STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

DRAFT

Final Report

MASTER

M&R
F1176
8-1

May 1977

RAILROAD ENERGY STUDY:

~~RESEARCH AND DEVELOPMENT NEEDS~~ ~~AND RECOMMENDATIONS~~

SUMMARY OF INDUSTRY STATUS AND FUTURE
Volume I: Freight Railroading

Prepared for:

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
1333 BROADWAY
OAKLAND, CALIFORNIA

CONTRACT E4-76-C-03-1176

SRI Project TCU 5419

AC03-76CS51176

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MGW

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

PREFACE

The work described in this report was performed by Stanford Research Institute, Menlo Park, California, for the Energy Research and Development Administration (ERDA) under Contract E4-76-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 served as project leader. Mr. H. Steven Procter was task leader for freight railroad studies. Mr. Clark Henderson was task leader for passenger rail studies. Participants in the freight railroad study included H. Steven Procter, Randall Pozdena, Stephen J. Petracek, Judith Monaco, David Marimont, Peter Wong, Marika Garskis, and Suzelle Ruano.

The principal author of this report was Mr. Albert Moon. Contributions were made by Mr. H. Steven Procter and Mrs. Suzelle Ruano.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

PREFACE	iii
LIST OF ILLUSTRATIONS	vii
LIST OF TABLES	viii
I INTRODUCTION	1
II SUMMARY	3
III MARKETABILITY OF NEW TECHNOLOGY IN THE RAILROAD INDUSTRY . .	9
Process of Technological Change	9
Factors Influencing Technological Change	10
Industry and Market Structure	11
Regulation	12
Funds	15
Labor Relations	15
Railway Suppliers	16
Outlook for the Railroad Industry	17
Structure of the Railroad Industry	18
Future Market for Railroad Freight Transportation	19
Rationalized Freight Transportation System of the Future .	22
IV EVALUATION OF ENERGY-SAVING IMPROVEMENTS	25
Evaluation of Costs and Effectiveness	25
Analysis of Cost and Energy Savings of Improvements Analyzed with the Long-Run Average Cost and Energy Model	25
Analysis of the Costs and Effectiveness of Nonmodeled Energy-Saving Improvements	28
Analysis of Individual Energy-Saving Improvements	29
Hardware Improvements	29
Operating Improvements	36
Modifications of Regulations	37
V RECOMMENDATIONS FOR RAILROAD ENERGY CONSERVATION	39
New Hardware Technology	39
Diesel Locomotive Waste Heat Recovery	40
Wheel Bearing Seal Resistance	42
Lightweight Freight Cars	42

V	RECOMMENDATIONS FOR RAILROAD ENERGY CONSERVATION (Cont.)	
	Positive Traction Control	43
	Energy Storage.	43
	Track Structure	43
	Intermodal Systems Analysis	43
	Alternative Fuels	44
	Railroad Operations	44
	Improved Timing and Standards of Maintenance.	44
	Speed Reduction and More Nearly Optimal Train Operations.	45
	Regulatory Policies	45
	Circuitry Reduction	46
	Improved Freight Car Utilization	46
	Revision of Long-Haul Rates	46
	Branch-line Abandonment Cases and Policies.	47
	Modal Shifts to Railroads	47
	APPENDICES	
	A MODEL NETWORK DESCRIPTION	49
	B RAILROAD ENERGY RESEARCH AND DEVELOPMENT	53
	REFERENCES	73
	BIBLIOGRAPHY	75

ILLUSTRATIONS

1	The Process of Technological Change	9
2	Sum of Present Worth Versus Years for Diesel Waste Heat Recovery System	31
3	Diesel Waste Heat Recovery Fuel Saved Versus Payback	32

TABLES

1	Projection of Economic and Transportation Indicators to 1995. . .	21
2	Results of Long-Run Average Cost and Energy Model Analysis. . .	27
3	Ratings of Nonmodeled Energy-Saving Improvements	28
A-1	Assumed Values and Inputs to the Long-Run Average Cost and Energy Model.	52

I INTRODUCTION

This report documents the conclusion of SRI's "Railroad Energy Study" performed for the Energy Research and Development Administration (ERDA) under Contract E4-76-C-03-1176. The objectives of the study were to:

- Provide a current, comprehensive, and accurate data base of railroad economic activity and energy consumption.
- Describe planned and postulated expansion and the time frame of future developments.
- Identify research and development needs related to improvements in energy utilization.
- Provide data that the federal government may use to determine its future role.

The study was organized into the following four tasks:

Task I: Industry Summary--A physical and operational description of the industry, leading to an economic model that is adequate to identify the cost impact of energy conservation programs.

Task II: Regulation and Tariff--A description of the regulatory and institutional environment and the relationships among regulations, costs, patterns of service, and energy consumption.

Task III: Efficiency Improvements--A search of new and proposed technology and operational techniques that would conserve energy in a cost-effective manner.

Task IV: Summary of Industry Status and Future: A description of the status of rail transportation in the future and the needs for research and development to achieve that future status, an analysis of those forces that will bring about the introduction of new operations and technology,

and an identification of the federal government's role in improving energy utilization.

In this report we summarize the findings of Tasks I, II, and III and describe the status of rail transportation in the future including needs for research and development, analyses of forces that would bring about innovations in technology and operations, and identification of the federal government's role in improving energy utilization.

II SUMMARY

In the railroad energy study we have examined the railroad industry's structure and facilities and have developed a Long-Run Average Cost and Energy Model to describe the impact of changes to operations or equipment on the cost of railroad transportation. We have also examined the regulatory and tariff environment of the industry and analyzed some energy impacts of rate structures, car utilization rules, and retention of light-density branch lines. We have identified efficiency improvements that might result in conservation of fuel by railroads and have examined the outlook for the railroad industry, the opportunities and constraints for marketing technological innovation and operational changes in the industry, the outlook for growth in railroad transportation, and the relationship between potential efficiency improvements and market constraints.

Recommended Actions

A memorandum of understanding between the Secretary of Transportation and the administrator of the Energy Research and Development Administration (ERDA) identifies ERDA as the primary hardware research agency, and DOT as being responsible for implementation of transportation policy and the conduct of research to support regulatory action. The memorandum calls for coordination in preparing programs and budgets. Within this program, participation of ERDA in all of the research areas is possible and desirable. This participation should take the form of research sponsorship, joint sponsorship, funding of adjoint studies to identify energy impact, and the conduct of studies to show the energy impact of proposed regulatory or other administrative actions.

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

- Improve hardware technology

- 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.

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, circuitry reduction, and branch-line abandonment. A group representing energy 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.

Industry Future and Factors Affecting Innovation

Future demand for freight service must be considered in relation to the strongest competitor--trucking. In this report we show that, in either a petroleum-deficient or high-growth scenario, the demand for railroad freight service will continue to grow slightly. In the petroleum deficient scenario there would be a shift of freight traffic from trucks to more efficient rail transportation; in the high-growth scenario the demand for freight services would increase as would the market share for trucks. The combination of these two effects would provide slight increases in railroad freight demand.

The factors affecting change in the railroad industry include industry and market structure, regulation, capital investment, labor relations, and suppliers. In general, a change in procedures or technology will occur if it:

- Meets compatibility requirements among different companies.
- Receives regulatory impetus or at least causes no regulatory-related penalty.
- Provides enough benefit to justify the capital required for implementation.
- Does not incur resistance from individuals or organized labor.
- Has a supplier willing to make some investment to manufacture or implement the improvement.

The success of a change also depends on other factors which are described in the text.

Analysis of Improvements

Possible technological, operational, and regulatory improvements have been analyzed using the Long-Run Average Cost and Energy Model and, where appropriate, a more general method, which is described in the text. The results of the modeling effort show that diesel waste heat recovery, low-resistance wheel bearing seals, positive traction wheel slip control, and empty freight car management have the potential for reducing both fuel consumption and costs. The problems associated with empty freight car management systems are not well defined and thus the actual cost estimate for implementation could not be defined. Based on fuel saved in operations alone, our analysis shows that a complete conversion to lightweight freight cars has a distinct energy advantage. The energy investment in building the equipment was not estimated, but our results indicate that the use of lightweight equipment will increase costs.

Among the improvements that could not be modeled, we found that fuel handling, consist load matching, improved maintenance, and elimination of cabooses would reduce energy consumption and produce a slight reduction in costs. Acceleration and speed reductions, intermodal systems, elimination of circuitry, and improved track structures have the potential for fuel savings, but the cost elements are unknown. The exact amount of fuel savings and costs of these improvements could not be estimated.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

III MARKETABILITY OF NEW TECHNOLOGY IN THE RAILROAD INDUSTRY

The railroad energy study has shown that there are technological improvements that may produce energy savings for the railroad industry. However, the introduction of new technology requires adaption by both institutions and individuals who have become comfortable with their current ways of doing business. In this section we describe the process of and factors influencing technological change in the railroad industry and discuss the outlook for the industry as background for evaluating conservation proposals that have been made and may be made in the future.

Process of Technological Change

In the context of this report, technological change is defined as any change in the factors of production that alters the cost, quantity, or quality of production output.* In the railroad industry, these factors include materials, equipment, production or operating processes, labor, and organizations. The principal reasons for changing these factors are to improve:

- Capacity
- Capital and labor productivity (reduce production costs)
- Product quality (the quality of freight service)
- Safety and the general working environment.

FIGURE 1 THE PROCESS OF TECHNOLOGICAL CHANGE

*Much of the material on technological change is summarized from another SRI report relating to the introduction of technological change in railroad switchyards [see S. J. Petracek et al., "Railroad Classification Yard Technology: A Survey and Assessment," Final Report No. FRA-ORD-76/304, pp. 150-174, SRI project No. 3983, Stanford Research Institute, Menlo Park, California 94025 (July 1976)].

Technological change should be viewed as a continuous process of interrelated progressive actions (see Figure 1). Although the simplified framework of the process of technological change in Figure 1 is somewhat incomplete because it does not account for the communication or feedback mechanisms between the different stages of the process, it can serve as a basis for a general discussion of technological change. We can define the stages of the process thus:

- Research refers primarily to applied research--that is, to investigations involving the application of known scientific and technological principles and developments to the solution of a problem.
- Invention is the point at which the concepts, ideas, and information developed during the research stage coalesce into a technically feasible design approach to solving a problem.
- Development is the stage where the basic plan or design is developed into an actual product, process, or technique that can be used as a potential solution to a problem.
- Innovation is the initial adoption of a technology that differs from the current technologies used in an industry. Innovation does not specifically imply a full-scale adoption of a new technology by any individual firm; instead, the term denotes a general pioneering effort in the utilization of a new technology.
- Diffusion is the imitation of the new technology by other firms within the industry, and the degree to which individual firms substitute an innovation for current technology.

Factors Influencing Technological Change

The U.S. railroad system represents the first use of modern transportation technology in the United States. Until recently, railroads dominated intercity freight transportation. However, the development of competing transportation technologies has successfully diverted more than half of the intercity freight traffic (in terms of ton-miles) from the railroads. Although the railroad industry has introduced some technological change, the rate of change has been much slower than that of the competing modes. There is widespread belief, both inside and outside the railroad industry, that U.S. railroad companies are overly

reluctant to introduce or adopt new technology. We discuss below the principal factors that influence, either positively or negatively, the introduction or adoption of new technology in the railroad industry.

Industry and Market Structure

The structure of the U.S. railroad industry significantly influences its process of technological change. Unlike most other large railway systems, the U.S. system is not government operated. It is a conglomeration of about 350 privately owned and operated railroad companies. Some of these companies own and operate extensive rail networks that serve large sections of the country, but the majority serve only small regions or local areas.

Because of the conglomerate structure of the U.S. railway system and long-distance freight transportation demand patterns, a large portion of the freight shipped by railroad travels over the lines of more than one railroad. Efficient handling of such freight requires that individual rail companies use compatible rail technology. A rail system that contains incompatible components, such as track sections of different gauges, will waste time and manpower in additional handling of freight during the interchange process.

The necessity of maintaining rail system compatibility can severely constrain the introduction of new technology that is incompatible with existing rail technology. The introduction of incompatible new technology would require large-scale replacement of existing equipment, which would necessitate a massive amount of capital and writeoff of a substantial railroad investment in fixed plant and/or equipment because of the typically long life of railroad equipment.

The relationships among different railroads within the industry are often ambiguous. Although all railroads are elements of a common system and therefore complement the services of each other, different railroads frequently are in competition for rail traffic between certain areas. Because of the regulation of railroad rates, this competition is not based on prices but on quality of service, which includes such factors

as reliability, transit time, availability of freight cars, and prevention of damage. Such competition may provide certain incentives for introducing technology that will improve an individual railroad company's quality of service.

Relationships among railroad companies affect the process of technological change in another way. Historic patterns of the introduction of new technology within the industry indicate that some railroads rapidly adopt a new technology, but the majority of railroads delay adoption until the leading railroads have tested and evaluated the new technology.

The speed at which a firm adopts a new technology is directly related to its size and the expected profitability of its investment. Large railroads tend to assume new technology more rapidly than small railroads because of their greater financial resources, experimental facilities, and economically stronger ties with equipment suppliers. However, small railroads may be quicker to utilize a new technology if their expected return on investment is greater. The profitability factor may explain why railroads that lead the industry in introducing one type of technology may be reluctant to introduce other types as rapidly. The trend toward fewer and larger railroad companies is expected to continue or accelerate in the future. This trend can thus be expected to have mixed, but overall positive, influences on the introduction of new technology.

The need to expand existing capacity is a primary motivation for technological growth in many industries. The market for railroad transportation can be expected to remain static or, at best, to grow at a very slow rate over the next 20 years. Thus, the addition of new capacity cannot be expected to provide the impetus for technological change.

Regulation

The railroad energy study examined the relationship between regulation of the railroads and energy consumption.¹ However, regulation of

the railroads also influences the introduction and diffusion of new technology in the industry.

The Association of American Railroads (AAR) was formed in 1934 through the consolidation of other railroad industrial organizations to represent the common interests of the industry in such areas as equipment and safety standards and car movements. Because AAR member railroads operate approximately 95% of the U.S. railway mileage and carry 99% of U.S. freight ton-miles, any regulation or standard adopted by the AAR generally becomes an industry standard. Therefore, the AAR significantly influences the process of technological change in the railroad industry through its regulatory and standard-setting activities.

Various federal, state, and local agencies also regulate the industry. Government economic and safety regulatory activities influence technological change most strongly. Other types of government regulation influence technological change to a lesser extent.

The government agency principally responsible for economic regulation of the railroad industry is the Interstate Commerce Commission (ICC), which was established by the Interstate Commerce Act of 1887 and was the first major federal regulatory agency. The charter and powers of the ICC have been modified several times since its establishment. At present, the ICC regulates the railroads primarily in the areas of rates, market entry and exit, and utilization of plants and equipment. Forty-seven states also have established regulatory commissions. However, because the interstate operations of most railways limit the regulatory authority of state commissions, these commissions have less effect on technological change than the ICC has.

Economic regulation can dramatically influence the direction, amount, and rate of technological change in the railroad industry. The highly regulated rate structure of the railroads has been cited as a major barrier to the innovative process within the industry. The current policy of the ICC is heavily committed to maintaining stability within the U.S. surface freight transportation system. The Commission is extremely adverse to establishing rates that may foster large

reallocation of traffic among competing railroad companies or among railroads and other competing transportation modes.

The ICC also regulates market entry and exit. Although the regulation of market entry probably has little impact on technological change, the regulation of a railroad's desire to exit a market by abandoning its trackage and right-of-way forces the railroad to continue an unprofitable service and thus lessens the availability of capital for investment in new technology. Technological change is also greatly restricted by regulation of intermodal mergers and acquisitions.

The regulation of safety is one of the major constraints on any transportation system. Railroad safety is principally governed by the Federal Railroad Administration (FRA), which has jurisdiction over such areas as track maintenance, inspection standards, locomotives, signals, safety appliances, and power brakes.

Safety regulations have a direct impact on the pattern of technological change within the railroad industry because they force the introduction and diffusion of new equipment throughout the industry. The regulation of railroad operating procedures by the FRA can either encourage or discourage efficient railroad operations while increasing safety.

There are a number of other areas besides economics and safety where the activities of government agencies other than the ICC and FRA can influence the technological change process in the railroad industry. Several laws have been enacted toward regulating railroad investment and capital generation. Because the availability of capital is often vital to the introduction of new technology, regulation of investment and capital generation can play a large role in determining whether new technology will be introduced and how rapidly it will be diffused.

