shipping weight as compared to commodity weight, the volume of freight moving between given points at one time and over time, the distance that goods move, the completeness of the service and the speed at which freight moves.

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
TITLE: Debunking the Rail Energy Efficiency Myth (CONTINUED)	PRICE / TM	+ Proposed unit of measure that eliminates the distortions that result from comparing purely physical units.
18. TITLE: Truck and Rail Energy Comparisons - Project 1275 PURPOSE: The purposes of the paper are (1) to illustrate the extent of the current statistical madness, (2) to present a potentially usable index for comparing the energy use of competing freight transportation systems and, finally, (3) to illustrate how "ton-miles per gallon" might be useful within a transportation mode to identify potential improvements in our national use of energy in the freight transportation system SOURCE: Performed by: SRI International, Energy Center Sponsored by: The Western Highway Institute Author: Patrick J. Martin Date: October 1980	TM / GALLON DOLLARS OF REVENUE PER GALLON OF FUEL USED	- TM/Gallon is not a valid index for intermodal energy use comparisons because it includes only one element of the transportation system services - the movement of goods. It excludes other important elements such as protection from delay, damage and loss. + This unit is an energy use index that allows comparison of total transportation services delivered to our economy in exchange for the consumed energy. For the total systems and for mixed freight, it was concluded that trucks add significantly greater value per unit of energy consumed than do trains.
19. TITLE: Energy Use in Freight Transportation PURPOSE: The energy efficiency of different modes of transportation are compared SOURCE: Performed by: Congressional Budget Office Sponsored by: U.S. Congress Date: February 1982	BTU / TM	- States that determining BTUs is difficult. It is necessary to include not only the energy used in propelling the vehicles but that consumed in manufacturing them and in building the guideways (tracks and highways) on which they run, as well as in maintaining each system. - States that some analysts believe this unit of measure does not reflect the different levels of service provided by each mode.

Previous Studies of Rail vs. Truck Fuel Efficiency (Continued)

STUDY	UNIT OF MEASURE DISCUSSED	ABSTRACT
TITLE: Energy Use in Freight Transportation (CONTINUED)	BTU / TM BTU / DOLLAR OF CARGO	Study shows that rail is more efficient than truck by about 2 to 1 based on this unit of measure. Cursorily mentioned as an alternative to Btu/TM, but not seriously considered. - General measurement problems for this unit include cargo density, different commodities with different handling requirements and limitations of data.
20. TITLE: Analysis of the Incremental Cost and Trade-Offs Between Energy Efficiency and Physical Distribution Effectiveness in Intercity Freight Markets PURPOSE: This report describes a study of the effects of changes in national transportation policy on the traffic allocation and the energy consumption of various modes of intercity freight transportation SOURCE: Performed by: Center for Transportation Studies, MIT Sponsored by: Federal Energy Administration Author: Paul O. Roberts; Marc N. Terziev; James T. Kneafsey; Lawrence B. Wilson; Ralph D. Samuelson; Yu Sheng Chiang; Christopher V. Deephouse Date: November 1976	TM / GALLON	Rationale for using TM/Gal to determine impact on overall fuel consumption in the MIT study was the compromise between the available models and use of informed judgment to tailor the results to fit the four market pairs studied in this project. After an extensive review of the available literature, it was determined that no simple yet accurate model exists for estimating fuel consumption.
21. TITLE: Truck/Rail Comparative Fuel Efficiency PURPOSE: Evaluating the relative energy efficiency of railroads and motor carriers. SOURCE: Performed by: American Trucking Association, Energy and Economics Department Author: Lana R. Batts Date: 1981	TM / GALLON	Notes that studies conducted prior to the Arab oil embargo employed the simple methodology of dividing the total amount of fuel that each mode consumed in a year into the total ton-miles moved, and often relied on the same data. Post-embargo analysis generally concluded that analysis based on TM/Gallon is simplistic, but bad numbers were felt to be better than no numbers.

APPENDIX I
ENGINE PERFORMANCE CURVE

APPENDIX I
ENGINE PERFORMANCE CURVE

This appendix details the Cummins F-350 engine specifications and performance curve. The Cummins F-350 engine was used to power each truck scenario in this study. It was determined to have the requisite power to haul the commodities investigated and is known as an efficient engine. Exhibit I-1 presents the specifications for the F-350 engine.

