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ENERGY CONSERVATION

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ENERGY STUDY OF RAILROAD FREIGHT TRANSPORTATION

Volume 1: Executive Summary

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August 1979

Work Performed Under Contract No. EY-76-C-03-1176

Stanford Research Institute
Menlo Park, California

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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Prepared for:

U. S. Department of Energy
Systems Efficiency Branch
Transportation Programs Office

Stanford Research Institute
Menlo Park, California

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PREFACE

The Energy Research and Development Administration (ERDA),* recognizing the need for an assessment of energy usage by railroad freight and passenger services and by rail transit systems, has sponsored the Energy Study of Rail Transportation as part of a comprehensive energy conservation program. The objectives of the study were:

- To describe rail transportation systems in terms of physical, operating, and economic characteristics; and to relate energy usage, services rendered, and costs.
- To describe the roles of private and public institutions in ownership, operation, regulation, tariff, and fare determination, and subsidization of rail transportation.
- To describe possible ways to improve efficiency.
- To provide data that the Government may use to determine its future role.

Work was organized in four tasks:

- Descriptions of rail transportation industries
- Regulation, tariff, and institutional relations
- Efficiency improvements
- Industry future and federal role

Results of the study are published in two report series of four volumes each, as follows:

ENERGY STUDY OF RAILROAD FREIGHT TRANSPORTATION:

Executive Summary, Volume I
Industry Description, Volume II
Regulation and Tariff, Volume III
Efficiency Improvements and Industry Future, Volume IV

ENERGY STUDY OF RAIL PASSENGER TRANSPORTATION:

Executive Summary, Volume I
Description of Operating Systems, Volume II
Institutions, Volume III
Efficiency Improvements and Industry future, Volume IV

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*The functions of ERDA have been transferred to the U.S. Department of Energy.

The Energy Study of Rail Transportation was performed by SRI International, Menlo Park, California, under Contract EY-76-C-03-1176. Ms. Estella Romo and Mr. Richard Alpaugh of ERDA were the contract monitors. Dr. Robert S. Ratner was the project supervisor. Mr. Albert E. Moon was project leader and task leader for freight railroad studies. Mr. Clark Henderson was task leader for passenger rail studies.

This report is Volume I of the Energy Study of Railroad Freight Transportation. Mr. Moon is the author. Participants in the research included: H. Steven Proctor, Randall Pozdena, Stephen J. Petracek, Judith Monaco, David Marimont, Peter Wong, Marika Garskis, and Suzelle Ruano.

The Energy Study of Railroad Freight Transportation was completed at an earlier date. It has not been printed prior to this time because of delays in its review and so that it could be released simultaneously with its companion piece, the Energy Study of Railroad Passenger Transportation. While more recent statistics are available for some aspects of the study, the generalized conclusions drawn and recommendations made for energy conservation actions still hold. Technologies and practices are little changed and it is believed the report can be as useful in this form as if it were updated, which could only be accomplished at significant cost.

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I INTRODUCTION AND OVERVIEW

The railroad industry plays a vital role in transporting goods, raw materials, and food necessary to the well being of the population and necessary to facilitate the operations of our industrial economy. Because of the vital part that the railroad industry plays in the economy and because of its ability to move goods with relatively small amounts of fuel, the U.S. Energy Research and Development Administration embarked on a study to determine the role of the federal government in promoting conservation in the industry and in freight movements in general. Toward this final objective, the study compiled a description of the railroad industry, its structure, equipment, facilities, economics, and energy consumption; compiled a description of the regulation of the industry and considered ways in which the regulation has affected fuel consumption by the railroads; and analyzed candidates for fuel efficiency improvement and evaluated them on the basis of economics and the likelihood of their adoption by industry.

This report summarizes the work of the study. The summary includes a description of the industry, an analysis of energy consumption by the industry, a discussion of mechanisms for evaluating efficiency improvement proposals, a description and evaluation of conservation efficiency improvement proposals, a description and evaluation of conservation opportunities, and a discussion of recommended activities.

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II THE RAILROAD INDUSTRY

Railroads in the United States once carried virtually all of the nation's intercity freight and passenger traffic. However, as new technologies emerged and the nation developed, the demand for railroad transportation changed drastically. Airlines and bus operators now provide over 90% of intercity passenger miles using public transportation and the trucking industry offers stiff competition to the railroads for almost all kinds of freight. The transition of the intercity railroads to this new competitive environment has been slowed by the durability and longevity of railroad assets and by regulatory and institutional constraints that have accumulated over the years.

Railroad Services

The principal service offered by the railroads is the movement of carloads of freight, loaded by the shipper, from shipper location to consignee. The carload freight moves in trains that travel between major system switchyards, where the cars are sorted into other trains until the destination is reached. Specialized services of the railroads include carriage by unit trains, trailer carriage, and container service. Unit trains are loaded at one shipper location and travel directly to one consignee destination, where they are unloaded and returned empty to the shipper, usually without being uncoupled for the entire round trip. Trailer and container services provide for the carriage of highway trailers or containers (less bogies) on flatcars to locations where they can be transferred to highway vehicles for local delivery.

About 851 billion revenue ton-miles were carried per year in 1973 and in 1974; depressed economic conditions led to a reduction in 1975 to about 753 billion ton-miles. In 1974, coal hauling accounted for the most carloadings and ton-miles of service and produced the greatest revenue for the railroads; it was followed, in revenue rank, by food, chemicals, farm products, transportation equipment, lumber and wood products, and pulp, paper, and allied products.

Railroad Facilities and Equipment

A railroad company can be described in terms of its facilities and equipment, which are most conveniently divided into railroad line, rolling stock (locomotives and cars), switchyards, and miscellaneous supporting equipment.

Railroads in the United States operate about 193,000 miles of railroad line, approximately 90% of it as single track. Block signals and centralized traffic control systems are used on about 80,000 miles of railroad to reduce the permissible spacing between trains and increase the capacity of the lines. The network connects with Canadian and Mexican railroads to provide service over virtually the entire North American continent.

Most railroad trains are drawn by diesel-electric locomotives. Nearly 30,000 of these units are in use, with predominant sizes in the 1,000- to 1,500-hp range for switching and in the 3,000- to 3,600-hp range for line haul operations.

A fleet of 1.7 million railroad cars is used to haul the freight. Of these, 25% are owned by shippers or by companies who lease cars to shippers or to the railroads; the remainder are owned by the railroads. Principal types of cars are boxcars, enclosed on all sides; flat cars, providing support only for the bottom of the load; gondolas, having an open top; open or covered hoppers that provide doors in the bottom for rapid unloading; tank cars for carrying liquid materials; and specialized cars for carrying products that require refrigeration, heating, or specialized support for the load.

Switchyards are used to sort cars with a common destination into groups or blocks; several blocks may make up a train. Two types of switchyards; the flat switching yard and the gravity, or hump yard, are in general use. The hump yard uses an elevated portion of track to provide acceleration to individual cars, which roll through a series of switches, usually remotely controlled, to arrive on a track with other cars of the same block. The flat switching yard uses a switch engine to accelerate cars on tracks in an area that is usually level. The hump yard lends itself more readily to automation because of the geometric layout of the facility. A 1975 survey showed that there were 4,169 switchyards in the United States, of which 124 were hump yards.

The railroads also maintain track maintenance vehicles, automobiles, trucks, buses, and highway trailers; other equipment includes extensive communications equipment and computers.

III RAILROAD ENERGY

Railroads in 1973 used a little over 4 billion gal of diesel fuel and about 435 million kWh of electricity for locomotive power. This results in an energy consumption of about 575 trillion Btu, or about 660 Btu per ton-mile of freight service. Lubricants, gasoline, and heating services added an estimated 40 trillion Btu, not significant in proportion to the locomotive energy.

The railroad locomotive converts fuel energy into work that overcomes the resistance of the train on level track and increased resistance caused by grades, curves, and accelerations. To understand fuel use patterns, fuel consumption was allocated to fuel spillages and losses, idling, and traction fuel. Traction fuel was further broken down into the amount required to transport the trains and their cargo over level, straight track at constant speed, and the amount allocated to grades, acceleration, speed variations, and track curvature.