Public concern for the environment has caused the development of numerous regulations that impact the railroad industry. The Environmental Protection Agency (EPA) is the principal regulatory agency in this area. Environmental protection regulations usually specify an acceptable standard level of performance that must be achieved, and the manner of

achieving this standard is often the responsibility of the regulated industry. Such regulations provide impetus for the development of alternative and competing technologies because individual hardware items and operating procedures to be used to establish a standard level of performance are not usually specified.

Funds

Relatively long capital turnover times (the ratio of capital to revenues), low earnings on investment, maintenance costs, and inflation are placing a squeeze on the railroad industry and its ability to generate necessary operating capital.

The competing demands for funds generated internally and for borrowed money are great. Dividends and expenditures to replace and upgrade plant and equipment are primary demands. Some of the capital expenditures are going for technologically advanced equipment; however, innovative equipment is usually installed only when replacement is required.

Because the demand for capital expenditures exceeds the supply of funds, the railroads must carefully budget their capital resources. Technological changes that could produce more capital and earning power often cannot be made because of capital shortage. New methods of financing or new sources of funds will be required to support the introduction and utilization of new and beneficial technology. Innovations that make existing equipment obsolete are also discouraged by the shortage of capital.

Labor Regulations

The reactions of railroad employees to technological change can significantly influence the success or failure of the change. If the labor force resists a certain change, the change will generally not succeed.

The labor force of the U.S. railroad industry is organized into powerful unions. Railroad operating personnel are represented by the

United Transportation Union (UTU) and the independent Brotherhood of Locomotive Engineers (BLE). Nonoperating railroad personnel are represented by numerous unions, many of which represent workers in other industries as well.

A major concern of railroad labor unions is the impact of new technology on job security, which has long been considered a critical issue by railroad labor. The railroad labor force decreased from 1,352,000 in 1947 to 526,000 in 1972, a 61% decline over a 25-year period. Another factor contributing to labor's concern about job security is that many railway workers have developed unique skills that are not applicable in other industries. It is thus difficult to justify the introduction of any new technology that will decrease the size of the railroad labor force.

Railroad wage rates can also influence or be influenced by the introduction of new technology. If a new technology requires workers to learn new skills, the union often negotiates a wage increase. If a technological change reduces skill requirements, the union generally attempts to maintain the previous wage scale. If a technological change raises efficiency and company earnings, the union often tries to garner a share of the benefits gained through increased wage rates. Despite the 61% decrease in overall railroad employment between 1947 and 1972, the percentage of operating revenues used for employee compensation has not decreased significantly. Employee compensation accounted for 49.9% of total operating revenues in 1947 and 47.6% in 1972.

Railway Suppliers

Railroad companies are fundamentally service rather than manufacturing companies and therefore depend heavily on railway suppliers for the development of new equipment technology. The railway suppliers can have a strong impact on the amount and type of technology offered to the railroads. Incentives for railroad suppliers to finance research and development are limited if there is little prospect for large-scale adoption of the developed technology.

Outlook for the Railroad Industry

The number and size of railroad companies and the market prospects for the industry are factors that influence the adoption of new technology in the railroad industry. We examine below the prospects for future changes in the industry and market structure.

In the early 1970s there were seven bankruptcies among the approximately 75 Class I railroads in the United States. Among the factors that contributed to the bankruptcies were inadequate profits, deteriorating roadbed and track structure, lack of adequate financing, competition, public policies that financed highway and waterway construction and operation on a pay-as-you-go or less than pay-as-you-go basis, antiquated regulations, and a multitude of labor problems. The key role of the railroads in the national economy forced congressional action in the form of the Regional Railroad Reorganization Act (the 3R's Act) of 1973 which provided for planning of a unified railroad company to be made up of the combination of parts of six of the bankruptcies, with provisions for abandoning whatever trackage the planners felt would be unprofitable. Subsequent legislation, the Railroad Revitalization and Regulatory Reform Act (the 4R's Act) of 1976, provided for both federal financing for rehabilitation of track, roadbed, and equipment and limited rate flexibility for the railroads. The act also made the possibility of railroad mergers more likely by limiting the amount of time the ICC could take to act on proposals and by providing that the Secretary of Transportation could initiate merger proposals with the consent of the railroads. These two acts provide an initial direction to the future course of the railroad industry.

The future of the railroad industry is likely to be characterized by increased merger activity resulting in fewer railroad operating companies; fewer miles of railroad, and a shifting market for railroad transportation that will depend on future levels of prosperity. Whatever the future level of national prosperity, the railroads will not increase their traffic by more than a very modest annual rate, and traffic could decrease under some circumstances. Further in the future,

a rationalized freight system may evolve where three freight services will provide for (1) bulk commodity movement, (2) nonbulk commodity movement over distances shorter than bulk movements, and (3) combined truck-rail intermodal service for nonbulk commodities.

Structure of the Railroad Industry

Railroads in the United States were built by 6,000 companies without any overall plan for the integration of operations and services they now perform. As a result, consolidations have occurred from the very start of the industry, and, since 1916, railroad mileage has decreased by about 20 percent.²

Mergers of railroad operating companies are expected to have the following benefits:

- A larger company should have the financial and management resources to overcome short-range adversities and to build a sound company.
- Consolidation of parallel, competing lines should allow for both the consolidation of traffic on lines that can be operated at densities that have lower costs and the elimination of other duplicate facilities.
- Consolidation of connecting, or end-to-end, lines should eliminate switching at interchange points, provide one-carrier responsibility for a greater part of the shipment, and produce better service.
- A combined railroad might be in a position to solicit traffic for movements that would be unprofitable for one or both roads but profitable for the combination.

Whether these benefits can actually be achieved is a matter of some debate. Certainly, examples that on the surface prove the contrary are numerous. The belief that mergers are good still prevails, however, and the industry can look forward to further consolidation.

Public policy has favored mergers since the Transportation Act of 1920, which directed the ICC to prepare a plan for consolidating all line-haul railroads into a limited number of systems. The Emergency Transportation Act of 1933 added to the ICC's power to encourage mergers, and the Transportation Act of 1940 again amended the merger provisions

of the Interstate Commerce Act and served as the basis for many changes in ownership and control that occurred in the 1950s³ and 1960s. About 40 mergers, acquisitions, and lease agreements occurred between 1958 and 1973.⁴

The intent of the 4R's Act is to plan a national railroad system and to promote mergers of companies in such a way that the system would be implemented. The provisions of the act include:

- Classification of railroad lines into those needed for a core network and those that are redundant.
- Studies of the benefits and costs of railroad restructuring.
- Limitations on the time the ICC can take to review merger applications.
- Financing for rehabilitation of lines and equipment on the essential parts of the national railroad network.

The act also enables the Department of Transportation to study and support merger applications.

Although many ideal railroad system configurations have been proposed,⁵ including a plan for two railroads, one public and one private as in Canada, and a plan for four, five, or six transcontinental railroads, drastic and large-scale consolidation is probably some years away. Piecemeal mergers and slow progress toward a rational network can be expected. The slow progress will result from resistance to change by many entrenched interests, the lack of clear-cut benefits from large-scale consolidation, and the sometimes conflicting public policies that on the one hand encourage competition between railroads and on the other provide assistance in merger analysis.

Future Market for Railroad Freight Transportation

The market for railroad freight transportation is determined by the overall level and distribution of the nation's economic activity. Railroads offer low-cost, but generally slow and uncertain, transportation that is primarily suited for long hauls of bulk commodities and for commodities that move between terminals in a manner similar to that of

bulk commodities. Most bulk commodities have low unit value. By contrast, competition from trucks results in the railroad's relatively small market shares in manufactured commodities, which have high unit value. Thus an economy that produces a relatively large proportion of manufactured goods tends to require more truck transportation relative to railroad transportation than one that consumes a large portion of less highly processed goods.

The economic trend in the United States is toward an increasing fraction of the gross national product (GNP) devoted to services (health care, education, entertainment, and government) rather than to the consumption of goods. The growth in services that require very little, if any, freight transportation does not contribute to the growth of the freight market; hence the total market is growing at a lower rate than the total GNP. Further, the goods used are more highly processed. As personal incomes have risen, an increasing portion of disposable income has been devoted to specialty foods, television sets, and so on, rather than to basic foodstuffs and clothing.⁶ These more highly processed goods are usually moved by truck because of their high unit value. Thus, transportation is a smaller proportion of the total cost, and the distribution costs are minimized by using more costly but faster and more reliable truck transportation.

The economy is dependent on many factors, such as the availability of energy and raw materials; the weather; and social and political trends. These factors change over time and can produce changes in the overall level of transportation needed; the distribution of the output affects the kind of transportation demanded. Although these factors are variable, we can postulate two extreme-case scenarios:

- A success scenario, which results from technological and management success in overcoming energy and raw material shortages, a general confidence on the part of the population in the ability of their institutions to succeed in these efforts, and fortuitous weather conditions that provide for abundant harvests.
- A distress scenario, which results from management and technological failure to overcome energy and raw material

shortages, a loss of confidence of the population in their institutions, and a steady worsening of the weather.

These scenarios, together with a third that takes into account a shifting of social values, are explored in detail in a recent study of the future of transportation.⁷ Since the sociological transition scenario did not produce results that were significantly different from those produced by the success and distress scenarios, we consider only the latter two.

Table 1 shows the gross national product and railroad and truck transportation for 1975 and for 1995 in both the distress and success scenarios. Freight ton-miles of railroad traffic range from 700 to 1,015 in the success scenario. The lower figure was derived by assuming that the amount of products shippable by rail will be about the same as it was in 1975, but that growth will occur in services and in manufactured goods. The higher figure is an adjustment that includes the addition of coal shipments to the predicted freight traffic. Because the trucking industry is more seriously affected by a depressed economy than the railroad industry, railroad traffic grows at a moderate pace, while the economy is almost stagnant.

Table 1

PROJECTIONS OF ECONOMIC AND
TRANSPORTATION INDICATORS TO 1995

Indicator	1975	1995	
		Distress	Success
Population (millions)	213.5	235	240
Gross national product (billions of 1975 dollars)	\$1,516.3	\$1,530	\$3,000
Freight ton-miles (10 ⁹)			
Railroads	750	1,015-1,025	700-1,015
Trucks, for hire and private	440	300	1,030-1,070

Source: Ref.. 7.

The projections in Table 1 were made under the assumption that available fuel will be very expensive in the distress scenario, and thus truck traffic will be discouraged; in the success scenario, the technology and management team will find ways around the fuel shortage (synthetic fuels or other energy sources) to permit the continued use of trucks. Truck productivity is improved by allowing larger units, such as triple tandem 27-ft trailers, on the interstate highways. Engine improvements and radial tires will limit fuel consumption so that increases in fuel cost will have less than proportional impact.

Rationalized Freight Transportation System of the Future

The rationalization of the freight transportation system will occur at the network and market levels and in the role that the various carriers play in transportation of freight. It appears that market factors will balance the transportation system by providing services that are attuned to both the characteristics and the length of shipments. Shipments are usually described as either bulk or nonbulk. Bulk commodity shipments are materials that can be pumped, poured, or dumped into and out of railcars or other vehicles. Such materials have low cost per unit of weight relative to processed or manufactured goods. Examples of bulk commodities are coal, sand and gravel, ore, grain, and chemicals. Another characteristic of bulk commodity shipments is that they usually travel in multiple carload lots between terminals located in rural or sparsely populated areas. Nonbulk commodity shipments are usually materials that are manufactured, for example, canned or processed foods, appliances (white goods), and automobiles. Because some of these commodities may move in multiple carload lots to distribution centers, they have some characteristics of bulk commodities and thus are called "neo-bulk" commodities.

The distance that can be traveled in a day by truck on an interstate highway is critical in the rationalization of freight shipment. A driver can make a round trip of about 200 miles in a day, or he can make a run of 400 miles in a day and return the next. For short distances, truck shipment would seem to be most economical for all nonbulk commodity

shipments and for a part of the bulk commodity shipments. For long distances, railroads and waterways, where available, would carry the bulk commodities, and trucks might carry nonbulk commodities, for example, for perhaps slightly longer distances. An intermodal system, with truck pickup and delivery and rail line-haul, would carry nonbulk commodities for longer distances. With appropriate systems analysis of vehicles, unit loads, and transfer systems, an intermodal system could minimize the overall cost of freight transportation.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

IV EVALUATION OF ENERGY-SAVING IMPROVEMENTS

The technological, operational, and regulatory improvements that have the potential for conserving energy have been identified in Tasks 2 and 3 of the railroad energy study^{1,8}. In this section we evaluate the costs and effectiveness of these improvements and their marketability in the industry.

Evaluation of Costs and Effectiveness

Before a marketability test can be performed, the effectiveness of the improvements, in terms of potential fuel savings, must be determined and the costs associated with buying and using the hardware of instituting and operating alternative procedures must be known. The relationships between the costs and the effectiveness will indicate a first level of priorities for further efforts to innovate.

A number of improvements can be described in sufficient detail to be analyzed with the Long-Run Average Cost and Energy Model developed for this project. However, other improvements, primarily those that involve operational changes, are more difficult to analyze with the model. These will be analyzed more generally.

Analysis of the Cost and Energy Savings of Improvements Analyzed with the Long-Run Average Cost and Energy Model

Ten improvements and five alternative fuels have been analyzed using the Long-Run Average Cost and Energy Model. The model was set up to represent the average 1973 freight haul of 516 miles. The characteristics of the corridor and the representative movement are described in Appendix A of this report. For each improvement, the appropriate changes to the main-line, branch-line, or yard components were made to estimate the percentage of difference from the base case that the improvement could

provide. The assumptions and changes to the model inputs are described in the report on Task 3.⁸

Interpretation of the cost comparison from the analysis requires a discussion of the treatment of various cost components in the model. The model produces annual cost estimates by adding a capital cost for invested funds to annual charges for maintenance, operations, and fuel. Thus, the effect of higher investment in equipment is included in the annual costs presented. If the cost index is the same or lower than the base case, we can conclude that savings in annual costs at least offset the effect of higher capital costs at the discount rate (10%) used in the analysis. Indicated savings will lead to a presumption of higher returns on investment that would make the use of the technology more attractive. On the other hand, if the cost index increases, the economic impact of the indicated energy savings will probably not provide high returns.

Table 2 shows the results of the analysis with the Long-Run Average Cost and Energy Model for the improvements analyzed. Both energy and cost savings can be achieved through the use of positive traction control, reduced empty backhaul, and diesel waste heat recovery. Of these, diesel waste heat recovery systems produce the greatest fuel savings (some 8%). A 7.5% reduction in empty backhaul of freight cars can also produce a fuel savings, but the effort to achieve such a reduction is not known. The greatest overall fuel savings could be achieved through the exclusive use of lightweight freight cars, but at a higher cost. Our analysis does not include the additional energy used in the manufacture of these cars. It should be noted too that lightweight equipment would not replace existing equipment completely for many years because of the long life of railroad cars. As expected, electrification can produce very large savings in fuel consumed, but at a very high cost.

Other alternative energy sources increase costs and produce either zero or negative fuel savings. Ammonia shows up very poorly as a substitute fuel, and turbine locomotives failed to produce fuel savings despite their lighter weight. They also result in increased costs.