I.1 PERFORMANCE

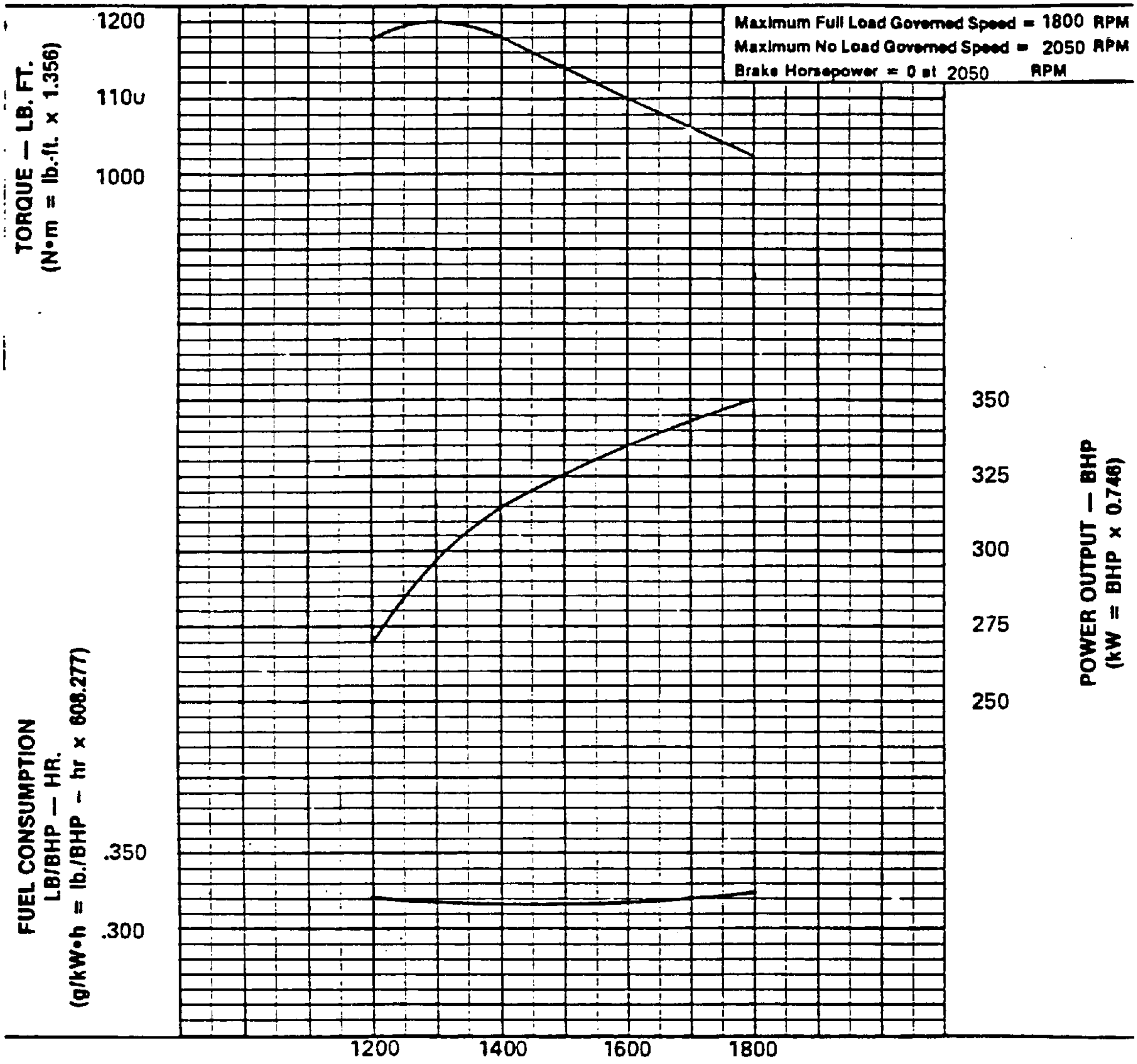
The following information was obtained from Cummins Engine Company literature. Engine performance at SAE standard J1349 conditions of 300 ft. (90 m) altitude (29.61 inches Hg [100 kPa] barometric pressure), 77 F (25 C) air intake temperature, and 0.30 inches Hg (1 kPa) water vapor pressure with No. 2 diesel fuel will be within 5% of that shown at the time of engine shipment. Actual performance may vary with different ambient conditions.

The curve shown in Exhibit I-2 represents performance of the engine with fuel system, water pump, lubricating oil pump, air compressor (unloaded), and with 10 in. (250 mm) H_2O inlet air restriction and with 2.0 in. (50 mm) Hg exhaust restriction; not included are alternator, fan, optional equipment and driven components.