Table 1 shows that an estimated 3,325 million gal of fuel or equivalent electric energy were allocated to freight service in 1973. Of this amount, 744 million gal (about 23%) powered idling locomotives. The fuel was used to produce a total of 2,057 billion gross ton-miles of traffic which required 1,949 million gal (59%) of fuel for movement over tangent level track, and an additional 600 million gal (18%) to move freight up grade and around curvature and to overcome higher specific fuel consumption. Table 2 shows a tentative allocation of the 600 million gal. The total of the values shown accounts for approximately the amount of fuel allocated to grade, curvature, acceleration, higher specific fuel consumption, and increased speed in Table 1. We consider the values for curvature and acceleration to be smaller than those actually encountered. The variation in specific fuel consumption is about 10% of the accepted figure. An average reduction in grade of 0.01%/mile (over 0.3% grade) might be considered high as a nationwide average. Table 2 illustrates the sensitivity of fuel consumption to these factors. Consumption is especially sensitive to speed.

Tables 1 and 2 show the magnitude of fuel consumed by freight movement. Additional insight can be gained by considering the total movement of freight and equipment moved by the railroads. Figure 1 shows the gross ton-miles of movement broken down by net freight, circuity, loaded cars, locomotives, cabooses, and empty car backhaul. By assuming that gross ton-miles can serve as a proxy for actual fuel consumption, we can estimate the potential for national fuel savings for weight- and mileage-related improvements.

Table 1

ESTIMATED FUEL ALLOCATION FOR ALL U.S. CLASS I FREIGHT RAILROAD OPERATIONS: 1973

	Amount
Reported nationwide fuel consumption (road units)	$3,665 \times 10^6$ gal[*]
Equivalent fuel for electrical power used for traction	27.4×10^6 gal[†]
Fuel allocated to spillage and unaccounted for	367×10^6 gal[‡]
Total fuel consumed	$3,325 \times 10^6$ gal
Allocation of remaining fuel Idle time, 148.8×10^6 hr Fuel @ 5 gal/hr	744×10^6 gal[§]
Traction fuel @ 0.06 gal/100 ft-tons	$1,949 \times 10^6$ gal[**]
Grade, curvature, acceleration, higher specific fuel consumption, and increased speed.	632×10^6 gal[‡]

[*] Interstate Commerce Commission, Bureau of Accounts, "Eighty-Seventh Annual Report on Transportation Statistics in the United States for the Year Ending December 31, 1973," Interstate Commerce Commission, Washington, D.C.

[†] 321.5×10^6 kWh of electrical energy was used for traction in road services. This was converted to gallons of fuel at the rate of 11,700 Btu of central station input per kWh at the driver, and a fuel heating value of 137,300 Btu/gal. The resulting factor of 0.085 gal/kWh converts the electrical energy consumed to 27.4×10^6gal.

[‡] SRI estimate.

[§] Idling time was assumed twice the operating time estimated for locomotives. Number of locomotives per train was computed at 2.9 from ICC statistics of locomotive unit-miles and train-miles. Reported train-hours in freight service of 25,432,000 resulted in an idling time of 148.8×10^6 h.

[**] Traction fuel was estimated by taking $2,057 \times 10^9$ ton-miles at 6 lb/ton resistance.

Table 2

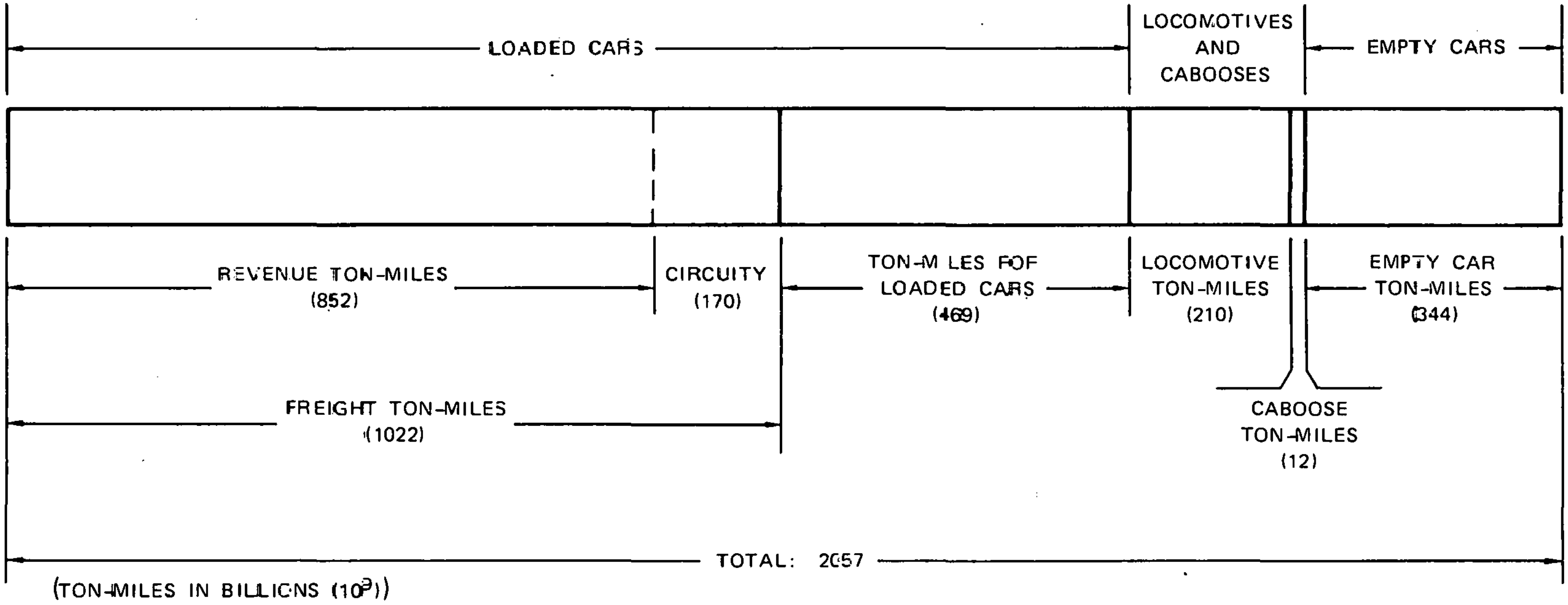
SENSITIVITY OF FUEL CONSUMED TO INCREMENTAL VALUES OF CURVATURE, ACCELERATION, AND GRADE FOR U.S. CLASS I FREIGHT RAILROADS: 1973

Train Resistance Source	Increment	Fuel Consumed per Increment
Curvature	10°/mi	49×10^6 gal
Acceleration	One acceleration to 30 mph/100 train mi	37×10^6 gal
Grade over 0.3%/mi	0.01%/mi	65×10^6 gal
Increased specific fuel consumption	0.005 gal/1000 ft-tons	163×10^6 gal
Increase in train speed	4 mph	271×10^6 gal

Figure 1 and Tables 1 and 2 provide a basis for analyzing components of fuel consumption. For example, if equipment weight were reduced, less fuel would be consumed in moving locomotives and cars, both empty and loaded. If we allocate fuel consumption, exclusive of idle and spillage, to movement of freight and equipment, 1,298 million gal of fuel are consumed in moving equipment. As shown in Figure 1, a total of 1,035 billion ton-miles are involved with moving loaded cars, locomotives, cabooses, and empty cars. This is 50.3% of the reported 2,053 billion total ton-miles. We therefore assumed that 50.3% of the 2,581 million gal consumed, or 1,298 million gal exclusive of idle and spillage, was used to move equipment.

This analysis indicates the following areas for investigation:

- Lighter weight equipment: 1.3 billion gal used to move equipment
- Operations improvement: 1.5 billion gal used in fuel losses, locomotive idling, and empty car movement
- Locomotive efficiency: 2.5 billion gal used to produce traction work
- Roadbed: 0.6 billion gal used in curves, grades, and braking energy.



SOURCE: Derived by SRI from ICC reports.