Table 2

RESULTS OF LONG-RUN AVERAGE COST AND ENERGY MODEL

	\$ / Net Ton	\$ / Net Ton- Miles	Gal or lb / Net Ton	Btu (x 10 ⁶) Btu/ Net Ton	Percent Increase/ Decrease from Base Case		Cost-Energy Ratio (\$ / Btu Normalized)
					Cost \$	Energy	
Base Case	13.4435	0.0261	1.3243	0.1818	--	--	1
Equipment weight							
. Lightweight freight cars	13.5269	0.0262	1.1206	0.1538	+0.6%	-15%	1.19
. Positive traction control	13.3046	0.0258	1.2410	0.1702	-1	-6	1.06
. Turbine locomotives	13.5361	0.0262	1.4123	0.1938	+0.6	+7	0.94
Operations							
Empty car management (45% empty backhaul)	13.3509	0.0259	1.2641	0.1736	-1	-5	1.04
(42.75% empty backhaul)	13.3046	0.0258	1.2410	0.1702	-1	-6	1.06
Helper crew districts	13.3972	0.0260	1.3382	0.1836	-0.3	+1	0.99
Locomotive and equipment efficiency							
. Diesel waste heat recovery	13.3972	0.0260	1.2132	0.1665	-0.3	-8	1.12
. Wheel bearing seal resistance	13.3972	0.0260	1.2502	0.1716	0	-6	1.06
Regeneration							
. Wayside storage (including electrified catenary, etc.)	13.9528	0.0270	--	0.1679	+1(+4)	-2(-8)	1.01
. Onboard storage	13.4435	0.0261	1.3058	0.1795	0	-1	1.01
Alternative fuels							
Petroleum-derived fuels	13.3509	0.0259	1.2919	0.1836	-1	+1	0.98
Derived synfuels	13.7365	0.0266	1.3243	0.1818	+2	0	--
Ammonia (diesel combination)	16.8591	0.0327	10.4774 lb	0.4605	+25	+153	0.50
Hydrogen	14.9765	0.0290	3.7928 lb	0.1957	+11	+8	1.03
Electrification	13.8139	0.0268	--	0.1702	+3	-6	1.10

Analysis of the Costs and Effectiveness of Non Modeled Energy Savings Improvements

To analyze the relative value of improvements that were not amenable to modeling, we used a procedure containing factors for potential fuel savings, costs, and implementation. The ratings are subjective because these improvements are not easily quantified. A three-part scale plus an unknown indication were used. For example, if an improvement had good potential for fuel savings, we rated it with a plus. A zero indicated no change, while a minus indicated an estimated negative impact. Unknowns were indicated as a blank. The details of the estimates for each improvement are given in the text. For additional background information on each improvement the reader is referred to the report on Task 3.⁸

Each improvement rated according to this scheme is shown in Table 3. The improvements are ranked from most effective to least effective to unknown effectiveness.

Table 3

RATINGS OF NONMODELED ENERGY-SAVING IMPROVEMENTS

<u>Improvement</u>	<u>Fuel Savings</u>	<u>Costs</u>	<u>Implementation Difficulty</u>
Fuel handling	+	+	+
Consist load matching	+	+	0
Improved maintenance	+	+	-
Elimination of cabooses	+	0	-
Diesel hydraulic locomotives	+	0	-
Acceleration and speed reduction	+		-
Intermodal systems	+		-
Elimination of circuitry	1		-
Improved track structure	+		

Improved fuel handling, consist load matching, improved maintenance and elimination of cabooses have favorable potential for fuel savings at about the same or less cost than now being experienced. Acceleration and speed reduction, intermodal systems, elimination of circuitry, and improved track structure have unknown cost implications. In some applications, diesel-hydraulic locomotives may offer potential savings.

Analysis of Individual Energy-Saving Improvements

Both the Long-Run Average Cost and Energy Model analysis and the more general analysis show the potential for fuel savings of improvements on a national level. We describe the improvements in greater detail below, identify their marketability, and suggest actions that might be taken to overcome marketability problems. In Appendix B we provide a list of ongoing research in each improvement area.

Hardware Improvements

Locomotive Diesel Waste Heat Recovery Systems--Waste heat recovery or bottoming cycle systems show potential for saving fuel used by the railroads. The fuel savings can be achieved with concomitant cost savings. If such systems were applied to only large, over-the-road diesels, which account for only about 40 percent of the fleet, the total cost of implementation would be relatively small. In addition, financing locomotives is easier than financing other investments because lenders feel the security is more easily repossessed and disposed of.

The bottoming cycle can be made from available components, but special designs to fit into the limited space in a locomotive will be required as part of the development process. The durability of diesels with a bottoming cycle unit needs to be demonstrated and the maintenance costs verified in order to convince railroad operating companies that the technology is a good investment.

An investment analysis of adding a bottoming cycle unit to a diesel unit has been prepared by us from data supplied by personnel from General Electric's Air and Space Division. We modified the original assumptions

about specific fuel consumption and held the price of fuel constant. (General Electric's analysis assumed rising fuel costs.) The results show that the unit will produce a 10% return investment after taxes with a payback period of about five years if the duty cycle and maintenance costs are as specified by our source. The return on investment is best if the unit is applied to larger engines. A higher (or lower) return could be obtained by railroads that operate their locomotives at duty cycles that are different from the national average.

In our investment analysis we estimated the payback period for three levels of fuel savings (see Figure 2). The upper curve represents the payback function for a 12% fuel savings estimated for a 4,000 hp diesel operated on an AAR-approved duty cycle. The same 12% fuel savings applied to a smaller locomotive operating on a national average duty cycle was used to calculate the second curve. The bottom curve was plotted using the model results, which account for the effects of grade and curvature, mismatch of consists, and the like. The effect of the amount of fuel saved on payback period (at 10% interest rate) is shown in Figure 3. The curve shows that waste heat recovery systems should be considered primarily for large units with potential fuel savings of more than 50,000 gal annually.

The economics of the bottoming cycle unit appear to be favorable for original installation on a locomotive, but the cost to retrofit an existing locomotive is much higher. With such a constraint, the introduction of bottoming cycle units will be slowed because many locomotives have been installed in the last five years, and quite a few are now on order, as the last of the units put into service after World War II are replaced. With a life of about 20-25 years, it will be some time before another big locomotive replacement opportunity exists. This lead time for the market to develop may inhibit manufacturers from initiating development work in a timely fashion.

The details of the bottoming cycle design, development, and costs were provided by a locomotive manufacturer. Although bottoming cycles are being developed for other applications, we are not aware of any active development of the bottoming cycle principally for railroad application.

FIGURE 2 SUM OF PRESENT WORTH VERSUS YEARS FOR DIESEL WASTE HEAT RECOVERY SYSTEM

FIGURE 3 DIESEL WASTE HEAT RECOVERY FUEL SAVED VERSUS PAYBACK

Wheel Bearing Seal Resistance--Low-resistance bearing seals can be produced at costs that are approximately the same as the production costs of bearing seals now in widespread use. If it can be shown that the life cycles of both old and new bearings and seals are the same, then a gain in energy savings can be achieved at almost no cost. We understand that tests are now underway to demonstrate the durability and effectiveness of low-resistance seals.

Benefits from the new seals will not accrue for a long time if the seals are installed on only new and rebuilt cars. Although older cars are continually being replaced or rebuilt, the life of a freight car may be 20-25 years, and a substantial portion of the fleet has been installed in the last 10 years. Retrofitting of cars in service, especially those that accumulate high annual mileages, may be economical, but research is needed to show the extent of retrofitting that could be economically justified.

Once the durability and life of the new seals is established, their marketability should not be a problem--the new seals would replace existing seals at a similar cost and for better performance for the user.

Lightweight Freight Cars--Our analysis of lightweight freight cars indicates that additional costs would be incurred if all freight were carried in lightweight freight cars, but that energy savings would be obtained. Therefore, lightweight freight cars should be used only when there is a large amount of empty backhaul and a large number of annual trips. Lightweight freight cars are widely used in unit train service, where these two conditions apply. In contrast to the potential energy savings from using lightweight cars, their manufacture requires substantially more energy than that required for a conventional car. This may negate the operating energy savings, depending on both the annual utilization and the source of the energy used in the manufacture of the car.

The marketability of lightweight freight cars is reduced by the higher initial costs, but this reduction is somewhat offset by the greater availability of funds from financial institutions who are more

willing to lend money for cars than they are for other investments, since cars, like locomotives, are easily repossessed, and there are other users available for their disposition.

Positive Traction Control--Positive traction control technology is well advanced and is in operation on a limited basis. Although there is only a small improvement in fuel savings for an average trip, the application of the technology to specific runs might produce significantly higher benefits; however, operational or track conditions might make it ineffective on other runs. Careful analyses by the railroads of their track characteristics, speed requirements, and policies for tractive effort and horsepower per ton will be required to gain the maximum advantage from this technology.

As with waste heat recovery systems and other improvements, the lead time required for new units to be put into service will postpone the benefits to be gained from positive traction control. Determining the costs and benefits of retrofitting would be a worthwhile research project.

Wayside Energy Storage Systems--The cost estimates of wayside flywheel storage systems are rough and uncertain. However, for specific grades or mountainous terrain where traffic density is high, wayside storage could be cost effective.

Wayside storage has been modeled as an adjunct to electrification. The logical wayside storage installation would require a power collection system similar to an electrified line. The FRA and a manufacturer are researching applications and technology for wayside flywheels. Their results should provide more information on the cost of such units. Helper districts and wayside energy storage would be used in similar situations. The requirements for high traffic density are similar, but it appears that helper districts may be more cost effective on low-density segments, and complete electrification may be more effective on high-density segments. Research now underway will provide additional insight into these issues.

Onboard Energy Storage Systems--For an entire trip, onboard storage appears to offer little in the way of improvement. However, specific applications, such as in a switch engine, may provide cost-effective improvements. In such an application, a smaller diesel engine would spin a flywheel unit that would provide the peak power needs that are only occasionally required of the switch engine. Higher overall efficiency might result.

Track Structure--It is generally believed that inadequate track structure, such as that found on old and poorly maintained lines, contributes to higher fuel consumption. Analysis of limited data from branch-line operations shows that the fuel submodel predicts lower fuel than is actually used. In addition, the effects of track hunting and "rock and roll" or swaying of cars on good track at higher speeds contribute to higher fuel consumption than is encountered under stable operation. However, the exact amount of this fuel consumption is not known. Research is needed to show the impact of poor track conditions and track train interactions on fuel consumption.

Intermodal Systems--Research is being conducted on the economic performance and hardware for intermodal systems, as well as on the aerodynamics of current intermodal components. Studies on the energy consumption of a more nearly optimal system have not yet been identified, and additional analysis is needed.

Turbine Locomotives--Despite the potentially lighter weight and lower maintenance costs of turbine locomotives, they did not perform well on the Long-Run Average Cost and Energy Model. The characteristics of turbine locomotives may be cost-effective for specific applications, but we did not find any such application in the freight railroading sector.

Diesel-Hydraulic Locomotives--Proponents of diesel-hydraulic locomotives claim that fuel consumption is reduced under load and that the

shut down and restart of diesel-hydraulic locomotives is easier than that of diesel-electric locomotives. The small size of existing units and the limited compatibility with the rest of the fleet indicate that these advantages might not be realized if the unit is widely adopted.

Alternative Fuels--The alternative fuels listed in Table 1 offer no attraction except as replacements for diminishing diesel supplies. Electrification offers the major fuel savings (at the railhead) but with an increase in costs. Each electrified segment of the U.S. rail network should be considered in some detail to assure that the most cost-effective segments are electrified first. A considerable amount of work on alternative fuels is presently underway to estimate the effects of the alternatives on the entire energy production system from source to user.

Operating Improvements

Fuel Handling--Interviews with railroad personnel indicate that increased attention to fuel handling has already saved a significant amount of diesel fuel, and additional improvements are being sought. Minor improvements to hardware and constant attention to detail seem to be the course of present activity.

Consist Load Matching--Individual control of locomotives in a multiunit consist is being tested by a manufacturer, a railroad operating company, and the FRA. The results of their research should provide additional information with which to estimate the benefits of both the hardware and the procedures. The cost of the hardware is small. Constraints to the use of consist load matching are that additional activities are required of the operator, and his attention to detail will largely govern the effectiveness of the procedure. Automation of consist load matching is a possibility after the effectiveness of the procedure is demonstrated. Although automation would increase costs, it would overcome labor problems. Retrofitting for either manual or automated consist load matching seems possible.

Reduced Maximum Speeds--Analysis of operations to provide only enough locomotives for the speed required for each train is good railroad practice. The energy savings obtained by the Union Pacific through the individual analysis of each train should prompt all railroads to reexamine their policies. Analyzing the power needs of individual trains can also augment the effectiveness of such hardware as the Fuel Saver or positive traction control. Computerized train consist preparation makes this tailoring possible and experienced "old timers" believe in its efficacy.

Improved Maintenance--Maintenance procedures could be more nearly timed to changes in the operating condition of the engine to achieve better performance at less cost. R & D is needed to develop new maintenance procedures and to compare them with existing procedures to establish the benefits. An impediment to improved maintenance is the possible overlap of labor craft classifications in the installation and monitoring of the instrumentation and fuel consumption and in the actual performance of the maintenance.

Helper Crew Districts--The performance of helper districts in the Long-Run Average Cost and Energy Model shows that their applicability is limited. On high-density lines, where hauling extra power on the train to negotiate steep grades would be wasteful of fuel and locomotive capacity, the helper district can be effective. Electrification should be considered where high traffic densities are encountered in mountainous terrain and where there is potential for energy savings through recapture of braking energy.

Modifications of Regulations

Modifications of railroad regulations were analyzed in the Task 2 report on the railroad energy study.¹ We discuss some of these modifications below.

Empty Car Utilization--There are some indications that the modification of regulations regarding the return of cars to the owning railroad increases utilization of the car. This improved utilization may take the form of fewer empty car miles. The FRA and the AAR are researching this issue. Phase I of their research is expected to be completed by June 30, 1977.

Reduction of Circuity--Some degree of circuity is needed to provide for competition between carriers and to avoid congested gateway terminals. However, regulations that maintain routes over lines that have merged into a single railroad need close reexamination as does the possibility of restricting the number of routings that is available to a shipper for the same freight bill. Data on routings have only recently become available as part of the annual sample of waybill statistics, but these data are not always complete enough to determine the amount of traffic that is being routed over paths that contribute to circuity.

Railroad Freight Rates--The effect of freight rates that favor the long haul of traffic by the railroads was analyzed in the Task 2 report, where it was pointed out that moving toward rates that were more nearly proportional to distance would cause new sources of supply to be developed, but that social impacts might be incurred from the relocation of jobs in the supply industry.¹ A gradual modification of the freight rates rather than a large-scale revision might eventually result in energy conservation without the predicted intense social impact.

Elimination of Low-Density Branch Lines--Provision of adequate alternative freight transportation, such as an intermodal carrier, would eliminate costly and energy-consuming low-density branch lines and avoid the social impacts of removing low-cost freight service altogether. The FRA is engaged in research to develop an intermodal system that has few branch lines.

V RECOMMENDATIONS FOR RAILROAD ENERGY CONSERVATION

In the railroad energy study we analyzed the economics, energy consumption patterns, structure, and regulations and rates of the railroad industry and identified proposals for improving the energy efficiency of railroad freight operations. We conclude that a railroad energy conservation R&D program must address the following areas:

- New hardware technology
- Improved railroad operations
- Regulatory policies
- Modal shifts to railroads.

New Hardware Technology

The evaluation of alternatives for railroad energy conservation shows that the following efficiency improvements should be developed or research should be done to explore ways of using them for energy conservation:

- Locomotive diesel waste heat recovery (bottoming cycle)
- Wheel bearing seal resistance
- Lightweight freight cars
- Positive traction control
- Energy storage
- Improved track structure
- Intermodal systems analysis.

Research is being conducted on all of the above improvements except the bottoming cycle for the diesel locomotive. We discuss each improvement below.

Diesel Locomotive Waste Heat Recovery

R&D is needed for the design and development of bottoming cycle components applied to diesel locomotives. The principle of a locomotive bottoming cycle is well understood, having been applied to other kinds of heat engines, and components have been built that will perform the functions that are needed to implement the system. However, integrating the components into the physical space available in a locomotive, and matching the component characteristics to the diesel engine to provide both low pressure drop for the exhaust heat exchanger and power coupling of the bottoming cycle motor to couple to the diesel engine are problems that must be addressed. The performance of the system and its durability in service must then be developed and demonstrated.

The following three-phase development and demonstration project is suggested:

Phase 1: Demonstration of the Principle--A demonstration of the principle of a locomotive bottoming cycle might be effected by assembling existing components and installing them on an instrumented diesel locomotive. This breadboard unit should have components located outboard of the enclosure of the locomotive for the test program to speed the demonstration. The fuel consumption of a locomotive equipped with a bottoming cycle in a test situation would provide design information and show potential fuel savings.

This demonstration would have to be conducted at a test facility because the maintainability of the units does not lend them to service in road operations. The DOT test track in Pueblo, Colorado, the AAR laboratories in Chicago, Illinois, or the manufacturer's facility would be possible sites for this prototype demonstration.