EXHIBIT I-1
SPECIFICATIONS

Power Rating (Formula 350)	**350 bhp**	**(261 kW)**
Rated Speed	1800 rpm	(1800 rpm)
Peak Torque (1300 rpm)	1200 lb.-ft.	(1627 N·m)
Nominal Torque Rise	18%	(18%)

EXHIBIT I-2
ENGINE PERFORMANCE CURVE



APPENDIX J
CONTRIBUTORS TO THIS STUDY

APPENDIX J
CONTRIBUTORS TO THIS STUDY

Study Sponsor

U.S. Federal Railroad Administration:

William Gelston, Chief, Economic Studies Division
Marilyn W. Klein, Senior Policy Analyst

Major Contributors

Abacus Technology Corporation:

Kathryn Derr, Project Manager
Thomas Jaron, Project Engineer
Raymond Zdancewicz, Analyst
Deepa Sodhi, Analyst
Harry Eck, Rail Fuel Efficiency Consultant and former Superintendent of Locomotive Operations, CSX
Ron Weiss, Truck Fuel Efficiency Consultant and former Operations Director, Maryland Transportation Company

Cummins Engine Company:

Max Bobb, VMS Manager
Larry Murphy, Vehicle Systems Technician

U.S. Department of Transportation, Transportation Systems Center

Morrin E. Hazel, Jr., Mechanical Engineer

Organizations that Provided Technical Information During the Project

The analysis that was performed for the rail and truck fuel efficiency study did not require the collection of large amounts of data from private industry or government. In general discussions with industry representatives, technical information was provided about efforts to improve fuel efficiency among operating transportation fleets, equipment and configurations used, and commodities carried. Abacus Technology interviewed selected industry contacts on the telephone and directed different questions to railroad and truck equipment operators. Different questions were also asked of equipment manufacturers vs. operators. The same questions were not directed to more than 9 companies or individuals.

Associations/ Brokerage Firms	Association of American Railroads American Public Transportation Association American Trucking Association Interstate Truckload Carriers Conference Trucking/Trailer Manufacturing Association Motor Vehicle Manufacturing Association Alex, Brown, & Sons, Investment Firm Arthur H. Fulton, Inc. Trucking Services, Inc. Richmond Transport Services, Inc.
Class I Railroads	Burlington Northern Railroad Company Conrail CSX Rail Transportation, Inc. Florida East Coast Railway Company Grand Trunk Western Railroad Company Illinois Central Railroad Company Kansas City Southern Lines Norfolk Southern Corporation Richmond, Fredericksburg & Potomac Railroad Company Santa Fe Railway Soo Line Railroad Company Southern Pacific Transportation Company Union Pacific Railroad Company
Regional/Local Railroads	Bessemer and Lake Erie Railroad Company Birmingham Southern Railroad Company Dakota, Minnesota & Eastern Railroad Corporation Duluth, Missabe, and Iron Range Railway Company Kyle Railroad Company Midsouth Rail Corporation Otter Tail Valley Railroad Company, Inc. Railtex, Inc. South Rail Winston-Salem Southbound Railway Company

Locomotive Manufacturers	General Electric Company, Transportation Systems Division General Motors Corporation, Electro-Motive Division
Railcar Manufacturers	Thrall Car Manufacturing Company Trinity Industries, Inc.
Railcar Component Manufacturers	Aero Transportation Products, New Product Development Standard Car Truck Company Timken Bearing Company, Transportation Services Marketing
Truck Fleets	Builder's Transport Crete Carriers Corporation Countrywide Truck Services Dallas & Mavis Forwarding J.B. Hunt Transport, Inc. Jones Motor Company Matlack, Inc. Munson Transport North American Van Lines Overnite Transport PIE Universal Am-Can Ltd. Wyatt Transfer, Inc.
Truck Engine Manufacturers	Caterpillar Cummins Engine Company Detroit Diesel Freight Liner Kenworth Truck Company Macks Trucks Navistar International Transportation Corporation Peterbilt Volvo-GMC-White

Trailer Manufacturers	Dorsey Corporation Freuhauf Great Dane Trailmobile, Inc.
Truck Component Manufactures	Aerodyne Industries Esbar, Inc. Horton Industries Kaiser of Cadillac Keysor Industrial Corporation Zepco Sales