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Figure 1. Distribution of Railroad Ton-Miles: 1973 Class I Railroad Freight Service

In addition to those areas of fuel conservation that can be identified from analysis of Tables 1 and 2 and Figure 1, other fuel conservation measures are possible. These include fuel substitution, intermodal operations, and modal shifts.

Fuel substitution is the replacement of petroleum-derived diesel fuel by synthetic liquid fuels or by other energy sources, such as the use of electrical energy produced from coal or nuclear plants to propel the trains. Intermodal operations involve the pickup and delivery of freight at terminal ends of shipments by truck, linehaul carriage by rail, and a system of rapid transfer of freight from one to the other at terminal points. Finally, shifting of freight shipment from trucks to rails would generally result in an energy savings.

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IV CONSIDERATIONS IN EVALUATING ENERGY CONSERVATION PROPOSALS

Cost and marketability are two factors which must be considered in relation to the amount of fuel saved in the evaluation of prospects for the success of proposals for railroad energy conservation. At today's energy prices, proposals that promise to save energy while reducing costs are much more likely to be adopted than those that result in higher costs for the savings of energy. In addition to costs, however, many other factors affect the marketability of new technologies or operational changes. This description of cost, fuel consumption, and marketability is included to provide background for the subsequent discussion in which conservation proposals are analyzed with these considerations in mind.

Railroad Costs

Railroad costs are characterized by a high proportion of fixed costs --those that do not vary with the scale of operation--and by a high degree of joint usage of facilities such as tracks or locomotives. This combination makes the analysis of the cost of performing specific railroad services highly difficult, because many of the costs must be allocated between various operating services. In spite of this difficulty, the development of cost relationships was considered very important in the analysis because of the need to analyze economic impact of energy conservation proposals on railroad operations. The project team approached the cost analysis from two directions. The first was to analyze the cost of operations on three distinct types of railroad operations needed to move a car from an origin to its destination: the linehaul part of the trip between major switching terminals; the switchyard part of the journey, which includes the work done to organize cars into groups with common destinations and to build trains; and the way train operations that pick up and deliver cars from the switchyard to the customer siding. The second approach was to consider the railroad company as an entity and to analyze historical costs reported by entities in an effort to gain understanding and perspective on component costs relative to the overall company picture.

The component costs relationships were codified into a Long-Run Average Cost and Energy Model. This model was derived from surveys taken by railroad companies and by researchers to relate such items as rail and tie wear with traffic, switch engine time with yard size and throughput, etc. Some of the results of the model are shown in Figures 2, 3, and 4 for the line haul, switchyard, and way train models, respectively. The models display the characteristic falling of average cost with increasing utilization. Parameters included in Figures 2, 3,