Phase 2: Prototype Design and Test--In this phase locomotive layouts would be designed, and the components to be used on the production locomotive units would be designed and fabricated. A prototype locomotive unit would be assembled from a modified locomotive unit and the components of the bottoming cycle system. After appropriate shakedown testing,

we recommend that the locomotive be installed at the FAST testing facility at the DOT test center. Although the FAST facility concentrates on tests of the design and durability of track and components, it offers a good opportunity to test a locomotive under controlled conditions and to accumulate hours, miles, and load on the unit in a short period of time.

After the prototype design and test is completed, recommendations should be made for changes in components, fuel savings and performance should be demonstrated, and firm estimates should be made of maintenance and manufacturing costs. Necessary additional analysis or testing should be identified at this point.

Phase 3: Feasibility of Retrofit on Existing Locomotives--The research in this phase would consider the economics, operational implications, and durability of the equipment used in adding heat recovery hardware to existing locomotives. The feasibility of retrofit depends on making components that can be fit within the dimensional structure of existing locomotives. Furthermore the costs of the components should be low enough to maintain the economics of the unit, and they should be durable enough to withstand the operating and service environment. Once the feasibility of building a new diesel equipped with a bottoming cycle is established, a decision can be made to proceed with similar research for a retrofit version of the bottoming cycle.

Federal sponsorship of phases 1 and 2 of the program will assure that the principle is thoroughly explored in a timely fashion and will enable suppliers to risk a test and demonstration that may not be successful or a market that may not be economical. The manufacture of bottoming cycle units should be undertaken by individual manufacturers at their own risk after they have evaluated the market.

Development Time and Cost--We estimate that phase 1 of the research and development program will cost between \$250,000 and \$500,000, depending on the availability of suitable components, the location of the test,

and the complexity of instrumentation used. The estimated time for the demonstration is from nine months to one year.

Phase 2 of the program will cost between \$1 and \$2 million for each of the original equipment and retrofit programs, depending on the complexity of the test program that is needed. Calendar time for the project is estimated at 18 months.

A locomotive manufacturer is the most suitable contractor for the research, as he is most likely to have test and fabrication facilities available. Some railroad operating companies have the necessary facilities and might be potential contractors. Economic and market studies to support the program and to demonstrate the market for the locomotives should be done by an independent contractor.

Wheel Bearing Seal Resistance

Development is underway or planned by suppliers and the AAR to demonstrate the effectiveness and durability of the new wheelbearing seal designs. The costs of retrofitting existing cars should first be determined and then examined to see whether they are justified by the energy saved. As this is an implementation study, DOT would have responsibility for the study, although ERDA can sponsor the work and identify the need for the analysis. The study could be conducted by a contractor (including the AAR), a railroad operating company, or an independent organization. Such a study is estimated to cost from \$75,000 to \$125,000. The estimated time for the study is six months to one year.

Lightweight Freight Cars

Suppliers of lightweight cars have devised cost-estimating procedures to aid in their marketing efforts. The cars are most marketable to users in high-density service. A relatively small project, which might be carried out at an academic institution, is to determine the life cycle energy content of a car and the potential for reclaiming the aluminum in a car once its useful life is ended.

Positive Traction Control

The Canadian National Railroad developed the positive traction control device and is promoting it. Several railroads are evaluating its usefulness. The methodology for analyzing individual train operations to make the best use of the device is available to most large railroads, so no new research and development is needed.

Energy Storage

Both wayside and onboard flywheel storage for switch engines are now under study. The work on wayside flywheels should include an analysis of the traffic density and other factors that will determine whether helper crew districts, wayside flywheels, or complete electrification is appropriate for a line. Research continues on advanced batteries and other energy storage technology. This research needs to be monitored to identify when to undertake specific railroad application studies as new technologies are developed.

Track Structure

A very extensive program is underway to analyze both the interactions between the track structure and the freight cars passing over it and the effectiveness of various kinds of track structure. Research should be initiated to determine the effects of these interactions on energy consumption. The research should initially include the collection of data on the relationship between train resistance and the occurrence of hunting or rock and roll. Later, models of energy consumption should be developed along with models of car and track behavior. Research relating the track condition to the coefficients of train resistance should also be undertaken so that the energy effects of track maintenance can be identified.

Intermodal Systems Analysis

Present intermodal system studies concentrate on economic and service effects. An R&D program should be initiated to identify an

intermodal system that would provide maximum energy benefits in terms of both railroad energy reduction and attraction of shipments from truck to rail.

Alternative Fuels

There are several studies of alternative fuels underway to estimate the effects of their use on society and the economy in general (including transportation systems). Further emphasis on energy conservation in these programs is not necessary.

Railroad Operations

The memorandum of understanding between ERDA and DOT identifies implementation and operations as the responsibility of DOT. ERDA should develop and maintain the capability to monitor programs of operational improvement and should assure that proper weight is given to energy savings.

Operational improvements leading to energy conservation can be promoted by encouragement from ERDA and by demonstrating the benefits of such improvements to the railroad personnel who will be modifying their operations. Improved railroad operations that will save energy include:

- Improved timing and standards of maintenance
- Speed reduction and more nearly optimal train operations.

Improved Timing and Standards of Maintenance

Research performed on diesel engines as part of exhaust emission studies indicates that maintenance can have an effect on fuel consumption. In addition, maintenance costs might be reduced if maintenance were performed on the basis of measured parameters rather than by calendar time. A research program that identifies quantities of engine performance, fuel consumption, and output and relates fuel consumption and maintenance to these measurements should be performed. The research should be performed in two phases.

The first phase would monitor diesel engine or alternator output, fuel consumed, and other pressures and temperatures to identify critical factors associated with degraded performance.

In the second phase of the work, a locomotive would be instrumented to monitor the critical factors identified in the first phase, and a maintenance policy based on those factors would be established. The maintenance frequency and cost and the fuel consumption of the instrumented unit should be compared with control units to determine the benefit of the improved maintenance.

The research should be undertaken by a railroad operating company, under the sponsorship of ERDA and with the participation of the FRA. The estimated cost for the project would be between \$250,000 and \$500,000 over a two- to three-year period.

Speed Reduction and More Nearly Optimal Train Operations

Research on speed reduction would show the benefits of matching speed to grade and roadbed conditions for minimum energy use, consistent with service requirements. Selection of the proper locomotive consist and the Fuel Saver should also be considered in the program. After fuel and cost savings have been demonstrated and techniques refined, computer programs and employee training should be developed to implement the policies.

Regulatory Policies

Regulatory policies developed in the past when energy was plentiful, may need to be reevaluated to ensure that they give proper weight to energy conservation. It has been shown that regulation has both direct and indirect effects on energy conservation and on the diffusion of new technology in the railroad industry. For these reasons, ERDA should develop a capability for analyzing proposals to create new regulations and to modify existing ones so that the impact of energy conservation can be shown. Such a group within ERDA should be present at regulatory agency hearings to represent the energy interests.

Because of the role of the DOT in research, development, and testing to support regulatory activities related to transportation, the activities of the new ERDA group must be carefully coordinated with those of the DOT.

The following areas would benefit from ERDA representation:

- Circuity reduction
- Improved freight car utilization
- Revision of long-haul rates
- Branch-line abandonment cases and policies.

Circuity Reduction

Research and analysis of reduction in circuity of freight car routing would initially focus on the cost and energy penalties that are incurred by retaining multiple-authorized routings between external gateway points on the property of a single railroad. Data should be collected on carloads of traffic moved over each alternate route within a few major carriers and one the costs and energy required to move these additional miles of train operation.

Improved Freight Car Utilization

The extent of poor freight car utilization and its causes are being studied by the railroad industry and the federal government. One of the proposals to improve freight car utilization is to modify the rules requiring direct return of cars to their owners when they are unloaded by a customer on another railroad. If, as expected, the data show that these rules increase empty car miles, the energy interest should be strongly represented as a reason for modifying the rules.

Revision of Long-Haul Rates

The effect of the rate structure on energy consumption must be considered in the regulatory process. This will require a commodity-by-commodity and market-by-market study to compare the energy impact of existing and proposed rates with alternative rates.

Branch-line Abandonment

Energy savings on branch lines should be considered on a case-by-case basis. Methods for evaluating individual energy impacts must be developed and policies for considering energy impacts must be established.

Modal Shifts to Railroads

The economics of transportation and distribution favors trucking over railroad transportation for many commodities because the railroad costs of owning and storing additional goods exceeds the cost increments of trucks. For longer trips, an advanced intermodal system, such as that described in a recent report for the DOT,⁹ will be competitive in service and lower in cost than trucking and is therefore expected to cause some shippers to shift to railroads.

Earlier in the railroad energy study we pointed out that measures to substantially discourage truck shipment would probably have to be applied in order to effect a major shift to railroads.⁸ Given a sufficiently grave concern for energy, drastic measures may be in order. A study of modal choice and energy conservation should be instituted to identify ways in which modal shifts could be effected and the costs of alternative strategies of effecting the shifts. Some of these alternative strategies include intermodal service; short, high-speed trains operated on premium schedules and moving without intermediate yard classification; higher fuel costs; higher road-user taxes; and direct taxes on highway transportation. The energy and economic impacts of each strategy should be evaluated.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Appendix A

MODEL NETWORK DESCRIPTION

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Appendix A

MODEL NETWORK DESCRIPTION

A network was constructed to represent an average freight haul. It was assumed that the freight was hauled along a branch line to a terminal where cars were sorted. The cars then move along a main line, pass through several intermediate yards, and arrive at a destination terminal where they are sorted again for their ultimate destinations. The cars are then delivered to their destinations aboard way trains along branch lines.

The input values for the model were chosen to approximate the average freight haul (see Table B-1). It was assumed that the net tons per year hauled on the main-line portion of the network was 20 million tons. Half of the net tons (10 million tons) were assumed to be hauled on a branch line a distance of 53 miles, which represents the average branch haul in the United States. This 53-mile haul was split so that half the distance (26.5 miles) is at each end of the main line. The branch-line average haul was assumed to be 70% of the branch-line length, giving 38 miles of branch line at each terminal. The main-line segment was assumed to be 463 miles, which resulted in 516 total miles hauled, which was the U.S. average haul in 1973. Corresponding to the U.S. average haul, 13 switches (7 per empty backhaul) per load were assumed. It was also assumed that the total branch-line miles in the network were 70% of the total miles hauled or 361 miles, of which 72 miles were modeled in detail in branch portion. The capital costs associated with the remaining 289 miles were included in the model.

Table A-1

ASSUMED VALUES AND INPUTS TO THE
LONG-RUN AVERAGE COST AND ENERGY MODEL

Branch-line haul (total)	53 miles
Branch-line haul (per line)	26.5 miles
Branch-line length (per line)	38 miles
Average load per car	61.2 tons
Terminal yards	2
Tons dispatched at terminal yards per year	10 million
Cost of handling at terminal yard	\$30/car
Total switches (7 switches per empty backhaul)	13/load
Gas per switch engine hour	7.4 gal
Switching at terminal yards	0.125 hours/car
Switching at intermediate yards	0.102 hours/car
Cost of handling at intermediate yards	\$25/car
Main-line miles	463
Main-line net tons per year	20 million

Appendix B

RAILROAD ENERGY RESEARCH AND DEVELOPMENT

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Appendix B

RAILROAD ENERGY RESEARCH AND DEVELOPMENT

The principal agencies engaged in research and development (R & D) for railroad energy conservation in the United States are the Department of Transportation (DOT) and the Energy Research and Development Administration (ERDA). The railroad industry and individual railroads have performed some research and development on operations to reduce fuel consumption and attendant costs and pollution. The research and development of the railroad supply industry is limited by the uncertainty of a payoff in the marketplace for new technology. State and local government activity in the energy area is related to the retention of railroad services in opposition to abandonment proceedings.

To avoid overlap and to assure that effective energy conservation is carried out, the Secretary of Transportation and the administrator of ERDA executed a memorandum of understanding, dated April 26, 1976, that defines the policy of working together to support energy-related transportation research. In general, the policy states that DOT is recognized as the source of transportation system requirements and implementation needs and is responsible for research, development, testing, assessment, and evaluation of all modes of transportation as necessary to support regulatory, operational, intermodal balance, and policy responsibilities. ERDA is responsible for ensuring the advancement and consideration of new conservation technologies, particularly advanced system components and propulsion systems. The memorandum also provides policies and procedures for joint planning, comments on programs, and information transfer.

R & D project titles and abstracts are given below. These have been compared with programs exchanged between ERDA and DOT. Programs that were not underway at the time the memorandum was written have been added to the list of R & D projects.

OPERATIONS

Study To Develop a Transportation Network and Operations Based Methodology To Examine the Energy Cost, Shipper Impact and Transportation Investment Tradeoffs Implied by Various Conservation Options for Freight Movements

A multimode intercity network employing various mode operations for freight flows and energy-use and transportation requirement simulators will be used to generate the basic information for the evaluation. Conservation options may be portrayed as variations in mode operations or technology, changes in freight flow patterns, or mode diversions. The model will compute changes in energy use, implied mode investments, and shipment characteristics.

Sponsoring agency: Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts 02142

Study released March 8, 1976

RFP 210-0120-ES

A Study of Impacts of Energy-Use Constraints on U.S. Freight Operations

Performing agency: CACI Inc., Federal, 1815 N. Fort Myer Drive, Arlington, Virginia 22209

Sponsoring agency: Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts 02142

Study awarded September 9, 1976

Contract DOT-TSC-1252

Demand Information and Forecasting Research Project

The objective of this project was to develop functional specifications for an advanced demand information and forecasting system to support intrarailroad car distribution. The system will be sufficiently generalized that it could be adopted by most Class I railroads on a voluntary basis. Phase I of the project, now completed, identified the requirements of the data system and the most promising forecasting technique. Sample data from several railroads were collected and analyzed to provide information about the current environment and associated problems. In Phase II, the recommendations of Phase I will be implemented on a Class I railroad. This demonstration is expected to provide the framework for evaluating the technical feasibility, operational suitability, and economic desirability of the system for other carriers.

Performing agency: Association of American Railroads

Investigator: Minger, WK (Tel 202-293-6256)

Sponsoring agency: Federal Railroad Administration

Responsible individual: Braddock, CH (Tel 202-426-2920)

Contract DOT-FR-30058

Start date: 1974
Completion date: 1976

Freight Car Management Program

This program presently involves four phases: (1) Systems operations including service reliability studies, data interface standards, and car cycle sampling; (2) Operating practices as involved with car service rules, per diem rates, and car distribution procedures; (3) information technology developing a car assignment model and a demand forecast model; and (4) Operating systems with the line operations phase involving Grand Trunk Western and Missouri Pacific and the yard operations phase involving the Kansas City Southern at Shreveport, Louisiana, and the Chicago Railroad Terminal Information System.

Performing agency: Federal Railroad Administration, Office of Rail
System Analysis and Program Development

Sponsoring agency: Federal Railroad Administration

Responsible individual: Braddock, CH (Tel 202-426-2920)

Status: Active

Notice date: Feb. 1976

Acknowledgment: FRA

Freight Car Utilization Research Program--Phase I

Since an increase in car utilization would effectively increase the car supply, a research and action program directed at improving utilization has been undertaken. A significant improvement probably can be achieved without revolutionary changes on the part of shippers, railroads, and government agencies. A quantitative assessment of the potential for improvement can be made when an adequate data base on car cycles is available. Analysis of these car cycles from load to load would reveal the fraction of time a car spends being loaded, moved by railroads, and unloaded. Car utilization is expressed in terms of a wide variety of indices. None is wholly satisfactory for evaluation of all aspects of utilization and none in common use permits analysis of the economic effectiveness of use of the car fleet. A \$12 million program, extending through 1980, is projected. The first phase, a two-year-program, includes the following studies: (1) analysis of current practices and problems; (2) development of car utilization measurement standards; (3) collection of data for a more complete car cycle analysis; (4) recommendation of projects for FRA consideration; (5) analysis of the impact of AAR and ICC rules, directives, and orders on car utilization; and (6) study of freight car time reliability. Each study is expected to identify specific opportunities for improvement in car utilization.

Performing agency: Association of American Railroads

Sponsoring agency: Association of American Railroads; Railway Progress
Institute; Federal Railroad Administration; Inter-
state Commerce Commission; Railroad Labor Organiza-
tions; Transportation Association of America

Responsible individual: Leilich, GM (Tel 202-293-5018)
Completion date: January 1977

Freight Car Utilization Research Program. Phase I. Task 6--Reliability Studies

The objective of Task 6 is to design and conduct a series of experiments, coordinated with Task 3, that will permit statistically sound evaluations of alternatives to improve rail service reliability and the effects these alternatives have on equipment utilization.