Principal Contributors of Technical Information During The Project

---

Mike Arter, Dakota, Minnesota & Eastern Railroad Corporation
G. Richard Cataldi, Association of American Railroads
Paul Clippard, Builder's Transport
Will Foley, Anchor Motor Freight
Bruce Flohr, Railtex, Inc.
Jeffrey Glover, Association of American Railroads
Rick Grimmer, Universal Am-Can Ltd.
Art Grotz, Federal Railroad Administration
Mike Hargrove, Ph.D., Association of American Railroads
Steve Holic, General Motors, Electro-Motive Division
Marsh Jones, CSX Rail Transportation, Inc.
Chuck Martin, CSX Rail Transportation
Bob Metzgar, Cummins Engine Company
Rick Paul, Peterbilt
Bill Piepmeier, Union Pacific Railroad Company
Dale Salzman, Union Pacific Railroad Company
Warren Stockton, Burlington Northern Railroad
Vic Suski, American Trucking Association
Chuck Tanker, Dallas & Mavis Forwarding
Bill Urban, Volvo-GMC-White
Jerry Weeks, Midsouth Rail Corporation
R.W. Wyckoff, Florida East Coast Railway Company

INTERMODAL TRENDS

AN AAR/POLICY & SPECIAL PROJECTS REPORT

Volume III, Number 10

A NEW FRA STUDY FINDS RAIL MORE FUEL EFFICIENT THAN TRUCK

L. Lee Lane
(202) 639-2163
September 2, 1991

INTRODUCTION

A new Federal Railroad Administration (FRA) report, *Rail vs. Truck Fuel Efficiency: The Relative Fuel Efficiency of Truck Competitive Rail Freight and Truck Operations Compared in a Range of Corridors*, is the most comprehensive research to date on the superior fuel efficiency of rail. Unlike previous studies that examined each mode's aggregate fuel efficiency, this study examines specific comparable moves. The report was performed by Abacus Technology Corporation of Chevy Chase, Maryland.

This *Intermodal Trends* (*IT*) discusses this new report. It makes the following points:

- For all scenarios, rail is more fuel efficient than truck.
- The report's findings confirm earlier Intermodal Policy Division (IPD) work.
- The study is based on specific comparable truck and rail movements, a substantial improvement over past studies of rail and truck relative fuel efficiency.

B. *These Findings Are Remarkably Similar To Those In An Independent Study The IPD Performed Last Year In Its Competitive Policy Reporter, Vol. I, No. 10, "Doublestack vs. Twin 48 Fuel Efficiency," Sept. 14, 1990.*

IPD compared doublestack trains along the Los Angeles - Chicago corridor with single and twin 48-foot dry vans, using the truck fuel efficiency estimates based on the National Motor Transport Data Base (NMTDB). The rail estimates were based on computer simulations by a western railroad.

IPD found that for this 2,207-mile corridor, single 48 dry vans were 2.5 times less efficient and twin 48 dry vans were 2.1 times less efficient than rail.

III. THE STUDY IS BASED ON SPECIFIC COMPARABLE TRUCK AND RAIL MOVEMENTS, A SUBSTANTIAL IMPROVEMENT OVER PAST STUDIES OF RAIL AND TRUCK RELATIVE FUEL EFFICIENCY.

A. *The Study Used Two Separate Computer Simulators For The Rail And Truck Scenarios.*

The Abacus study examined 38 comparable moves -- 43 rail and 38 truck -- using computer simulations. Previous studies of rail/truck fuel efficiency generally have used overall industry data for fuel comparisons. The study did not examine longer combination vehicles in comparison with rail.

The rail model -- the train performance simulator -- is a product of the U.S. Department of Transportation's Transport Systems Center. It combines route and commodity data with information on the train configuration (locomotive and consist) to give a simulation of train performance. The truck model -- the vehicle mission simulation -- is a research algorithm of the Cummings Engine Company designed to measure truck performance.

Data for appropriate routes, shipment sizes, and configurations came from railroad and trucking industry officials.

B. *The Study Covered Only Truck-Competitive Commonly Important Commodities (CICs).*

The report specifically excluded bulk commodities carried by unit trains. The authors included such truck-competitive commodities as intermodal freight, motor vehicles, canned goods, beverages, and sawmill products. In two short-haul scenarios (54 and 22 miles), grain hauled in a mixed freight train was one of the commodities carried. The selection of these CICs was based on an IPD 1989 *Intermodal Trends*, "Key Commodities in Rail/Truck Competition," March 3, 1989.

Copies of the FRA report are available from Policy & Special Projects by calling **(202)-639-2155.**

If you have questions or seek further information, please call Leland S. Case at (202) 639-2157.

Rail vs. truck fuel
efficiency