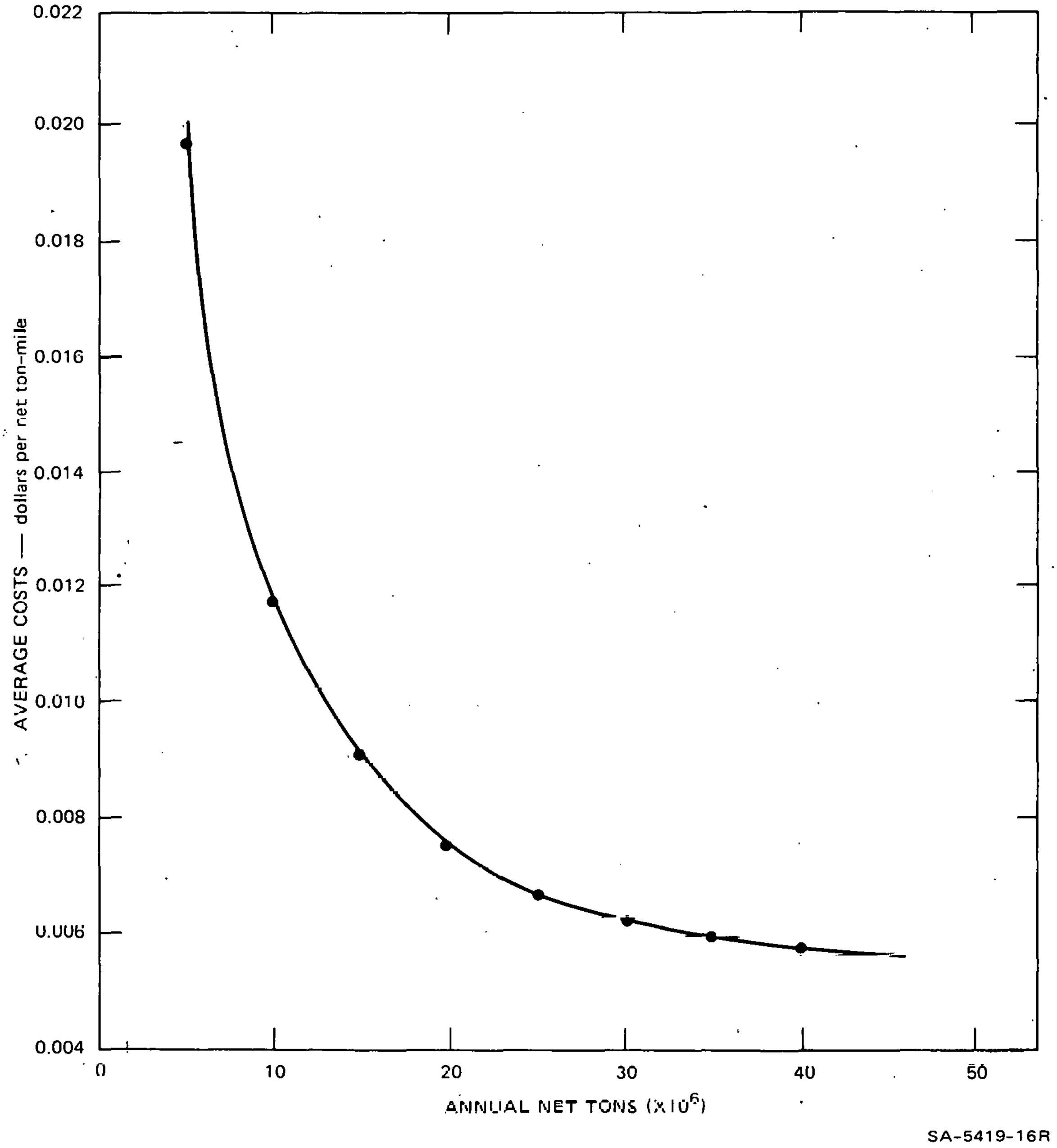


FIGURE 2 MAINLINE COMPONENT LONG-RUN AVERAGE COST MODEL

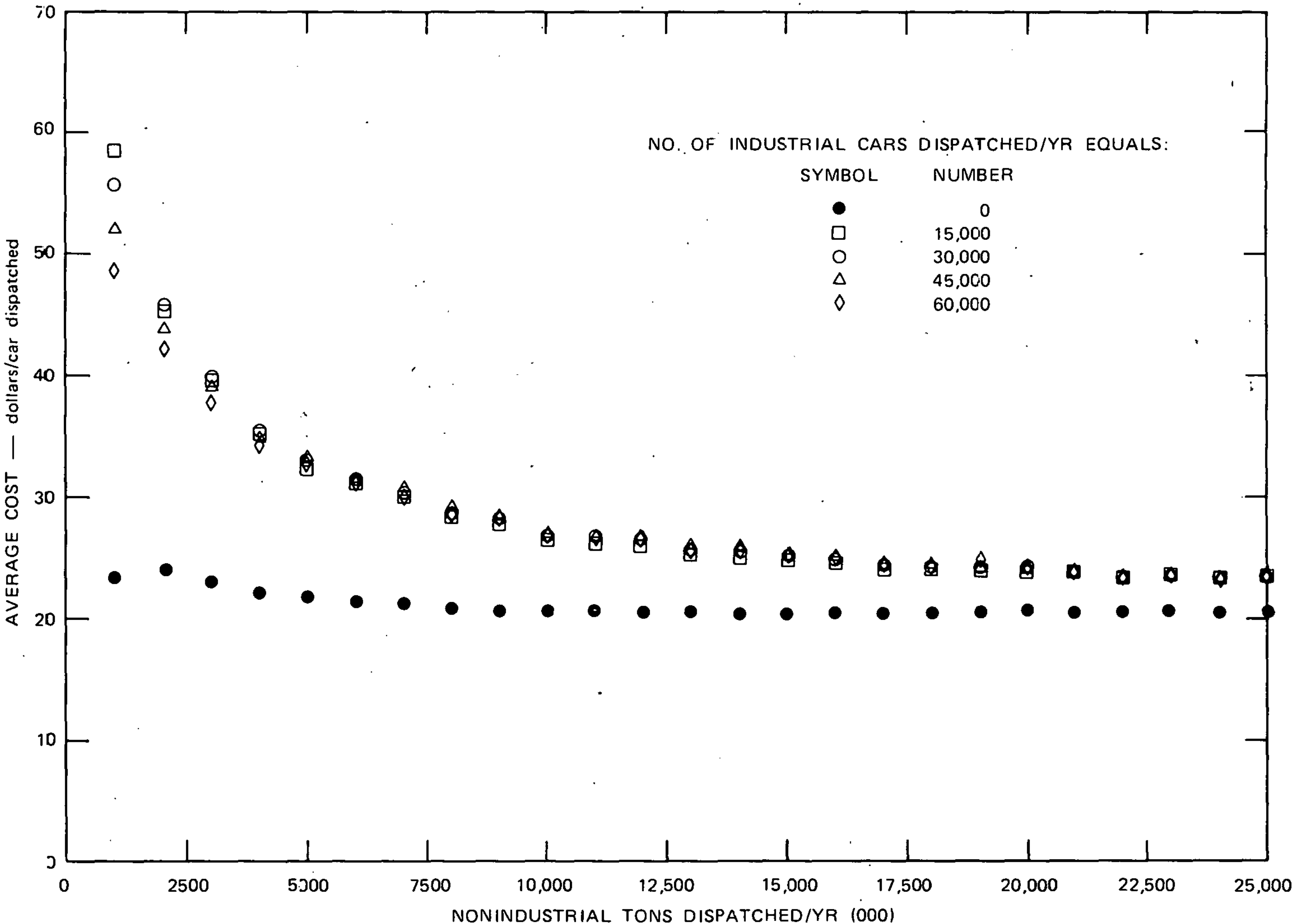
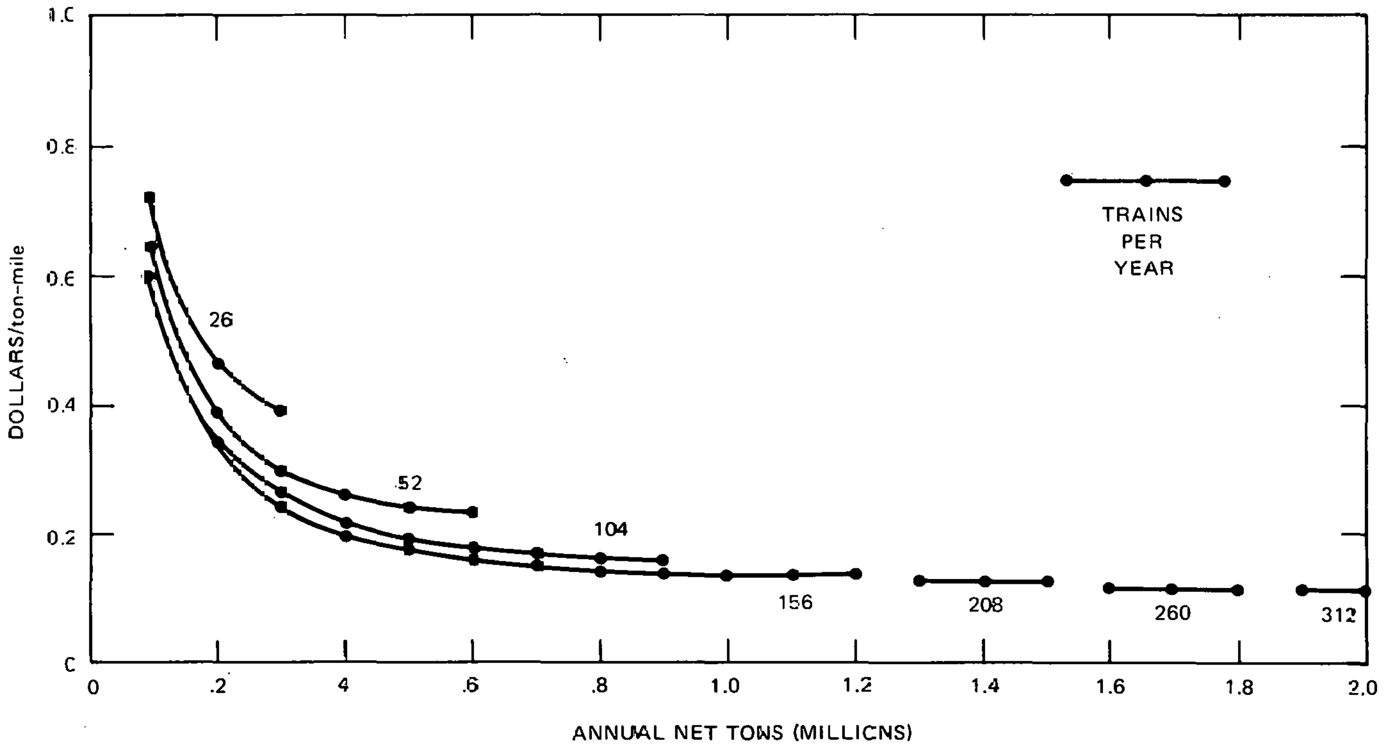


FIGURE 3 LONG-RUN AVERAGE COST OF SWITCHYARD OPERATIONS



NOTE: 20 mile/10 mph speed.

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FIGURE 4 AVERAGE COST OF WAY TRAIN OPERATION ON BRANCH LINES and 4 suggest the kinds of analysis possible with the models; the effects of industrial switching activity on the switchyard cost, and the effects of train frequency on the cost of way train operations are shown.

The component models are used in tandem to represent an average journey of about 516 miles, covering 53 miles on branch lines, two switchyards, and 463 miles of linehaul operation.

Despite the sophistication of the component models, the interaction between the components, especially between switchyard and linehaul operations, is complex, widely variable, and difficult to describe analytically. The second approach, that of analyzing whole companies, shows some of the effects that can result as adaptions to physical and economic conditions are made over time. Figure 5 shows the relationships derived from an analysis of expenses reported by Class I railroads to the interstate commerce commission. The analysis shows the relationship between company size, represented by track mileage, and the average cost per ton-mile carried. The short-run average cost for each railroad, regardless of size (shown by the curved lines), shows a theoretical minimum at about 23 million gross tons annually. The long-run average cost (the lower, straight line) constructed from this analysis shows that the minimum cost per ton-mile is virtually constant, regardless of the company size. In other words, no economies of scale are found between a company with a 500-track-mile system and the largest company in the country.

Fuel Consumption Computations

A detailed fuel consumption analysis was undertaken by compiling formulas based on work done by the locomotive to overcome rolling resistance, negotiate grades, overcome resistance of curves, and accelerate the train. The formulas have been programmed for computerized solution in conjunction with the long-run average cost and energy model. With the fuel consumption formulation, the fuel implications of alternate technologies or operations can be analyzed. Figures 6 and 7 illustrate how the cost and fuel computations can be simultaneously performed to gain insight into such parameter variations as linehaul speed or train length for local pickup and delivery.