For further information on related studies see also RRIS 099398, Section 26A, 099399 17A, 099400 17A, 099401 17A, 099402 24A.

Performing agency: Association of American Railroads
Investigator: Yarbrough, HF (Tel 404-688-0800)
Sponsoring agency: Association of American Railroads
Responsible individual: Leilich, GM (Tel 202-293-5018)

Study of Shipper Demand Concerning Empty Railroad Freight Cars Needed for Material and Commodity Loading

Create a functional design of the elements and processes (system architecture) necessary for a technically advanced system to collect and predict shipper requests (orders for freight cars to load). Such a system must be operationally suitable and economically justifiable for use by individual Class I railroads as part of their systemwide empty freight car distribution activity. These are related to current FRA project reports on Car Management Studies.

Performing agency: Association of American Railroads
Sponsoring agency: Federal Railroad Administration
Responsible individual: Shamberger, RC (Tel 202-426-2608)
Contract DOT-FR-30058(CR)
Active: February 1976
Start date: June 1973

St. Louis Terminal Project

The railroad industry's Labor/Management Committee, which is comprised of the chief executives of railroads and labor organizations, established a number of labor/management programs to work on specific problem areas. The St. Louis Terminal Project is one such activity. A Task Force on Terminals was established by the Labor/Management Committee with the objective of increasing the reliability, speed, and efficiency of car movements through a major existing railroad terminal so that the quality and saleability of rail transportation will be improved, thereby attracting additional traffic and improving employment opportunities. The improvements are to be made without capital expenditures. This objective is being achieved through a series of experiments involving changes in operating practices, labor agreements, rates, and regulations. Missouri Pacific's St. Louis Terminal division was selected as the laboratory for this experimentation. A project team was formed to head up the project.

The project director and associate director were recruited from the ranks of management and labor. The St. Louis Terminal Project consists of the following activities: (1) identification of potential changes, (2) implementation of experiments, and (3) development of a method to measure the quantitative impacts of experiments. A computerized car movement evaluation system was developed. This system and the underlying approach can be used by any railroad. This project is unusual in that labor and management are working together to implement significant changes in railroad terminal operations that will lead to improved service and more and better jobs. The lessons learned from this project should have wide application throughout the industry.

Performing agency: Task Force on Rail Transportation of the Labor/Management Commission

Investigator: Dyer, VG (Tel 314-622-2750) Zamarioni, FJ

Sponsoring agency: Railroad Labor Organizations; Association of American Railroads; Federal Railroad Administration; Missouri Pacific Railroad

Responsible individual: Collins, DW (Tel 216-228-9400, X 32)

Contract EB-400-0-ARR-849

Development of a Train Handling Control Model for Freight Train Locomotive Engineer Performance

The objective of this project is to reduce data taken in locomotive cabs on revenue freight runs to the form of a mathematical model of the train handling performance of a locomotive engineer. As a minimum, the following phases of freight train handling will be modeled: starting the train from rest, controlling the train through changes in grade, and stopping the train. The data records include settings of locomotive controls, speed, accelerations, motor load, brake system pressures, wheel slip, drawbar force, slack condition, drawbar angle, and main generator voltage. Also available are supervisor ratings of each engineer's performance on each recorded test run. The development of this model is expected to contribute to the understanding and improvement of selection, training, and evaluation of engineers and to support the development of improved locomotive operating controls and displays.

Funds for this project are administered by DOT/Transportation Systems Center, Cambridge, Massachusetts.

Performing agency: Turpin Systems Company

Investigator: Birdsall, JB (Tel 213-998-1404)

Sponsoring agency: Federal Railroad Administration

Responsible individual: Ofsevit, D (Tel 213-893-6321)

LOCOMOTIVE AND EQUIPMENT

Fuel Saver System for Train Locomotive with Relay Sets for GP-40 Locomotive

Performing agency: Touch Stone Mfg. Co., Jackson, Tennessee 39301
Sponsoring agency: U.S. Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts 02142. Attn: Procurement Office, Code 8323-1
Study awarded October 15, 1976
PR 611-7323-FB/s

Develop and Test Self-Synchronous Motor Traction System

Performing agency: General Motors Corporation, Delco Electronics Division, Goleta, California 93017
Sponsoring agency: Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts 02142. Attn: Procurement Office, Code 8322
Study awarded February 23, 1977
Contract DOT-TSC-1303 (TSC/612-0377-GF)

Fabrication and Packaging of Two Engineering Prototype Nondestructive Railroad Roller Bearing Diagnostic Systems

Performing agency: SKF Industries Inc., 1100 First Ave., King of Prussia, Pennsylvania 19406
Sponsoring agency: Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts 02142. Code TSC-852
Study awarded March 18, 1977
RFP TSC/611-0364-GMF

Investigation of the Aerodynamic Drag of Containers and Trailers on Flatcars

Wind tunnel tests have been conducted on one-fortieth scale models of trailers on flatcars (TOFC) and containers on flatcars (COFC). Various configuration changes to reduce aerodynamic drag were explored. Experiments on very simplified models were also conducted to obtain a fundamental understanding of the phenomena involved.

Performing agency: Hammitt (Andrew G) Associates
Investigator: Hammitt, AG (Tel 213-541-1328)
Sponsoring agency: Transportation Systems Center, 612-0278-AT
Responsible individual: Barrows, T (Tel 617-494-2451)
Completion date: March 1976

Advanced Concept Train: Vehicle Demonstration and Evaluation

This project involved the fabrication of a new lightweight train featuring an advanced flywheel energy storage system with twice the capability of current flywheel designs. Savings of 30 to 40 percent in total power requirement were anticipated.

Sponsoring agency: Department of Transportation

Freight Car and Locomotive Costing

The object of this project is to develop a set of methodologies and procedures for use in estimating the nature of cost and its variability in purchasing, maintaining, and operating freight cars and locomotives.

Performing agency: Peat, Marwick, Mitchell and Company

Sponsoring agency: Federal Railroad Administration

Responsible individual: Pomponio, J. (Tel 202-426-0771)

Contract DOT-FR-55055

Completion date: January 1978

REGENERATION AND STORAGE

University of Wisconsin Flywheel Energy Management Powerplant System Evaluation

Performing agency: University of Wisconsin, Madison, Wisconsin
Sponsoring agency: U.S. Department of Transportation/UMTA, UAD-72,
2100 Second St., S.W., Room 6418, Washington D.C. 20590
Study awarded January 19, 1977
Contract DOT-UT-70037

Study of Flywheel Energy Storage: Phase 1

Performing agency: General Electric Company and Garrett Airesearch
Manufacturing Company of California
Sponsoring agency: Department of Transportation, Urban Mass Transportation Administration, Office of Procurement and Third-Party Contract Review, Major Systems Division, UAD-71,
2100 Second St., S.W., Room 6416, Washington, D.C. 20590
Study awarded February 15, 1977
Contract DOT-UT-60096T and DOT-UT-60097T

Flywheel Energy Storage Unit for Yard Switch Engine-Feasibility Study

The objective of this research is to determine the technical and economic feasibility of employing flywheel energy storage technology to yard switch engines as a potential means of reducing fuel consumption, noise levels, exhaust emissions, and overall maintenance costs. This work will include the development of a "breadboard" installation for testing with a 1500 hp locomotive. A trailing car will be used to house the flywheel unit, and the necessary control integration and traction motor modification will be made to a railroad-furnished switcher. Four different railroads will assist in conducting 90-day operational evaluations.

The contract to a performing organization has not yet been awarded.

Sponsoring agency: Federal Railroad Administration, Office of Research and Development

Responsible individual: Cracker, WF, Jr (Tel 202-426-0855)

Start date: February 1976

Completion date: January 1978

INTERMODAL SYSTEMS

Systems Engineering for Rail-Highway Intermodal Freight System

The objective of the systems engineering effort in connection with intermodal systems is to define and analyze the great number of variables that affect the design, layout, and equipment for use in a rail-highway intermodal system. The areas to be investigated include the functions required of gateway and intermediate terminals (light density as well as heavy density service in each type of terminal); the equipment needed to operate an efficient system, such as rolling stock, handling equipment, and propulsion; and the control processes necessary to optimize utilization of plant. It is anticipated that test and evaluation of the design concepts selected will be conducted in cooperation with the railroad industry and local and state governments on a cost sharing basis. The project will involve two phases of work; the first will be a parallel, 180-day phase covering exploratory planning and the preparation of proposals for the second phase. It is anticipated that a 12-month type contract for the second phase will be awarded to one of the first phase contractors. The systems engineering work will be related to the development of improved rail-highway intermodal services and will involve the equipment, systems, and facilities utilized therein, such as transfer handling equipment, rail rolling stock and motive power, intermodal containers, intermodal trailers, terminals, and management information and control systems. The services to be performed will include exploratory planning, systems analysis, concept formulation, evaluation of alternatives, developmental planning, and preliminary engineering.

Sponsoring agency: Department of Transportation, Federal Railroad Administration, 400 7th St., S.W., Rm. 5413A.
Attn: J. Kerner, Washington, D.C. 20590

Study released November 15, 1976
RFP DOT-FR-4249/JK

Determination of Unit Maintenance Costs for Intermodal Flatcars

The objective of this project is to determine accurately the maintenance cost per mile of intermodal flatcars operating in dedicated service between city pairs. The method used is to operate six specially identified cars between Chicago and New Orleans on the Illinois Central Gulf Railroad. All repairs will be tabulated through the AAR Data Exchange System, and the mileage for each car will be recorded on an axle-mounted odometer. Pretest and posttest measurements of critical components will be made in order to project their useful life.

Performing agency: Trailer Train Company
Investigator: Greenfield, LP (Tel 321-786-1200)
Sponsoring agency: Trailer Train Company
Completion date: July 1976

An Experiment in Freight Modal Choice: Delineating the Rail-Truck Interface

The specific objectives of this project are: (1) to identify the economic characteristics of freight traffic that is rail and truck competitive in more detail than has been practicable to date; (2) to identify the marketing strategies most likely to succeed in attracting freight traffic to the most socially desirable and efficient mode of rail or truck transportation in terms of governmental economic, energy, and environmental policies; (3) to estimate the true magnitude of any misallocation of traffic between the rail and truck modes of transportation and what might be done to alleviate that misallocation.

Performing agency; Pennsylvania State University, University Park

Investigator: Stenger, AJ

Sponsoring agency: Office of Systems Development and Technology, Department of Transportation

Responsible individual: Meck, JP (Tel 202-426-4138)

Contract DOT-OS-50210 (CS)

Completion date: June 1976

ALTERNATIVE FUELS

Canadian Railway Electrification Study: Phase I--Development of Study Plan

The objectives of this study are to bring into sharper focus the time frame within which electrification of significant portions of Canadian railways is likely to occur, and to develop and describe a program of investigation, research, and development designed to permit a smooth transition to effective electrified operation at that time. The study will identify the factors that will influence the decision of the Canadian railways to electrify operations. These factors will be explored in order to determine their effect on the timing and economics of conversion and to identify gaps in technological, operational, and managerial knowledge or skills necessary to achieve conversion satisfactorily. Programs of investigation, research, and development will be developed to overcome the identified gaps in technological, operational, and managerial knowledge or skills and to enable smooth transition to electrified operation under Canadian conditions. The cost items involved in electrification will be identified and an approach for the methodology for costing the electrification stages will be recommended. General economic criteria for evaluation of the electrification decision will be established and alternative approaches to, and methods of, financing electrification will be identified. A process for monitoring future trends of relevant characteristics of particular factors that will have a significant influence on the electrification decision will be developed. Appropriate areas will be considered for Canadian railway pilot electrification projects, both freight and passenger, that might be implemented as intermediate, experience-gaining steps towards major conversions, and the rationale and general planning for their implementation will be suggested.

Performing agency: Canadian Institute of Guided Ground Transport

Investigator: Corneil, ER (Tel 613-547-5777)

Sponsoring agency: Transportation Development Agency

Responsible individual: Brenkmann, M (Tel 514-283-7846)

Contract 14 ST. T8200-5-5507

Completion date: June 1976

Railroad Electrification/Energy Program

Project Independence seeks to reduce vulnerability to petroleum import disruptions. Electrification of a major segment of the nation's railroads will contribute toward achieving this goal. FRA is in the planning stages of an electrification program for identifying the benefits that accrue to both the nation and the railroad operators from electrification, determining the incentives the railroad industry needs to start electrification, and performing R&D where it is most cost effective in the field of electrification. Already established is the fact that 100,000 barrels

of petroleum would be saved per day if 22,000 miles of track were electrified (and 22,000 seems economically justified). Additional savings would result if modal shifts from auto and intercity truck freight occurred. There are plans to electrify the 14-mile passenger track at the Transportation Test Center. The immediate use of the electrified track will be for testing of Northeast Corridor equipment prior to putting it into revenue service and for determining cost effective methods of installing the catenary system. In addition, the railroad industry will be surveyed to determine what use it may have for the facility.

Contract not yet awarded, planned for FY 1977.

Sponsoring agency: Federal Railroad Administration, Office of Passenger Systems Research and Development

Responsible individual: Novotny, R

Status: Proposed

Notice date: February 1976

Acknowledgment: FRA

Continuation and Expansion of Existing Program on Upgrading of Coal Liquids

Performing agency: UOP Inc., Des Plaines, Illinois 60016

Sponsoring agency: Energy Research and Development Administration, Washington, D.C. 20545

Study awarded February 24, 1977

Contract EF-C-01-2566

Laboratory Program to Support Operations of the H-Coal Project

Performing agency: Hydrocarbon Research Inc., McLean, Virginia 22101

Sponsoring agency: Energy Research and Development Administration, Washington, D.C. 20545

Study awarded February 24, 1977

Contract EF-77-C-01-2547

Railroad Energy Cost Data Projections for Diesel/Electric and Electrified Operation

Performing agency: Arthur D. Little, Inc., Cambridge, Massachusetts 02140

Sponsoring agency: Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, Massachusetts 02142

Contract DOT-TSC-1156, Modification 2, (TSC/612-0379-GF)

Fuel Study

The navy has recently completed a survey of the worldwide availability of nonmilitary specification aircraft and shipboard fuels that could conceivably be utilized by the navy during periods when shortages of specification fuels exist. The navy has also recently initiated a program to produce 100,000 barrels of oil shale crude which will be subsequently refined into military fuels. A need exists to (1) identify

the consequences on system safety, operation, maintenance, and reliability resulting from the use of nonmilitary specification petroleum-base fuels in naval boilers, diesels, and gas turbines; and (2) develop a test and evaluation plan for the products resulting from the 100,000 barrel Oil Shale Experiment. Accordingly, the navy is seeking interested parties, and funds have been budgeted for the development of fuel qualification procedures, the qualification of nonspecification conventional fuels through laboratory analyses and combustion experiments, and the development of logistics and usage guidelines for conventional and synthetic fuels.

Sponsoring agency: Office of Naval Research (Code 611), 800 North Quincy St., Arlington, Virginia 22217

Study released February 11, 1977

ROLES OF INSTITUTIONS

Regulation of Rail Transportation or (Economic Studies of Railroads)

This study investigates regulatory issues, such as carrier costs, rates, ratemaking, competition, and financial analysis.

Performing agency: Ernest and Ernst, 1025 Connecticut Avenue,
Washington, D.C. 20036

Sponsoring agency: Department of Transportation, Office of the Secretary,
Procurement Operations Division, TAD 43, 400 Seventh
St. S.W., Washington, D.C. 20390

Study awarded August 10, 1976

Contract DOT-OST-019

Report of Analysis and Evaluation of Foreign Transportation Regulatory Experience

Performing individual: James R. Nelson, Amherst, Massachusetts 01002

Sponsoring agency: Federal Railroad Administration, Department of Transportation, 400 Seventh Street S.W., Room 5416A,
Washington, D.C. 20590

Study awarded August 17, 1976

Contract DOT-FR-T5150

Study Entitled Policy Sensitive Freight Model Development

Performing agency: Massachusetts Institute of Technology, Cambridge,
Massachusetts

Sponsoring agency: Department of Transportation, OS, TAD-43, 400 Seventh
St. S.W., Washington, D.C. 20590

Study awarded January 17, 1977

Contract DOT-OE-70006 (DOT-OST-039)

Design of a System for Dissemination, Communication, and Technology Transfer of Energy Related Programs to Local Governments

Performing agency: Public Technology, Incorporated, Washington, D.C. 20036
Investigator: S. Markovich

Sponsoring agency: Energy Research and Development Administration Operations,
Division of Procurement, Washington, D.C. 20543

Study awarded February 22, 1977

Study of Rail Mergers and Consolidations

The Rail Services Planning Office of the Interstate Commerce Commission has commenced a nationwide study of rail mergers and consolidations. The purpose of the study is to review the advantages and disadvantages of

such arrangements, to identify the principal problems involved, and to propose solutions to the problems identified. The Office anticipates the use of some outside contractors and consultants in studying specific issues. Individuals and firms interested in possible contracts should submit detailed information concerning their capabilities and prior experience not later than 15 April 1977.

Sponsoring agency: Rail Services Planning Office, Section of Transportation Policy Planning
Study released March 22, 1977.

Effects of Partial Deregulation in the Transportation Industry

This investigation focuses on movements of commodities, such as grain, that are exempt from regulation when moved by highway and waterway and includes an examination of the implications of extending the regulatory exemptions to railroads. The study will be correlated with a cost analysis to show the effects of deregulation on productivity, rates, and modal choice.

Performing agency: Transportation Center, Northwestern University,
Evanston, Illinois
Investigator: Moses, LN
Sponsoring agency: National Science Foundation
Completion date: December 1977

Techniques for Evaluating Options in Statewide Transportation Planning/Programming

The objective of this study is to provide transportation planning methodologies that will be policy sensitive, that is, allow the testing and evaluation of options in a fashion that will produce timely results for decision making. Unified transportation funds, multimodal financial programming, and federal interest in "low-capital intensive" options are among the reasons for identifying major transportation issues facing state decision makers. Policy issues include transit operating subsidies, public acquisition of railroad rights of way, study of rail service versus highway construction, and impact analyses of various options.

Performing agency: Voorhees, (Alan M) and Associates, Inc., PEI Division,
8-18
Investigator: Bellomo, SJ (Tel 703-893-4310); Stowers, JR
Sponsoring agency: Transportation Research Board, National Cooperative Highway Research Program
Responsible individual: Spicher, RE (Tel 202-389-6741)
Completion date: February 1978

Freight Data Requirements for Statewide Transportation

Many state departments of transportation (and other state and regional agencies) are now concerned with preparing, or assisting in the preparation of, statewide "master plans" for highway, rail, air, pipeline, and water facilities to serve existing and future freight flows. The

objective of this study is first to develop the type, amount, and relative importance of freight data required to develop statewide transportation system plans and then to design and develop techniques, methods, and procedures for assembling these data. A manual describing in detail appropriate techniques for data acquisition, processing, verification, and maintenance will be prepared.

Performing agency: Creighton, Hamburg Inc., 8-14
Investigator: Memmott, FW; Blackwell, RB
Sponsoring agency: Transportation Research Board, National Cooperative Highway Research Program
Responsible individual: Spicher, RE (Tel 202-389-6741)
Completion date: February 1977

Rail Line Abandonment-Curtailment and Rural Development

The purpose of this project is to assist state governments in establishment and determination of state rail transportation planning and decision making. The project report emphasizes the options and alternative strategies open to state governments when faced with rural rail abandonments or rail service curtailment. The impacts on rural communities and their future development are also investigated.

Performing agency: Council of State Governments
Investigator: Runke, JF (Tel 606-252-2291); Black, WR
Sponsoring agency: Department of Commerce
Responsible individual: Rendahl, R (Tel 202-967-2816)
Contract 99-6-9383
Completion Date: November 1976

Developing Local Strategies as Alternatives to Abandonment of Light Density Railroad Lines

By identifying, compiling, and stressing innovative procedures that local interests may take either to preserve their rail service or to facilitate transition to a new form of transportation service, this research aims to assist in ameliorating potential deleterious impacts of rail abandonment. The objective is to develop a handbook to assist shippers, local and state governmental units, and planners when their rail service is scheduled for abandonment.

Performing agency: Tennessee University
Investigator: Patton, EP; Langley, CJ
Sponsoring agency: Office of University Research, Department of Transportation
Responsible individual: Murphy, T. (Tel 202-426-4416)
Contract DOT-OS-50125
Completion date: September 1976

Computer-based Railroad Network Model

The objective of this project is to develop a computer-based railroad network model that will be capable of facilitating the analyses of, and

providing insights into, the potential impacts of alternative public policies aimed at plant and/or corporate rationalization of the railroad industry. Outputs of primary interest will include rates of plant utilization, revenue generation, estimated costs, and probable viability, all analyzed on a segment-by-segment basis. Additional modifications will be completed by April 1976.

Performing agency: International Business Machines Corporation
Sponsoring agency: Federal Railroad Administration
Responsible individual: Bouve, T (Tel 202-426-2920)
Contract DOT-FR-40012
Completion date: June 1976

Effective Utilization of Work Force

The objective of this project is to conduct research in the economic factors critical to effective utilization of the railroad work force. Factors to be included are employee compensation, effect of working conditions on employee productivity, investment in training/experience, effects on employment of line abandonments, employee willingness to relocate, and the like.

Contract not yet awarded.

Sponsoring agency: Federal Railroad Administration, Office of Rail
Economics and Policy Development
Responsible individual: Collins, DM (Tel 202-426-0771)
Status: Active
Notice date: February 1976

Railroad Labor Study: Line Haul

The purpose of the study is to expand experiments at the St. Louis terminal to other terminals and conduct line-haul experiments to improve car utilization, employee productivity, and capital utilization.

Performing agency: Association of American Railroads
Sponsoring agency: Federal Railroad Administration, Office of Rail
Economics and Policy Development
Responsible individual: Collins, DM (Tel 202-426-0771)
Contract DOT-FR-43003
Notice date: February 1976

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

REFERENCES

1. S. J. Petracek, "Railroad Energy Study: Regulation and Tariff," Vol. 1, "Freight Railroading," Report on Task 2, Contract E4-76-C-03-1176, SRI Project TCU 5419, Stanford Research Institute, Menlo Park, California 94025 (January 1977).
2. A. E. Moon et al., "Railroad Energy Study: Description of Rail Transportation in the United States," Vol. 1, "Freight Railroading," Report on Task 1, Contract E4-76-C-03-1176, SRI Project TCU 5419, Stanford Research Institute, Menlo Park, California 94025 (January 1977).
3. V. Sloss, T. Humphrey, and F. Krutter, "An Analysis and Evaluation of Past Experience in Rationalizing Railroad Networks," Massachusetts Institute of Technology, Cambridge, Massachusetts (March 1975).
4. Task Force on Railroad Productivity, "Improving Railroad Productivity," Final Report, Washington, D.C. (November 1973).
5. W. Allman, "A Survey of Rail Network Rationalization Proposals," paper presented at the 56th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1977.
6. A. L. Morton, "The Changing Market for Rail Freight Transportation," Transportation Research Board No. 511, Transportation Research Board, National Research Council, Washington, D.C. (1974).
7. D. Curry et al., "Transportation Alternatives for the United States in the Next Fifty Years," SRI Project 5040, Stanford Research Institute, Menlo Park, California (March 1977).
8. H. S. Procter, A. E. Moon, and J. Monaco, "Railroad Energy Study: Efficiency Improvements," Vol. 1, "Freight Railroading," Report on Task 3, Contract E4-76-C-03-1176, SRI Project TCU 5419, Stanford Research Institute, Menlo Park, California 94025 (March 1977).
9. R. S. Reebie et al., "National Intermodal Network Feasibility Study," Part 1. Reebie Associates, Greenwich, Connecticut (May 1976).

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

BIBLIOGRAPHY

- Ainsworth, D. P., Keale, M. J., Liba, C. J., Levinson, H. M., "An Improved Truck/Rail Operation: Evaluation of a Selected Corridor," Reebie Associates, prepared for U.S. Department of Transportation, Federal Highway Administration, Contract DOT-FH-8158 (December 1975).
- Aluminum Company of America, "Lightweight, Long-Lasting Aluminum Freight Cars for Coal Unit Train Service," paper presented to Power Company, Boise, Idaho, 1975.
- "Aluminum Gondola for Canadian Coal," Railway Locomotives and Cars, pp. 23-24 (January 1972).
- American Society of Mechanical Engineers, "1974 Rail Transportation Proceedings," papers and discussions from Joint ASME/IEEE Railroad Conference, Pittsburgh, Pennsylvania and Winter Annual Meeting of the ASME, Detroit, Michigan, 11-15 November 1973 and 1974.
- "AMTRAK Receives Swedish Guest," Modern Railroads (October 1976).
- Anyos, T., Lizak, R., Wilhelm, J., Hirschberg, K., "Technology Transfer-Transportation," NASW-2455, Stanford Research Institute, Menlo Park, California 94025 (September 1974).
- Armbruster, F. E., Candela, B. J., "Research Analysis of Factors Affecting Transportation of Coal by Rail and Slurry Pipeline," Vol. 1, Hudson Institute, Inc., prepared for Burlington Northern Inc. (April 1976).
- _____, "Research Analysis of Factors Affecting Transportation of Coal by Rail and Slurry Pipeline," Appendix, Vol. 2, Hudson Institute, Inc., prepared for Burlington Northern Inc. (April 1976).
- Association of American Railroads, "Indexes of Railroad Material Prices and Wage Rates: Railroads of Class I," Series Q-MPW-90, Economics and Finance Department, Washington, D.C. (28 January 1976).
- Association of American Railroads, "More Miles to the Gallon . . . The Railroads," Office of Information and Public Affairs, Washington, D.C.

Association of American Railroads, "Operating and Traffic Statistics: Freight Train, Passenger Train, and Yard Service Performance; Motive Power and Car Equipment; and Traffic Statistics--Class I Line-Haul Railroads in the United States--Year 1974," O. S. Series No. 216, Annual Issue, Economics and Finance Department, Washington, D.C. (April 1975).

Association of American Railroads, "Railroad Mileage by States: December 31, 1974," Economics and Finance Department, Washington, D.C. (December 1975).

Association of American Railroads, "Railroads in the Energy Crisis," Office of Information and Public Affairs, Washington, D.C. (1974).

Association of American Railroads, "Revenues, Expenses, and Freight Traffic: Class I Railroads in the United States--Calendar Year Ended December 31, 1974," Economics and Finance Department, Washington, D. C. (3 July 1975).

Association of American Railroads, "Statistics of Railroads of Class I in the United States: Years 1964 to 1974," Statistical Summary Number 59, Economics and Finance Department, Washington, D. C. (July 1975).

Association of American Railroads, "Yearbook of Railroad Facts: 1976 Edition," Economics and Finance Department, Washington, D.C. (1976).

Baker, P. H., Schulze, F. W., "Progress in Railway Mechanical Engineering (1969-1970 Report of Survey Committee): Locomotives," General Electric Company, American Society of Mechanical Engineers (August 1970).

_____, "Progress in Railway Mechanical Engineering: 1970-1971 Report of Survey Committee--Locomotives," paper presented at the General Electric Company, American Society of Mechanical Engineers, Winter Annual Meeting, 28 November-2 December 1971.

_____, "Progress in Railway Mechanical Engineering: 1971-1972 Report of Survey Committee Locomotives," paper presented at the General Electric Company, American Society of Mechanical Engineers, Winter Annual Meeting, New York, New York, 26-30 November 1972.

Banner, P. H. "The Energy Situation: A Rail Viewpoint," Transportation Journal, Vol. 13, No. 3 (Spring 1974).

Beachley, N. H., Frank, A. A., "Increased Fuel Economy in Transportation Systems by Use of Energy Management," Prepared for U.S. Department of Transportation, Office of the Secretary, Office of University Research, Contract DOT-TST-76-57 (1976).

Bjerkehagen, O., Kollberg, B., "Energy Economics Through Solid-State Power Conversion," Railway Gazette International, Vol. 129, No. 12, pp. 459-461, December 1973.

"BN Gets Electrification Study Results: GE Sees Beginning of New Rail Era," Modern Railroads, Vol. 29, No. 6, p. 21 (June 1974).

Boeing Company, "SOAC: State-of-the-Art Car Engineering Tests at Department of Transportation High Speed Ground Test Center. Final Test Report. Volume I. Program Description and Test Summary," U.S. Department of Transportation Systems Center, Contract UMTA-MA-06-0025-75-1 (January 1975).

Boeing Company, "SOAC: State-of-the-Art Car Engineering Tests at Department of Transportation High Speed Ground Test Center. Final Test Report. Volume II. Performance Tests," U.S. Department of Transportation, Urban Mass Transportation Administration, Transportation Systems Center, Contract UMTA-MA-06-0025-75-2 (January 1975).

Boone, J. W., "The Implications of Railroad Energy Conservation for Logistics Systems Planning in the United States," Transportation Research, Vol. 8, No. 4-5, pp. 415-418 (October 1974).

Bowick, D. M., "The Benefits of Railroad Electrification," British Railways Board, Railway Management Review, Vol. 74, No. 2, pp. A37-A45 (1974).

Breimeier, R., "Energy Requirements of Inland Waterway Transport and Freight Trains (Complete Trainloads) Carrying Heavy Bulk Goods [Der Energiebedarf von Binnenschiffen und Gueterzuegen (Ganzzuegen) beim Massenguttransport]," Internationales Verkehrswesen, Vol. 26, No. 3, pp. 104-107 (1974).

Brettman, E., "Investigating the Optimal Economic Speed for Rail Vehicles [Optimal-Wirtschaftliche Geschwindigkeit Spurgebundener Fahrzeuge]," Eisenbahntechnische Rundschau, pp. 26-34 (January 1975).

Brinegar, C. S., "Rail Service in the Midwest and Northeast Region," Vol. 1, "A Report by the Secretary of Transportation," (1 February 1974).

Broering, L. C., Holtman, L. W., "Effect of Diesel Fuel Properties on Emissions and Performance," Cummins Engine Company, paper presented at the Society of Automotive Engineers meeting, 9-12 September 1974.

Broom, T. R., "Fuel Conservation," Florida East Coast Railway, paper presented at the Annual Railway Fuel and Operating Officers Association Meeting, 15 September 1975.

Burgess, S., Colucci, R., Rossi, L., "Solving the Branch Line Problem: A Critique of the Light-Density Line Analyses of the Preliminary

- System Plan," State of New York, Department of Transportation, New York State Railroad Task Force (2 April 1975).
- Burgess, S. et al., "The Off-Branch Cost Myth: The Effect of Branch-Line Railroad Abandonments on System Costs," State of New York, Department of Transportation, New York State Railroad Task Force (September 1975).
- Campbell, K., "Electrification: A Time for Reappraisal?" Canadian Pacific Rail, Railway Management Review, Vol. 74, No. 2, pp. A1-A5 (1974).
- Casey, R. F., "Summary Data For Selected New Urban Transportation Systems," U.S. Department of Transportation, Transportation Systems Center, Contract DOT-TSC-OST-72-35 (November 1972).
- Chaddock, J. B., Sud, I., "Energy Study of Underground Rapid Transit," Duke University, High Speed Ground Transportation Journal, Vol 6, No. 3, pp. 391-407 (September 1972).
- Chesser, A. H., "Transportation and Energy," United Transportation Union, Stanley H. Ruttenberg & Associates, Inc. (1975).
- Clemow, C. J., "Planning for Railway Electrification," British Railways Board, Institution of Electrical Engineers, Proceedings, Vol. 119, No. 4, pp. 431-440 (April 1972).
- "Cleveland Tests AC Traction Motors," Railway Locomotives and Cars, Vol. 146, No. 3 (March 1972).
- Clover, T. L., "The Steam Hydraulic Locomotive," paper presented to the Winter Annual Meeting of the Rail Transportation Division of the American Society of Mechanical Engineers, November 1973.
- CONSAD Research Corporation, "Criteria for Line Retention," prepared for United States Railway Association (February 1975).
- Creswick, F. A., "Energy Requirements for the Movement of Intercity Freight," Battelle Columbus Laboratories, Association of American Railroads (15 December 1972).
- Creswick, F. A. et al., "A Study of the Environmental Impact of Projected Increases in Intercity Freight Traffic," Battelle Columbus Laboratories, Association of American Railroads (15 June 1971).
- Curry, J. P., "Case Studies of Transit Energy and Air Pollution Impacts," De Leuw, Cather and Company, Inc., prepared for the Environmental Protection Agency (May 1976).
- Danzig, J. C. et al., "Procedures for Analyzing the Economic Costs of Railroad Roadway for Pricing Purposes: Volume I, Procedures," TOPS On-Line Services, Inc., prepared for U.S. Department of Transportation, Contract DOT-FR-30028, Federal Railroad Administration (January 1976).