Marketability of New Technology or Processes

The rate at which the railroad industry can absorb technological or operational changes of the magnitude necessary to have an impact on energy conservation is limited. The railroad industry and its market structure results in a large number of companies that must simultaneously compete and cooperate to make common use of new ideas and equipment. Limitation of funds, caused by low returns on capital, forces investment in projects with rapid payback. Lenders prefer to lend on rolling stock because it can be repossessed as collateral and has a widespread

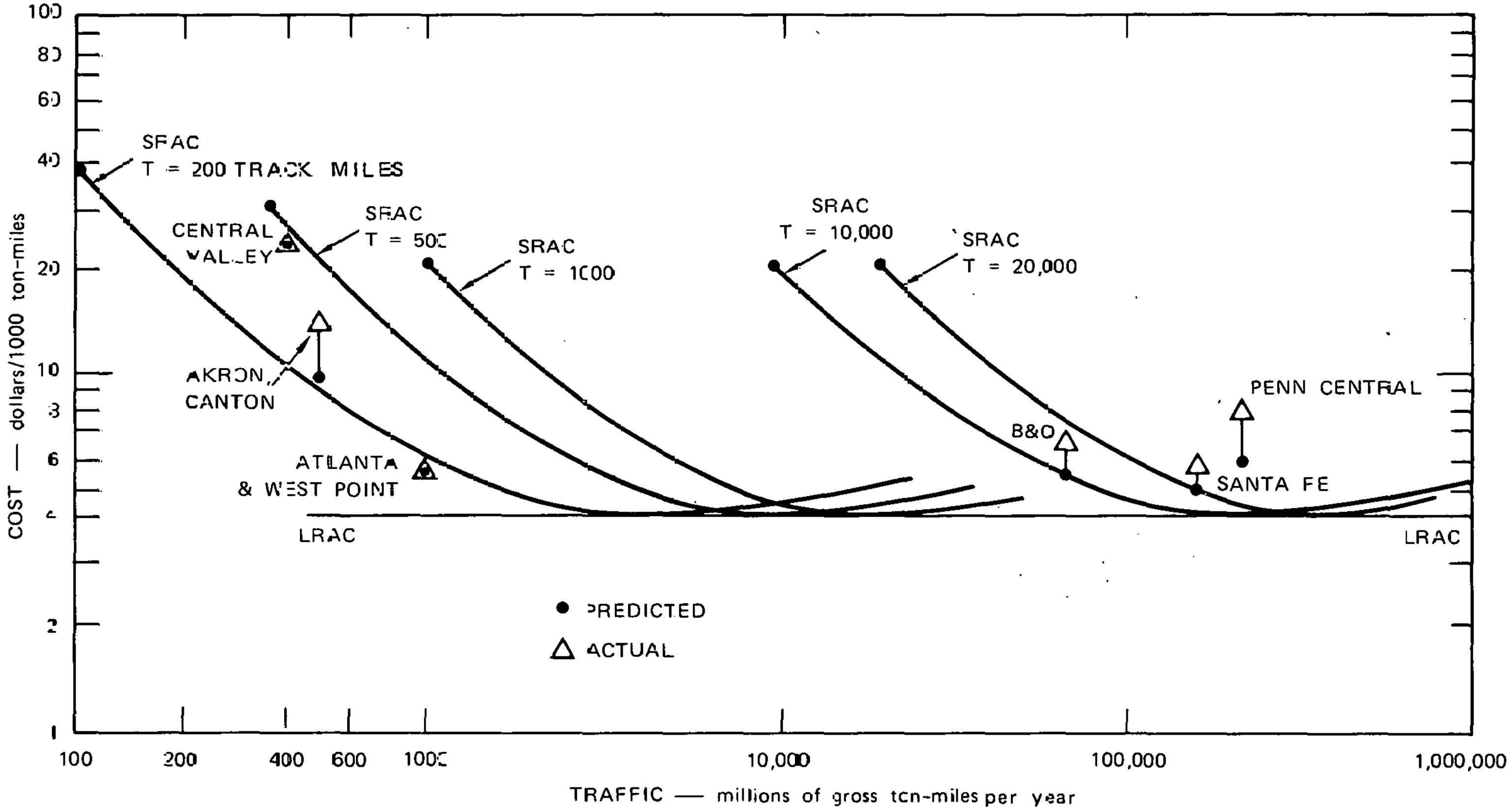

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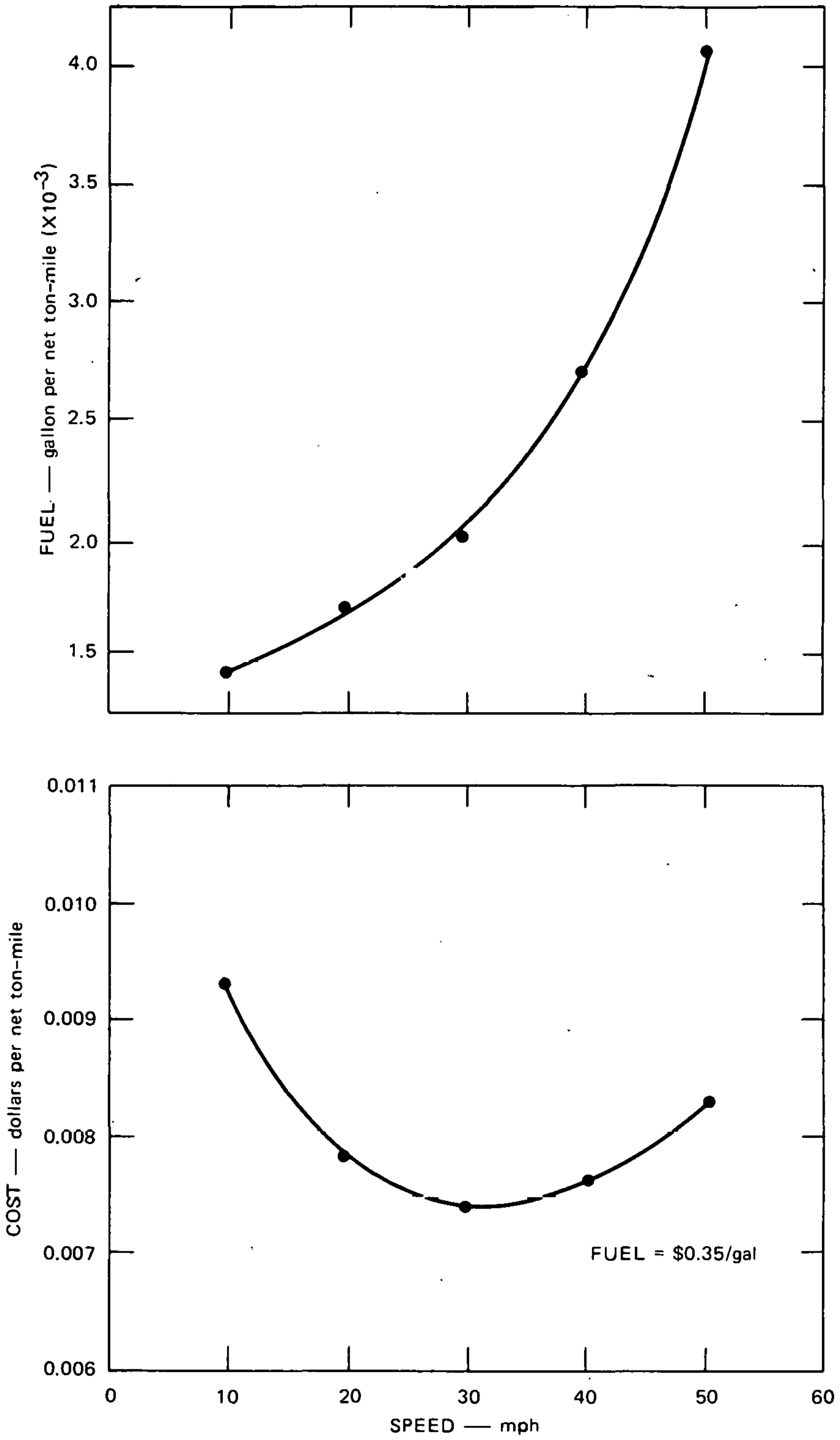
FIGURE 5 SHORT- AND LONG-RUN AVERAGE COSTS



NOTE: All curves for 20 x 10^6 net annual tons 500-mile line.

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FIGURE 6 MAINLINE COMPONENT FUEL AND AVERAGE COST VERSUS SPEED

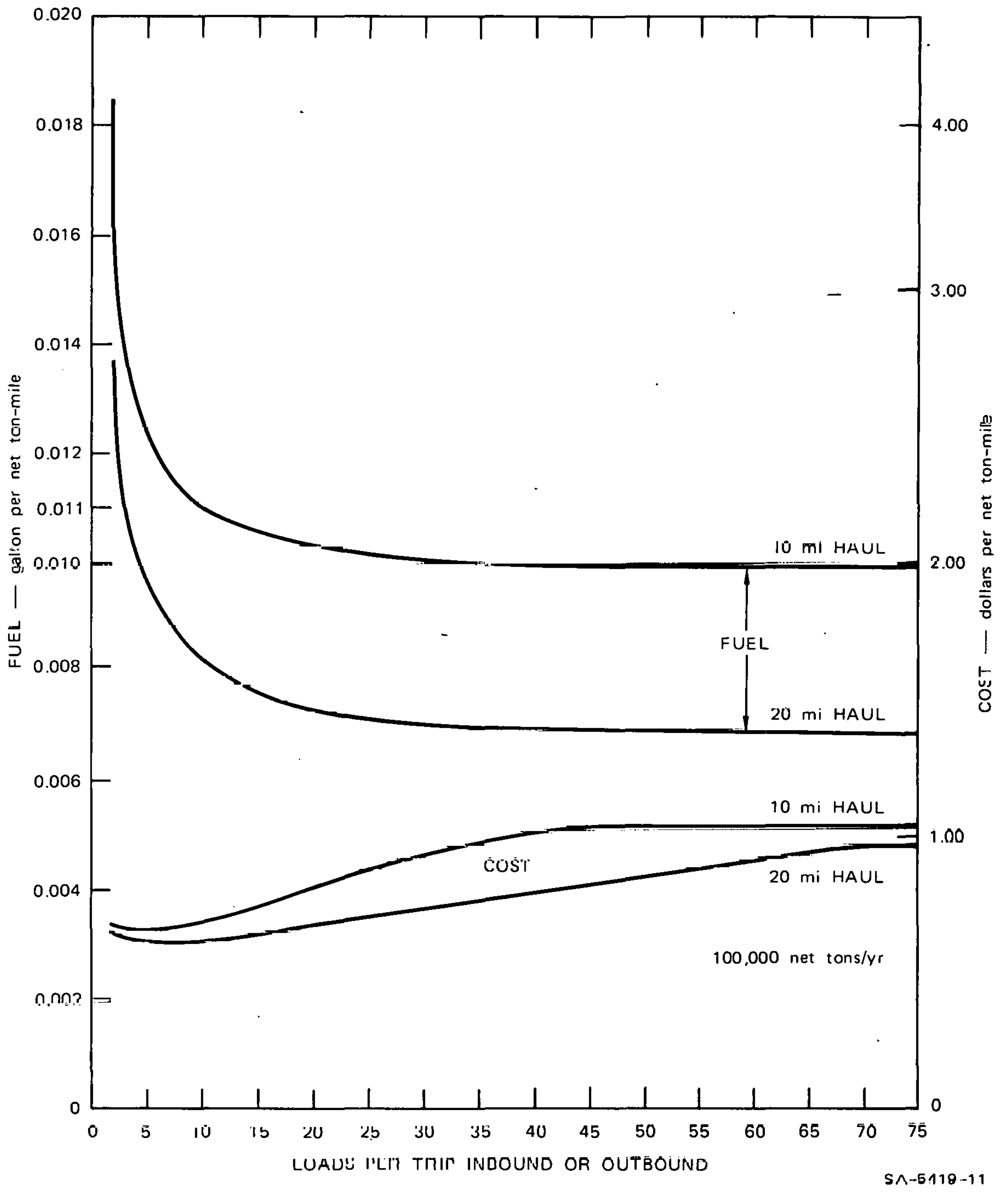

FIGURE 7 WAY SWITCHING TRAIN VARIATION OF AVERAGE COST AND FUEL CONSUMPTION WITH TRAIN LENGTH

market if it is of conventional and compatible design. A complex web of work rules achieved by years of bargaining with employees also provides many operating restrictions.

The regulation of U.S. railroads by government agencies has developed over more than a hundred years of legislative, judicial, and administrative activity. At present, the railroad industry is one of the most heavily regulated industries in the country. It is subject to federal, state, and local regulations, principally in the areas of rates, service, and operations, accounting, financial practices, safety, and environmental protection. It is widely accepted that these regulatory controls have significantly influenced both day-to-day railroad operating procedures and long-range rail planning activities, including the development and implementation of rail technology.

Coupled with the industry picture as it is today is the fact that the railroad industry is growing more slowly than the rest of the economy, as services constitute a larger and larger share of the country's gross national product, while trucking accounts for the transportation of the increasingly high valued manufactured goods. As a result, the industry sees only a small chance that growth can erase the result of gambles in technology that do not pay off.

The constraints of the industry itself and the outlook for future growth dictate that any technology adopted by the railroads must have been demonstrated to meet its performance requirements. The need for proven technology has forced the attention of the project team toward evaluation and consideration of technologies and operational improvements that are basically composed of principles that have been extensively proven in other applications; the primary requirement for adoption by the railroads, then, would be the demonstration of these principles for a railroad application in a railroad environment. Because the supply is also highly fragmented, some railroad equipment suppliers may not be able or willing to undertake the risk associated with change; therefore, government support of demonstration and development may be necessary.

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V DESCRIPTION AND EVALUATION OF CONSERVATION OPPORTUNITIES

The project team analyzed the cost, energy and fuel implications, and marketability of the following conservation opportunities:

- Improved equipment
- Roadbed improvement and braking energy recovery
- Improved operations
- Alternate fuels
- Intermodal operations
- Encouragement of shippers to use railroads
- Regulation and tariff

Improved Equipment

Proposed equipment improvements that were analyzed included lightweight freight cars, lighter weight locomotives brought about by using wheel slip control, lighter weight engines achieved by turbine power, improved wheel bearing seals, waste heat recovery from diesel engines, and alternative drive trains.

Because the effort spent on moving both loaded and empty freight cars, railroads have worked continuously to reduce car weight. High-strength steel, fiberglass reinforced plastic, and other lightweight materials have been used as car components to reduce weight. Aluminum is being used on a number of gondolas and hopper cars in an effort to reduce training weight and increase capacity of cars. Analysis of using aluminum cars on an average freight run shows a 15% energy reduction at a net increase in capital and operating cost of less than 1%. In applications where high utilization is achieved, such as in unit train service, the additional capacity would be expected to fully justify the cost of the car. The aluminum car energy advantage is reduced, however, by the greater amount of energy needed to produce aluminum as opposed to the steel it would replace.

Lighter weight locomotives, or the need for fewer locomotives in a power consist, are possible with wheel slip controls now being tested for diesel-electric locomotives. Improvements in wheel-rail adhesion in excess of 15% are claimed on the basis of static tests. Such an improvement in the field would achieve energy savings of almost 5% at a cost savings of about 1%.

Turbine-powered locomotives, equipped with advanced technology turbines, may potentially provide a cost and energy savings due to lighter weight, reduced idle time, and reduced maintenance. However, even a turbine with a 25% improvement in specific fuel consumption over current technology did not reduce weight sufficiently to achieve an energy savings; moreover, the operating cost of the turbine-powered locomotive is estimated to be higher, despite a reduction in maintenance operations.

Wheel bearing seals for freight cars equipped with roller bearings cause power loss because they must rub against the axle and maintain a tight pressure to reduce or eliminate loss of lubricant in the bearing. Experiments being conducted with new seal configurations that provide the seal with less friction drag on the car indicate that, on an average train, such a friction reduction would reduce fuel consumption by about 6%. The new seal designs reportedly are no more expensive than the existing designs.

Recovering waste heat from the exhaust of a diesel engine and converting it to useful mechanical energy appears to be a promising technology for fuel conservation. In such a system, heat from the exhaust gases of the engine is used to power a vapor-cycle engine, using organic working fluids with relatively low boiling points. According to data obtained from a manufacturer interested in developing the system, a fuel savings of about 8% might be achieved at no increase in overall operating cost. Selective application of locomotives equipped with recovery systems would produce fuel savings at significant cost savings.

The project team also reviewed performance information on diesel hydraulic locomotives. Reported ease in restarting the units would reduce idle requirements, and some increase in drive train efficiency might result in unknown costs. A small unit suitable for switchyard operation is currently being evaluated by several U.S. railroads.