Davis, L. C. et al., "Technical Feasibility of Magnetic Levitation As a Suspension System for High-Speed Ground Transportation Vehicles," Ford Motor Company, Contract DOT-FR-10026, Scientific Research Staff (February 1972).

"Diesel Engine Design Trends," Automotive Engineering, Vol. 83, No. 1 (January 1975).

Dukowicz, J. K., "The Single-Sided Lim with Saturated Back Iron," Mitre Corporation, Contract DOT-FR-7-35248 (January 1972).

DuVal, D., "What You Should Know About Diesel Diets," Trains, pp. 36-40 (May 1973).

Dyer, T. K. et al., "Rail Transit System Cost Study," Thomas K. Dyer, Inc., U.S. Department of Transportation, Transportation Systems Center, Urban Mass Transportation Administration, Contract DOT-TSC-UMTA-75-22 (January 1976).

Eck, H. C., "Fuel Conservation and Train Operation," Chessie System, Railway Fuel and Operating Officers Association, paper presented at the Thirty-Seventh Annual Meeting of the Railway Fuel and Operating Officers Association, 1973.

"Electrification Outlook Brightens," Railway Signaling and Communications, Vol. 63, No. 3, pp. 13-17 (March 1970).

"Electrifying Could Save Money," Railway System Controls, Vol. 4, No. 5 (May 1973).

"Energy Conservation and Public Transit: An Interim Rebuttal by the American Public Transit Association." (undated)

"Energy--Today's and Tomorrow's Energy Constraints Further Emphasize the Need For True Intermodalism to Get and Keep Our Economy Growing," Handling and Shipping.

Escher, William J. D., "Prospects for Hydrogen as a Fuel for Transportation Systems and for Electrical Power Generation," Escher Technology Associates, Oak Ridge National Laboratory, September 1972, ORNL-TM-4305.

Federal Council for Science and Technology, "Energy Research and Development Opportunities for Heavy Duty Transportation," Committee on Energy Research and Development Goals, Washington, D.C. (July 1972).

Federal Council for Science and Technology, "Research and Development Opportunities for Improved Transportation Energy Usage (REDOTEUS)," Committee on Energy Research and Development Goals, Washington, D.C. (July 1972).

- Feulner, A., "Gas Turbine Propulsions of the German Federal Railway [Gasturbinenantriebe bei der Deutschen Bundesbahn]," MTZ Motor-technische Zeitschrift, Vol. 36, No. 6, pp. 161-167 (June 1975).
- Foley, E. P., Shaw E. B., "Making and Economic Evaluation of Railroad Electrification," Railway Management Review, Vol. 74, No. 2, pp. A46-A65 (1974).
- Foley, G., "Long-Range Planning and the Energy Crisis," Railway Gazette International, Vol. 129, No. 12 (December 1973).
- Foster, R. W., Escher, W. J. D., "Hydrogen-Fueled Railroad Motive Power Systems, A Feasibility Study," ETA Report PR-70, Escher Technology Associates, U.S. Energy Research and Development Administration (September 1976).
- Fraize, W. E., "U.S. Transportation: Some Energy and Environmental Considerations," Mitre Corporation (September 1972).
- Franzen, S., "Optimal Power in Electric Locomotives," paper presented at the International Electric Vehicle Symposium and Exposition, 19-21 February 1974.
- Friedlander, G. D., "Railroad Electrification: Past, Present, and Future," IEEE Spectrum, Vol. 5, No. 7, pp. 50-65 (July 1968).
- Fuller, J. W., Hyman, W. A., "Energy and Environmental Effects of Railroad Abandonment," Wisconsin Department of Transportation, Transportation Research Board Meeting, Washington, D.C. (January 1976).
- Gannett, H., "A Dictionary of Altitudes in the United States," Fourth Edition, Bulletin No. 274, Series F, Geography 47, United States Geological Survey, Department of the Interior, Washington, D.C. (1906).
- Garde, M. R., "Gas Turbine Train Development in France," French National Railways, American Society of Mechanical Engineers, paper presented at the Gas Turbine Conference and Products Show, Houston, Texas, 2-6 March 1975.
- Gay, W. F., "Energy Statistics: A Supplement to the Summary of National Transportation Statistics," DOT-TSC-OST-75-33, U.S. Department of Transportation, Transportation Systems Center (August 1975).
- _____, "Summary of National Transportation Statistics," DOT-TSC-OST-76-11, U.S. Department of Transportation, Transportation Systems Center (June 1976).
- General Electric, "The Recovery of Waste Heat Using Rankine Bottoming Cycles as an Effective Means of Fuel Conservation," Space Division, Advanced Energy Programs (27 April 1976).

- Goss, W. P., McGowan, J. G., "Energy Requirements for Passenger Ground Transportation Systems," paper presented at the Intersociety Conference on Transportation, Amherst, Massachusetts, 23-27 September 1973.
- Goss, W. P., McGowan, J. G., "Transportation and Energy: A Future Confrontation," Transportation, Vol. 1, No. 3, pp. 265-289 (November 1972).
- Gouse, S. W., Jr., Rawal, C. H., "Split Propulsion for High Speed Ground Transport," Carnegie Institute of Technology, American Society of Mechanical Engineers, Rail Transportation Proceedings, papers and discussions from Joint IEEE-ASME Railroad Conference, Jacksonville, Florida, 14-15 March 1972.
- Hamilton, S. G., "Railroad Electrification Today," General Electric Company, Railway Management Review, Vol. 74, No. 2, pp. A15-A36 (1974).
- Hammitt, A. G., "Aerodynamic Forces on Freight Trains," Vol. 1, "Wind Tunnel Tests of Containers and Trailers on Flatcars," Final Report, FRA/ORD-76-295.I, Andrew G. Hammitt Assoc., U.S. Department of Transportation, Federal Railroad Administration (December 1976).
- Hampton, R. N., "Financing Railroad Electrification," Railway Management Review, Vol. 74, No. 2, pp. A78-A81 (1974).
- Handy Railroad Atlas of the United States, Rand McNally & Company, Chicago, New York, San Francisco (1973).
- Harley, E. T. et al., "The Management of an Electrified Railroad," Railway Management Review, Vol. 74, No. 2, pp. A82-A106 (1974).
- Harman, R. G., "Fuel in Transport," Traffic Engineering and Control, Vol. 15, No. 10/1, pp. 477-499 (February 1974).
- Harris, C.C., Jr., Hille, S. J., "Rail, Truck, or Small Car - Which is the Energy Saver?" Business Horizons, Vol. 17, No. 6, pp. 57-64 (December 1974).
- Hay, W. W., Railroad Engineering, Vol. 1 (John Wiley & Sons, New York, New York, 1953).
- R. L. Hines Associates, Inc., "USRA Yard Classification Planning Project: Maximum Throughput and Associated Expenditures in Selected Yards" (2 January 1975).
- Hirst, E., "Energy Consumption for Transportation in the U.S.," ORNL-NSF-EP-15, Oak Ridge National Laboratory (March 1972).
- Hirst, E., "Energy Intensiveness of Passenger and Freight Transport Modes: 1950-1970," ORNL-NSF-EP-44, Oak Ridge National Laboratory (April 1973).

Hirst, E., "Energy-Intensiveness of Transportation," ASCE Journal of Transportation Engineering, Vol. 99, No. TE1, pp. 111-122 (February 1973).

Hirst, E., "Transportation Energy Use and Conservation Potential," Science and Public Affairs, Vol. 29, No. 9 (November 1973).

Hopkins, J. B., "Measurements of Fuel Consumption in Branch-Line Railroad Operations," Preliminary Findings, U.S. Department of Transportation, Transportation Systems Center (March 1975).

_____, "Railroads and the Environment: Estimation of Fuel Consumption in Rail Transportation. Volume I. Analytical Model," U.S. Department of Transportation, Transportation Systems Center, Federal Railroad Administration, May 1975, DOT-TSC-FRA-75-16-I.

Hopkins, J. B., Newfell, A. T., Hazel, M., "Fuel Consumption in Rail Freight Service: Theory and Practice," U.S. Department of Transportation, Transportation Systems Center, paper presented at the 56th Annual Meeting of The Transportation Research Board, Washington, D.C., 22 January 1977.

Hoppe, C. F., "Evaluation of the WABCO AC Propulsion System," Vol. 1, "CTS/UMTA AC Propulsion Project," UMTA-ON-06-0006-74-3, Cleveland Transit System (September 1974).

Hottel, H. C., Howard, J. B., New Energy Technology: Some Facts and Assessments (Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 1971).

Huffman, R. A., Walker, J. L., "Rapid Transit System Simulation with Interactive Graphics Display," Transportation Planning and Technology, Vol. 1, pp. 205-217 (1973).

Humphrey, T. J., "Framework for Predicting External Impacts of Railroad Abandonment," DOT-TST-74-78, Massachusetts Institute of Technology, (March 1975).

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

_____, "Financial and Operating Statistics of Class I Railroads for the Six Months Ended June 30, 1973," Statement No. 100, Bureau of Accounts, Washington, D.C.

_____, "Financial and Operating Statistics of Class I Railroads for the Twelve Months Ended December 31, 1973," Statement No. 100, Bureau of Accounts, Washington, D.C.

- _____, "Freight Commodity Statistics Class I Railroads Year Ended December 31, 1974," Bureau of Accounts, Washington, D.C.
- _____, "Portions of 1974 Interstate Commerce Commission Annual Reports from 22 Class I Railroads," Bureau of Accounts, Washington, D.C. (Xerox copies of sections)
- _____, "Rail Carload Cost Scales: 1973," Statement No. ICI-73, Bureau of Accounts, Washington, D.C.
- _____, "Ratios of Empty to Loaded Freight Car-Miles by Type of Car and Performance Factors for Way, Through and All Trains Combined - Class I Line-Haul Railroads - Calendar Year 1968," Statement No. 6-69, Bureau of Accounts, Washington, D.C. (September 1969).
- Janota, M. S., "The Internal Combustion Engine for Rail Traction," Rail Engineering International, Vol. 3, No. 3 (March 1973).
- Johansson, A. V., "A New Excitation System for Diesel-Electric Locomotives," paper presented at the Joint IEEE-ASME Railroad Conference, San Francisco, California, 16 April 1975.
- Jones, L. W., "Liquid Hydrogen as a Fuel for the Future," Science, Vol. 174, pp. 367-370 (October 1971).
- Kahn, A. E., The Economics of Regulation: Principles and Institutions, Vol. 1 (John Wiley and Sons, New York, New York, 1970).
- _____, The Economics of Regulation: Principles and Institutions, Vol. 2 (John Wiley and Sons, New York, New York, 1970).
- Kaiser Engineers, "Energy Conservation Tradeoff Study for Baltimore Region Rapid Transit System," Report No. 74-25B-RE, Mass Transit Administration, State of Maryland Department of Transportation (March 1974; updated September 1975).
- Kalman, G. P., Hafele, B. W., "Feasibility Study of Linear Induction Motor Thrust Boosters for Diesel-Electric Locomotives," DOT-FR-9-0014, Garrett Corporation, AiResearch Manufacturing Division, 21 March 1969.
- Kalra, P., "Dynamic Braking," IEEE Spectrum, Vol. 12, No. 5, pp. 63-66, (May 1975).
- Keeler, T. E., "Railroad Costs, Returns to Scale, and Excess Capacity," The Review of Economics and Statistics, Vol. 56, No. 2, pp. 201-208 (May 1974).
- Keller, R., "Gas Turbine Drive for New High Speed Trains," paper presented at the Gas Turbine Conference and Products Show, Houston, Texas, 2-6 March 1975.

Kibblewhite, G. G., "Progress in Design and Operation of A. C. Locomotives and Multiple-Unit Trains," Institution of Electrical Engineers, Proceedings, Vol. 119, No. 4, pp. 425-430 (April 1972).

Kneafsey, J. T., "Costing in Railroad Operations: A Proposed Methodology - Studies in Railroad Operations and Economics - Volume 13," Massachusetts Institute of Technology, Department of Civil Engineering (March 1975).

Krambuhl, J. C., "How to Conserve Fuel and Lubes," Railway Locomotives and Cars, pp. 34-35, (October/November 1974).

Kumar, S., Dix, R. C., Willis, T., "A Preliminary Study of Fuel Consumption in Trains Due to Roller Bearing Seal Resistance," Illinois Institute of Technology, Mechanics, Mechanical, and Aerospace Engineering Department (November 1976).

Lang, A. S., Soberman, R. M., Urban Rail Transit: Its Economics and Technology (The M.I.T. Press, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1964).

Lawson, L. J., "Kinetic Energy Storage: A 'New' Propulsion Alternative for Mass Transportation," paper presented at the Intersociety Conference on Transportation, 23-27 September 1973.

Lawson, L. J. et al., "ATA Rail Transit Conference Held in San Francisco, California on April 14 and 16, 1974. Car Equipment Sessions. Papers," American Transit Association (August 1974).

Leilich, R. H., "Study of the Economics of Short Trains," Peat, Marwick, Mitchell and Company (June 1974).

Leilich, R. H. et al., "Energy and Economic Impacts of Projected Freight Transportation Improvements," DOT-TSC-OST-76-61, Peat, Marwick, Mitchell and Company, Battelle Columbus Laboratories, Transportation Systems Center (November 1976).

Leilich, R. H., Prokopy, J. C., Ruina, D., "Industrial Energy Studies of Ground Freight Transportation," Vol. 1, DI-14-01-001-1670, Peat, Marwick, Mitchell and Company, Federal Energy Administration (July 1974).

, "Industrial Energy Studies of Ground Freight Transportation," Vol. 2, "Appendices," DI-14-01-001-1670, Peat, Marwick, Mitchell and Company, Federal Energy Administration.

Lenard, M., "The Prediction of Freight Train Fuel Consumption: A Preliminary Report," Working Paper, DOT-FR-54090, The MITRE Corporation, METREK Division, 24 January 1977.

Lieb, J. G., "A Comparative Analysis of the Energy Consumption for Several Urban Passenger Ground Transportation Systems," Mitre Corporation, Urban Mass Transportation Administration (February 1974).

"Locomotives: Energy-Crisis Asset," Railway Age, Vol. 175, No. 2 (January 1974)

Loebl, A. S., et al., "Transportation Energy Conservation Data Book," 1st Edition, ORNL-5198, Oak Ridge National Laboratory, prepared for the United States Energy Research and Development Administration (October 1976)

Lorentzsen, N. M., "BN Cashes in on the Low-Sulphur Coal Boom," Railway Gazette International, Vol. 130, No. 11, pp. 433-436 (November 1974).

Luthra, S. P., Norain, A., Mathur, H. B. "Bi-Fuel Approach to Burning Ammonia in Diesel Engine," Institution of Engineers (India) Journal, Mechanical Engineering Division, Vol. 53, pp. 64-68 (November 1972).

Lutin, J. M., "Comparison of Energy Savings for Work Trips: An Analysis of Alternative Commuting Patterns for New Jersey," Princeton University, Transportation Program (August 1974).

Lyon, E. C., "Planning for Railway Electrification," Railway Management Review, Vol. 74, No. 2; pp. A64-A77 (1974).

Malliaris, A. C., Strombotne, R. L., "Demand for Energy by the Transportation Sector and Opportunities for Energy Conservation," U.S. Department of Transportation, Transportation Systems Center, Office of the Secretary, Washington, D.C., paper presented at the Inter-society Conference on Transportation, Denver, Colorado, 23-27 September 1973.

Martin, P. J., Roddin, M. F., "Fuel Usage for Passenger Transport Between Selected City Pairs," Stanford Research Institute, Menlo Park, California 94025 (14 December 1973).

Masry, A. C., Paullin, R. L., "Transportation Vehicle Energy Intensities," DOT-TST-13-74-1, NASA Ames Research Center/United States Department of Transportation, Joint Reference Paper, 20 June 1974.

Mays, R. A., Miller, M. P., Schott, G. J., "Intercity Freight Fuel Utilization at Low Package Densities: Airplanes, Express Trains and Trucks," paper presented at the Fifty-Fifth Annual Meeting of the Transportation Research Board, Session #52, Washington, D.C., 20 January 1976.