Roadbed Improvement and Braking Energy Recovery

The analysis presented in Section 3 shows that about 25% of line-haul locomotive fuel is used in increased speeds and to overcome grades, curves, and accelerations. Widespread elimination of this fuel use is probably not possible; however, on extreme curves or grades, two alternatives can be considered: (1) rebuild the line to reduce the curves and grades, and (2) recover braking energy by regeneration and storage.

Research is under way to study the feasibility of regenerating energy used to brake trains on downgrades, transfer the energy to a wayside storage unit, and transfer the stored energy to another train on the upgrade. The project team reviewed the analysis of electrical utilities to find means of storing large amounts of energy and found that flywheel technology appears to be the most suitable for near-term consideration; however, improved batteries with a more efficient charge-discharge cycle may be superior for longer-term considerations (i.e., in the 1990 to 2000 era). The wayside flywheel storage economics are very sensitive to traffic density, grade, and other site-specific factors. Analysis with the long-run average cost and energy model on an average freight haul shows that energy can be saved, but that cost is increased. More detailed cost and performance studies are needed and are under way.

An alternative to wayside storage is on-board storage. A transit application of on-board storage using flywheels is now being demonstrated, and has shown significant savings in that environment where the cars are accelerated and decelerated frequently. The larger amount of stored energy needed from slowing the train and the longer period before its reuse appear to make the on-board unit less effective than wayside units for freight applications. On the other hand, a flywheel storage unit might be very effective in a switch engine, where large amounts of power are required for short periods of time and where extended periods of idling might be used to charge the energy into a flywheel.

Improved Operations

Since the rapid rise of diesel fuel prices in 1973 and 1974, railroad companies have made significant improvements in operations to reduce fuel consumption. More widespread use of techniques that have been used by some carriers will likely result in further fuel economies. Reduction of loss during refueling, efficient train operation, matching consists to loads, helper crew districts, improved maintenance practices, and empty car management were analyzed for cost and energy conservation potential.

Use and standardization of automatic fueling equipment, installation of collectors and reclaiming equipment, and instruction of employees in refueling procedures can reduce fuel losses dramatically.

Efficient train operation and the matching of locomotive consists to loads have been used in limited applications with good results. Several railroads have reduced maximum speed where schedule requirements permit and where speed is not critical to capacity of lines. Analysis of the practice with the long-run average cost and energy model shows that, while fuel can be saved by this practice, car and locomotive utilization reductions result in higher costs below about 30-mph average speeds. Other train handling procedures, such as coordination of brake application and throttle reduction and avoiding high idle speeds, are ways that the experienced operator can use less fuel. Careful analysis of routes and opportunities to perform fuel-saving maneuvers is being implemented. Tests are under way on operation of a locomotive consist with independent control of the units in the consist. Before the availability of this equipment, all units in the consist operated at the power setting commanded by the operator. With such a capability, one locomotive unit can be operated at a more efficient throttle setting of 7 or 8 (highest) while the others are operating at notch 1 under conditions when the entire power of the consist is not needed. The cost of the equipment and its installation is nominal, and fuel savings of up to 5% have been reported.

Rather than pulling locomotives that will be needed only on a short section of steep grade along an extended run, helper crews may be used effectively. A helper crew is stationed with a locomotive at the bottom of the grade, where it couples to the train as it stops, adds its additional tractive effort to lift the train over the hill, then uncouples and returns to its station. The practice is an old one, but higher wages and the diesel engine's superior performance to steam engines have limited their growth. Renewed consideration of helper districts as a substitute for larger locomotive consists, wayside flywheels, or grade reduction is needed.

Existing practices in maintaining diesel locomotives consist of periodic maintenance operations and evaluation of engine condition by observing the exhaust gas smoke. However, finer tuning and performance of the engine might be obtained by monitoring engine performance measurements and initiating maintenance procedures based on tolerance to these measurements. Measurements of engine output and fuel consumption would provide a first-order check on fuel efficiency that could be used as an indication of need for maintenance.

Hauling empty freight cars accounts for almost 40% of annual gross ton-miles produced by the railroad industry (see Figure 1). Specialized freight cars, with limited opportunities for being loaded in both directions, and uneven distribution of producing and consuming areas are chief contributors to empty mileage. A joint industry-government task force is investigating the general problem of freight car utilization, including empty backhaul. Also under analysis are various proposals to make a combination car, such as a unit that could be used either as a hopper or boxcar, thereby providing more versatility.

Alternative Fuels

Another way of conserving scarce petroleum resources is to substitute fuels that are not derived from petroleum or are more plentiful components of crude petroleum. Alternate fuels studied include heavier petroleum fuels, synthetic petroleum fuels, ammonia, and hydrogen, and coal and nuclear energy to power electrified railroads.

Residual fuel oil is a tar-like substance that remains after gasoline, diesel fuel, and other useful products have been extracted. It is usually burned to produce process heat or steam for electrical generation. Mixtures of residual oil were used in combination with diesel oil in experiments during the 1950s. Because the wear of cylinders, pistons and rings increased, and the non-uniform nature of the material made injectors more prone to clogging, the use of residual fuel oil was discontinued at that time.

Synthetic petroleum is produced from oil shale, oil sand, or coal. The characteristics of diesel fuels produced from these synthetic fuels are very similar to those produced from petroleum; thus, the operating characteristics are very similar. Costs at this time are significantly higher than those of natural petroleum products.

Experiments have been conducted on a small scale to introduce ammonia into the air intake charge for the cylinder, then introduce a limited amount of diesel fuel through the injector for ignition and smooth operation, particularly at part throttle settings. Up to 80% of the diesel fuel was replaced by ammonia at full load, but the overall reduction of diesel fuel consumption is much less--on the order of 10% when averaged over the duty cycle. The analysis shows an increase in operating cost (because of assumed higher capital and maintenance costs) and higher energy consumption for the combined fuel usage, although diesel fuel use is cut by about 10%.

Experience with producing and transporting hydrogen for aerospace applications and with burning hydrogen in internal combustion engines indicates that a hydrogen-fueled locomotive might be practical. However, because of the volume of the hydrogen fuel, a tender would be required to carry the cyrogenic fuel. The cost of such a system, including hydrogen transport and storage facilities, is substantial, and would not be recovered by fuel economies at today's prices.

As a hedge against further fuel price increases, a number of railroad operating companies have performed studies of electrification feasibility on portions of their systems. On very dense lines, savings in locomotive maintenance and the availability of higher reserve power may produce operating economies at today's fuel prices. At this time, marketability of the electrification technology is severely limited by the large amounts of capital required for an electrification project. If a large operating company were to electrify its most dense routes, the total capitalization of the company might rise by 25%--a difficult accomplishment for almost any existing railroad company.

The advantage of electrification in saving petroleum fuel is also limited by today's use of petroleum and natural gas to fire boilers.

Intermodal Systems

Combinations of highway and rail transport of freight offer potential economic and energy advantages. The railroad provides an efficient line haul function, as the productivity of the locomotives and crew can be made very high and the energy utilization is relatively good because of low losses incurred at the wheel-rail interface. On the other hand, short trains, high equipment weights, and limited access make local pickup and delivery by rail a more costly and inefficient process than could be achieved with trucks. Using trucks for the pickup and delivery functions, having a load unitizing system for rapid transfer between trucks and railroads, and development of an efficiently designed and integrated system should result in operating cost and fuel economies.

In practice, today's intermodal system is severely constrained because unit loads are designed to highway specifications and do not take advantage of the capacity of the railcar to carry a higher and wider load. The ratio of equipment weight to load weight is therefore higher than that for shipments in conventional rail cars. The most common load is a conventional highway trailer, and the weight of the wheels, and the space under the trailer mean that additional weight, aerodynamic drag, and instability and clearance problems due to a high center of gravity are encountered.

There are also service and cost problems. Because trains with trailers or unit loads are expedited, added costs make their service more expensive than conventional train operations; furthermore, even with expediting, door-to-door times of the intermodal shipments usually cannot match those of straight trucking.

Research is under way to develop more compatible equipment that will reduce weight and energy. More research on service and cost is necessary; while a truck-competitive service is most often discussed and analyzed, a complete spectrum of services is needed.

In the future, some of these problems may be overcome by an advanced system that provides a wider load-carrying capacity than the conventional rail technology and will provide more flexibility for loading, carrying, and unloading unit loads that are compatible with highway dimensions.

Encouragement of Shippers to Use Railroads

A large number of shippers prefer truck to railroad transportation because of the faster and more dependable service provided by the truckers. In fact, in 1975, trucks carried over half the amount of intercity ton-miles of freight that railroads handled, despite costs that are two to three times higher than those of the railroad and an average energy consumption about three times as great. For high valued goods, and for components or inventory that would cause significant disruption or loss of sales if shortages were to occur, the overall cost of using trucks for fast and reliable delivery is lower.

Trucks can achieve this faster and more reliable service through inherent advantages. The departing trailer does not have to wait for other shipments to make up a train, and can depart as soon as it is loaded. Similarly, intermediate classification is not needed because the trailerload goes directly to the destination behind the same vehicle. The trailerload does not have to meet connections from one train to another because it moves directly to its destination. Finally, railroad freight is more subject to damage than truck freight--the railroad environment is harsher and the responsibility for safe delivery is spread over a greater number of persons.

In the face of strong economic reasons for the shipper's preference for trucking for some commodities, making significant shifts of traffic to railroads from trucks will be very difficult. With urgent attention given to the fuel shortage, controls applied to trucking would probably force some shift. On the other hand, some changes to railroad operations that would bring selected market segments to the railroads might be accomplished at modest cost.

Regulations and Tariff

Our examination of the impact of regulation on the railroads' use of energy focuses on three primary areas: (1) relationships within the current rate structure, (2) empty car mileage, and (3) rates on low-density traffic routes. The examination of historic data and the output of SRI's Long-Run Average Cost (LRAC) Model indicate that government regulatory policies and practices can indeed influence the level of energy consumption by the railroads.

Regulatory policies and practices have caused the railroad rate structure to be developed in a way that seems to favor long hauls of many commodities. For certain commodities, rates do not vary at all over a span of more than 2,000 miles, although the output of the LRAC Model shows that length of haul is a major determinant of costs and energy involved in rail transportation. The analysis indicates that some long-haul rates are disproportionately low in relation to distance and appear to have risen less in relation to the cost and energy consumption levels than the average of rail rates. In many cases, such rate relationships involve cross-subsidy, which tends to obscure the true costs associated with the production of specific commodities. In effect, the regulated rate structure has been designed to encourage producers distant from markets and to create a greater demand for transportation and in turn a greater demand for energy.

The result of such a rate structure is a breakdown of the natural locational advantages of regional producers and a freer movement of goods between regions, as was intended by Congress. Although such a policy may have been appropriate at the time of its inception, and still may be, it clearly encourages the substitution of transportation outlays for other production outlays. To the extent that greater energy usage results, the policy should probably be reviewed.

Our examination shows that the transportation of empty freight cars by U.S. railroads requires a significant expenditure of energy. To a large extent, movements of empty freight cars are an inevitable consequence of directional imbalances of traffic. Low rates on backhauls could in some measure lessen empty car mileage. Other factors that contribute to empty car mileage include specialization of equipment, patterns of freight car ownership, and the rules related to the disposition of empty freight cars. The ICC has influence over emtpy car mileage through its promulgation and enforcement of car service rules. Often, during periods of car shortages, the ICC has deliberately increased empty car miles to spread the adverse impact of the shortages. This practice, although it has "spread the poverty," has also increased the shortages. Recent emergency orders (1973) actually had the effect of shifting shortages from the West to the East. Another regulatory policy that tends to lessen efficiency in the use of freight cars is the ICC's reluctance to allow non-railroad car owners to contribute to the freight car fleet.

The present ratemaking policies have not allowed rail carriers to selectively raise or reduce the rates charged for the transportation of various commodities along low-density branch lines. Thus, railroads are often forced to carry traffic that, from an economic and/or energy standpoint, should be transported by some other mode or not at all. In the long run, the capability to raise rates for branch-line service or to abandon low-density collection and distribution lines would tend to result in a centralization of industrial activity, thus substantially reducing the economic and energy costs associated with these services. In the short run, however, such changes could actually increase energy consumption because traffic movements may be diverted to a more energy-intensive mode.

Recommendations

As a result of our analysis, we recommend research activities to:

- Improve hardware technology
- Develop alternative fuels
- Encourage railroad operating companies to take energy conservation measures
- Assure that regulatory policies give proper weight to energy conservation
- Promote rail transportation as an alternative to more energy-intensive modes.

Our specific recommendations are highlighted below.

Improve Hardware Technology

Recovering waste heat from the exhaust of a diesel locomotive is possible. Research is needed to demonstrate the efficiency, maintainability, and service life of a heat recovery system in railroad service.

From preliminary estimates of cost and performance, it appears that a bottoming cycle unit would be a good investment at today's fuel prices for a locomotive in average service. The attractiveness of this investment would increase with higher fuel prices and for certain applications where high utilization of the locomotive is achieved.

Federal participation in the development program for a bottoming cycle is needed because the cost is higher than a single supplier would wish to undertake, and the market may develop slowly because of the number of relatively new locomotives now in service or to be in service at the time that a unit would become available. A proposed three-phase development program would result in the construction of a laboratory version of the system from which could be gathered design data, a demonstration of serviceability and durability in railroad service, a feasibility study of retrofitting units on existing locomotives, and a prototype demonstration of retrofit hardware. The estimated time for the demonstration program is about three years, and the estimated cost is $3.5 million.

Research is underway or planned on improved wheel bearing seal resistance, lightweight freight cars, positive traction control, and wayside and onboard energy storage systems. Additional studies are needed to identify the most promising applications and to examine both the feasibility of retrofitting existing units and the overall energy content of some of the systems. Research is also underway on track structure and track train dynamics and on intermodal systems. The primary thrust of this research is improvement of existing systems, but the energy implications of track structure and intermodal systems need to be clearly identified. In all of these areas, a group representing energy interests should support contract monitors, and, in some cases, there should be funding of supporting studies.

Develop Alternative Fuels

Alternative fuels for railroad locomotives hold a promise for conserving significant amounts of petroleum-derived diesel fuel. The use of alternative fuels is retarded by the costs of the fuels themselves, their performance in existing equipment, the need to develop new equipment, and the costs of developing new distribution systems. To achieve this conservation opportunity, efforts must be made to find an alternative fuel that minimizes these constraints.

Encourage Railroad Operating Companies to Take Energy Conservation Measures

Research and analysis that shows the benefits of alternative operating practices will encourage operating companies to adopt these operating practices. Two areas that deserve further study are the timing of maintenance operations and the optimization of individual train performance. Maintenance based on measurements of engine operating parameters could potentially reduce the cost and frequency of maintenance operations and improve locomotive operating efficiency.

Identification of suitable measures, development of policies based on the measurements, and evaluation of the alternative procedures should be the subjects of further research. Optimization of individual train performance would identify a pattern of operation for a particular train to minimize fuel consumed, subject to service constraints for the freight in the train and to such other constraints as system power requirements and line capacity needs. Computer programs, locomotive cab displays, and other elements necessary to improve operating practices are available and need to be brought together to demonstrate energy-saving benefits.

Assure That Regulatory Policies Give Proper Weight to Energy Conservation

Issues analyzed in the course of this study include long-haul versus short-haul rate structure, freight car utilization, circuity reduction, and branch-line abandonment. A group representing energy conservation interests that is capable of analyzing the energy impact of these issues and presenting them to regulatory agencies is needed.

Promote Rail Transportation as an Alternative to More Energy-Intensive Modes

Our analysis shows that the lower costs of railroad transportation compared with trucking are offset by longer rail transit times and uncertainty in the amount of time needed to move a shipment by rail. The costs associated with these longer and more unreliable shipping times for many commodities are less than the added cost of truck shipment. Strategies for improving railroad service and for raising the effective cost of truck service need to be studied for their impact on energy savings, additional transportation and distribution costs, and labor and other interest groups.

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