Mazziotti, D. F., Meyer, M., "Railroad Abandonment: The Administrative Decision-Making Process," DOT-OS-40019, Institute of Urban and Regional Research, University of Iowa, U.S. Department of Transportation, Office of University Research, Washington, D.C. (June 1974).

- Mazziotti, D. F., Meyer, M. C., Dueker, K. J., "Railroad Abandonment and Re-Use Planning: Relationship with Statewide Transportation Planning and Citizen Participation," Interim Report, TR 33, The Institute of Urban and Regional Research, University of Iowa, U.S. Department of Transportation, Office of University Research, Washington, D.C. (December 1974).
- McBrian, R., "New Motive Power Technology," Technological Change and the Railways, The Denver and Rio Grande Western Railroad, pp. 206-220.
- McCall, B. F., "Rails, Energy and Economics," paper presented at the Annual Railway Fuel and Operating Officers Association Meeting, 15 September 1975.
- McClean, H. G., "Long-Term Trends in North American Diesel Power," Railway Gazette International, Vol. 129, No. 3, pp. 101-104 (March 1973).
- Memmott, F., Scholz, F. S., "Trunk Route Analyses: A Useful Tool for Statewide and Regional Rail Planning," presented at the 55th Annual Meeting of the Transportation Research Board, Washington, D. C., January 1976.
- Moon, A. E., "Guidebook for Planning to Alleviate Urban Railroad Problems," Vol. 3, DOT-FR-20037, Stanford Research Institute, prepared for U. S. Department of Transportation, Federal Railroad Administration, Federal Highway Administration (August 1974).
- Mortimer, N. D., "The Energy Costs of Road and Rail Freight Transport: U. K. 1968," Open University, England (February 1974).
- Mutch, J. J., "Transportation Energy Use in the United States: A Statistical History 1955-1971," Rand Corporation Santa Monica, California (December 1973).
- National Academy of Sciences, "Optimizing the Use of Materials and Energy in Transportation Construction," Special Report 166, Transportation Research Board, Proceedings of a Conference, 12-14 November 1975.
- "New York Subway Tries Out Flywheel Energy Storage," Railway Gazette International, Vol. 131, No. 1, pp.23-24 (January 1975).
- "No Easy Answers in the Search for Fuel Economy," Railway Gazette International, Vol. 131, No. 2, pp. 54-57 (February 1975).
- Nouvion, F. F., "Electric or Diesel Traction: The Right Basis for Comparison," Railway Gazette International, Vol. 127, No. 10, pp. 377-380 (October 1971).
- The Official Railway Guide, North American Freight Service Edition, National Railway Publication Company, New York, 109th Year, No. 3, (November/December 1976).

Peat, Marwick, Mitchell and Company, "Profiles of Public Transportation Plans and Programs: An Appendix to the 1974 National Transportation Report," U. S. Department of Transportation, Office of the Secretary, Washington, D. C. (May 1975).

Perry, C. F., Anderson, W., "Recent Experiences with Sulfur in Distillate Type Fuels Burned in U. S. Navy Diesel Engines," paper presented at the Diesel and Gas Engine Power Conference and Exhibit, Houston, Texas, 28 April-2 May 1974.

Petracek, S. J., et al., "Railroad Classification Yard Technology: A Survey and Assessment," DOT-TSC-968, Stanford Research Institute, U. S. Department of Transportation, Transportation Systems Center (July 1976).

Railway Fuel and Operating Officers Association, "Fuel Conservation From An Operating Viewpoint," Compiled by H. C. Eck (1976).

Raposa, R. L., "Energy Demand and Consumption Requirements for Solid-State Controlled Linear Induction Motor Propulsion Systems," High Speed Ground Transportation Journal, Vol. 9, No. 1, pp. 345-353, (1975).

Raskin, D., Yutko, R. T., "Energy Storage Propulsion System for Rapid Transit Cars: System Design and Equipment Description," DOT-UT-550, Metropolitan Transportation Authority (NY), NY State Department of Transportation, Urban Mass Transportation Administration, Garrett Corporation (September 1975).

Raush, R. W., et al., "ATA Rail Transit Conference Held in San Francisco, California on April 14 and 16, 1974, Operations Sessions," American Transit Association (August 1974).

Reebie, R. S. et al., "National Intermodal Network Feasibility Study," Vols. 1-4, Part 1, DOT-FR-20065, Reebie Associates, prepared for U.S. Department of Transportation, Federal Railroad Administration (May 1976).

Reebie, R. S. et al., "National Intermodal Network Feasibility Study," Appendices 1-4, Part 2, DOT-FR-20065, Reebie Associates, Peat, Marwick, Mitchell and Company, prepared for U. S. Department of Transportation, Federal Railroad Administration (May 1976).

"Reliability: The New Dimension," Railway Locomotives and Cars, pp. 9-12 (April 1973).

Rice, R. A., "Energy Efficiencies of the Transport Systems," Carnegie-Mellon University, Society of Automotive Engineers, prepared for Meeting, 8-12 April 1973, and International Automotive Engineering Congress, Detroit, Michigan, 8-12 January 1973.

- _____, "System Energy and Future Transportation," M. I. T. Technology Review (January 1972).
- _____, "System Energy as a Factor in Considering Future Transportation," paper presented at American Society of Mechanical Engineers Annual Meeting, December 1970.
- Roberts, F. S., "Weighted Digraph Models for Energy Use and Air Pollution in Transportation Systems" R-1578-NSF, Rand Corporation (December 1974).
- Roberts, P. O., "Forecasting Freight Flows Using a Disaggregate Freight Demand Model," paper presented at the Transportation Research Board Annual Meeting, January 1977.
- Roberts, R., "How They Compare: Energy Efficiency of Transport Modes," Modern Railroads, Vol. 30, No. 11, pp. 52-56 (November 1975).
- "Romanian Switcher Still Under U. S. Test," Railway Age (25 August 1975).
- Ronan, W. J., "Gas Turbine/Electric Cars in Commuter Service," paper presented at the Symposium on Rapid Transit Vehicles for City Services, 22-23 April 1971.
- Ross, B. A., "Electric Energy for Transport in the Immediate Future," Railway Management Review, Vol. 74, No. 2, pp. A6-A14 (1974).
- _____, "Energy Aspects of Rail Electrification," American Electric Power Service Corporation, Wisconsin University, Madison, The Role of U. S. Railroads in Meeting the Nation's Energy Requirements, Proceedings of the conference held at the University of Wisconsin, 6-8 May 1974.
- _____, "Meeting Tomorrow's Railroad Power Requirements," IEEE Transactions on Power Apparatus and Systems, Vol. 90, No. 2, pp. 393-400 (March 1971).
- Roth, R. D., "An Approach to Measurement of Modal Advantage," American Trucking Associations, Inc., Department of Economics, Washington, D. C. (December 1976).
- Sanders, D. B., Reynen, T. A., "Characteristics of Urban Transportation Systems: A Handbook for Transportation Planners," DOT-UR-20019, De Leuw, Cather and Company, U. S. Department of Transportation, Urban Mass Transportation Administration, Federal Highway Administration (May 1974).
- Santa Clara County Transit District, Metropolitan Transportation Commission, "Rapid Transit Development Project - (RTDP)," (9 March 1973)

- Sawyer, R., "Gas-Turbine Progress on the Railroads," ASME Journal of Mechanical Engineering, Vol. 94, No. 8, pp. 26-30 (August 1972).
- Scott, W. M., "Economics for Positive Traction Control Equipped GP-40 Locomotives," Report No. 132, Technical Research Centre Research and Development, Canadian National Railways (19 May 1976).
- Scott, W. M., Skene, R. B., "Positive Traction Wheel Slip Control: Its Development and Performance," paper presented at the Railway Fuel and Operating Officers Association Annual Convention, Chicago, Illinois, 28 September 1976.
- Scott, W. M., Skene, R. B., Biglow, B. A., "Locomotive Traction Performance Measurement," paper presented at the IEEE-ASME Joint Railroad Conference, San Francisco, California, 15-17 April 1975.
- Sebald, A., Herendeen, R., "The Dollar, Energy, and Employment Impacts of Air, Rail, and Automobile Passenger Transportation," University of Illinois, Center for Advanced Computation, Energy Research Group, Urbana, Illinois (September 1974).
- Shedd, T., "Main Line Electrification Coming Soon? Part I," Modern Railroads, Vol. 26, No. 5, pp. 40-43 (May 1971).
- Sloss, J., Humphrey, T. J., Krutter, F. N., "An Analysis and Evaluation of Past Experience in Rationalizing Railroad Networks," DOT-OS-40002, Massachusetts Institute of Technology, prepared for U. S. Department of Transportation, Office of University Research (March 1975).
- Smith, D. I., "How to Measure Specific Fuel Consumption - II," Railway Age, pp. 40-42 (23 February 1976).
- Society of Automotive Engineers, Inc., "Powerplants for Industrial and Commercial Vehicles: A Look at Tomorrow," SP-270 (April 1965).
- Spenny, C. H., "Simulation of Power Collection Dynamics for Simply Supported Power Rail," DOT-TSC-FRA-72-1, U. S. Department of Transportation, Transportation Systems Center, (November 1972).
- Staeheli, G. A., "Fuel Conservation," paper presented at the Annual Railway Fuel and Operating Officers Association Meeting, 1974.
- _____, "Fuel Conservation - Energy Conservation," paper presented at the Annual Railway Fuel and Operating Officers Association Meeting, 15 September 1975.
- Stickler, J. J., "Evaluation of Noncontact Power Collection Techniques," DOT-TSC-FRA-72-7, U. S. Department of Transportation, Transportation Systems Center (July 1972).

- Storment, J. O., Wood, C. C., Mathis, R. J., "A Study of Fuel Economy and Emission Reduction Methods for Marine and Locomotive Diesel Engines," DOT-TSC-OST-75-41, U. S. Department of Transportation, Office of the Secretary and U. S. Coast Guard, Washington, D. C. (September 1975).
- Sudworth, J. L., Waldron, G. W. J., "The Role of Stored Energy in British Railways," paper presented at Conference on Energy, Europe and the 1980's, held in London, England, 6-10 May 1974.
- Tassin, Y. M., "Energy and Time Savings Associated with Rapid Ground Transportation Systems," Railway Management Review, Vol. 74, No. 2, pp. 1-8 (1974).
- Tihansky, D. P., "Methods for Estimating the Volume and Energy Demand of Freight Transport," Rand Corporation, Santa Monica, California (December 1972).
- Tope, D. W., "Rolling Resistance of Freight Cars," The Tim Ken Company (11 June 1971).
- Turbut, G., Spirea, E., "Increase in the Role of the Railways in the Future, As a Result of Decreasing Costs of Transport and Energy Consumption," Rail International, No. 7, pp. 621-625 (July 1975).
- "Unit Trains: Utility Acquires Aluminum Cars," Railway Locomotives and Cars, pp. 16-17 (October 1970).
- United States Congress, Office of Technology Assessment, "A Review of National Railroad Issues," Washington, D. C. (December 1975).
- United States Congress, Office of Technology Assessment, "Energy, the Economy, and Mass Transit," Washington, D. C. (December 1975).
- United States Congress, Senate, Committee on Agriculture and Forestry, "Prelude to Legislation to Solve the Growing Crisis in Rural Transportation," Part 1, "Transportation in Rural America: An Analysis of the Current Crisis in Rural Transportation; Part 2: Meeting Rural Transportation Needs," The Economic Research Service, U. S. Department of Agriculture, The National Area Development Institute, Lexington, Kentucky, prepared for the 94th Congress, 1st Session, Washington, D. C. (10 February 1975).
- United States Congress, Senate, Committee on Public Works, "Transportation and the New Energy Policies (Part 1)," prepared for the 93rd Congress, 1st Session (11 December 1973).
- United States Department of Transportation, "1974 National Transportation Report: Current Performance and Future Prospects," Office of Transportation Planning Analysis, Washington, D. C. (July 1975).

- United States Department of Transportation, Federal Railroad Administration, "A Review of Factors Influencing Railroad Electrification," FRA-OPP-74-01, paper presented at the Third International Electric Vehicle Symposium, Washington, D. C., 20 February 1974.
- United States Department of Transportation, Federal Railroad Administration, "1973 Carload Waybill Statistics. Territorial Distribution, Traffic and Revenue by Commodity Classes," Office of Rail Systems Analysis and Program Development, Washington, D. C. (June 1975).
- United States Department of Transportation, Federal Railroad Administration, "Proceedings of the 11th Annual Railroad Engineering Conference, Cooperative Research Effort Among Railroads, Railroad Associations, Industry and Government," held at Pueblo, Colorado, 23-24 October 1974.
- United States Department of Transportation, Federal Railroad Administration, "Proceedings: Symposium on Economic and Public Policy Factors Influencing Light Density Rail Line Operations, 10-11 January 1973, University of Colorado, Boulder," Washington, D. C. (1973).
- United States Department of Transportation, Federal Railroad Administration, "12th Annual Railroad Conference Proceedings, Effect of Heavy Axle Loads on Track," FRA OR&D 76-243, held at Pueblo, Colorado, 23-24 October 1975.
- United States Department of Transportation, Federal Railroad Administration, Federal Highway Administration, "Report to Congress: Railroad-Highway Safety Part II: Recommendations for Resolving the Problem" (August 1972).
- United States Department of Transportation, Federal Railroad Administration, The Wisconsin Department of Transportation, "Proceedings: The Role of the U. S. Railroads in Meeting the Nation's Energy Requirements," conference held at the University of Wisconsin, Madison, 6-8 May 1974.
- United States Department of Transportation, Secretary of Transportation, "Railroad Abandonments and Alternatives: A Report on Effects Outside the Northeastern Region," Report to the United States Congress, Washington, D. C. (May 1976).
- United States Department of Transportation, Transportation Systems Center, "Energy Statistics: A Supplement to the Summary of National Transportation Statistics" (August 1976).
- United States Department of Transportation, Transportation Systems Center, "Freight Transportation: A Digest of Technical Papers," Vol. 1, DOT-TSC-OST-77-68, (28 October 1976).
- United States Department of Transportation, Transportation Systems Center, "Research and Development Opportunities for Improved Transportation Energy Usage," DOT-TSC-OST-73-14 (September 1972).

- United States Department of Transportation, Urban Mass Transportation Administration, "Subway Environmental Design Handbook," Vol. 1, "Principles and Applications," 2nd Edition, Washington, D. C. (1976).
- United States General Accounting Office, U. S. Comptroller General, "Information Available on Estimated Costs to Rehabilitate the Nation's Railroad Track and a Summary of Federal Assistance to the Industry," RED-76-44, Report to Congress, 21 November 1975.
- United States Railway Association, "Final System Plan, Volume I (Parts I and II): for Restructuring Railroads in the Northeast and Midwest Region Pursuant to the Regional Rail Reorganization Act of 1973" (26 July 1975).
- United States Railway Association, "Preliminary System Plan, Volume I: for Restructuring Railroads in the Northeast and Midwest Region Pursuant to the Regional Rail Reorganization Act of 1973" (26 February 1975).
- Walbridge, E. W., "Per Passenger-Mile Energy Consumption and Costs for Suburban Commuter Service Diesel Trains," UMTA-IL-11-0006-74-1, University of Illinois, Chicago Circle (August 1974).
- "The Way Ahead for the Diesel-Hydraulic," Railway Gazette International, Vol. 129, No. 3, pp. 105-109 (March 1973).
- Westinghouse Electric Corporation, "Electric Power Systems for High Speed Ground Transportation," DOT-9-0025, Transportation Division (August 1969).
- Winestone, R. L., "Estimating AMTRAK Ridership," Rail Passenger Programs Division (August 1976).
- Wojciechowski, P. H., Dunn, H., "Energy Regeneration and Conversion Efficiency in a Hydraulic Hybrid Propulsion System," High Speed Ground Transportation Journal, Vol. 9, No. 1, pp. 383-392 (1975).
- Wong, J. Y., "System Energy in High Speed Ground Transportation," High Speed Ground Transportation Journal, Vol. 9, No. 1, pp. 307-320 (1975).
- Yasukawa, S., Todoriki, M. "Calculation of Optimal Train Performance Curves in the UHSGT," Railway Technical Research Institute, Quarterly Report, Vol. 15, No. 3, pp. 160-161 (September 1974).