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ENERGY STUDY OF RAIL PASSENGER TRANSPORTATION
Volume 1: Executive Summary

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By
Clark Henderson

August 1979

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

Stanford Research Institute International
Menlo Park, California

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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Contract No. EY-76-C-03-1176

Prepared for:

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

Stanford Research Institute International
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PREFACE

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

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

Work was organized in four tasks:

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

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

ENERGY STUDY OF RAILROAD FREIGHT TRANSPORTATION:

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

ENERGY STUDY OF RAIL PASSENGER TRANSPORTATION:

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

*The functions of ERDA were transferred to the Department of Energy.

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

This report is Volume I of the rail passenger transportation series. Mr. Clark Henderson was the author. He was assisted by Ms. Marika Garskis.

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I INTRODUCTION

Purpose

This report summarizes the results and conclusions of three reports prepared in SRI's Energy Study of Rail Passenger Transportation. The report treats the following topics: physical assets and services of rail passenger systems; energy demands and intensities; roles of local institutions; the industry future; and the role of the federal government. Readers interested in detailed data should examine the following reports:

- Volume II: Description of Operating Systems
- Volume III: Institutions
- Volume IV: Efficiency Improvements and Industry Future.

Information regarding costs, revenues and subsidies were collected and are presented in Volume II. Initially, it was intended that a long-range cost model would be developed. This proved not to be feasible because of the great diversity among some 30 rail passenger transportation systems treated and also because of the lack of accurate and detailed data on individual systems.

Rail passenger transportation has shifted almost entirely to the public sector, in contrast to railroad freight transportation. Consequently, regulation of rail passenger transportation services and control of fares or tariffs is accomplished directly by the institutions responsible for the operation and support of systems rather than by separate regulatory agencies as is done for rail freight. See Volume III for a discussion of these matters.

Period Covered

Data for these reports were collected in 1976 and 1977 and, in most cases, cover calendar year 1975. In some cases, noted in Volume II, data are for an earlier calendar year or for a final year including a part of 1975.

Quality of Data

We emphasize here, as in the other reports, that the quality of data published by and for rail systems, as well as data obtained directly from operating systems, leaves much to be desired in areas of coverage, accuracy, and ease of interpretation. Therefore, analysts using data from the three SRI reports should give close attention to comments regarding the quality of specific items of input data. (There is a single exception to this criterion: BART has excellent data on most of the subjects treated in this research.)

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II CAPITAL ASSETS AND SERVICES

This section presents data on the major capital assets used and the services rendered annually by four types of rail passenger services in the U.S.: national rail passenger network, suburban railroads, heavy-rail transit, and light-rail transit.

Major Assets

The passenger equipment, rail line, and stations identified as parts of the rail passenger transportation systems are summarized in Table 1. Minor items, such as yard equipment and maintenance-of-way vehicles, are not treated.

Table 1

MAJOR CAPITAL ASSETS

<u>Asset Type</u>	<u>National Network</u>	<u>Suburban</u>	<u>Heavy- Rail</u>	<u>Light- Rail</u>	<u>Total</u>
Passenger equipment					
Locomotives	368	485	--	--	853
Cars	2,208 ^a	4,593 ^a	9,593	938	17,332 ^a
Rail diesel cars	--	160	--	--	160
Facilities					
Miles of line	29,149	2,203	511	188	32,051
Stations	527	773	801	135 ^b	2,241

^aIncludes both electric and locomotive-drawn cars.

^bStreet stops are not included.

Services Rendered

Three measures of services rendered by rail passenger systems are used: car-miles, passenger-trips, and passenger-miles. Annual summary data appear in Table 2.

Table 2

RAIL PASSENGER SERVICES RENDERED ANNUALLY
(millions)

<u>Annual Service</u>	<u>National Network</u>	<u>Suburban Railroads</u>	<u>Heavy- Rail</u>	<u>Light- Rail</u>	<u>Total^a</u>
Car-miles	272	173	424	15	884
Passenger-trips	18	250	1,523 ^b	83	1,883
Passenger-miles	4,310	3,867	10,296	316	18,788

^aMinor discrepancies result from rounding.

^bIncludes light-rail in Boston.

Reports on services rendered vary greatly in accuracy. Railroads report car-miles of travel in revenue service, passenger-trips, passenger-miles, and seat-miles; these data are regarded as relatively dependable. Transit systems generally report car miles and passenger-trips but do not always segregate revenue and nonrevenue services. There is also often reason to doubt the precision of the quantities reported. Estimates of passenger-trips are usually based on revenue collected from passengers and an estimate of the average fare per passenger. Estimates of passenger miles are based on the number of passenger trips and an often poorly substantiated estimate of average trip length. (BART has dependable records on passenger-trips and passenger-miles and is the principal exception to these observations.)

Units of services used here are not standard and therefore are not true measures of service quantities. For example, the characteristics of cars vary greatly in weight and passenger capacity; consequently, the "car-mile" does not provide an adequate measure of service for use in engineering and operations analyses. Passenger-trip lengths vary greatly and trips are made for many purposes. However, the number of trips to and from work via suburban railroads and transit are often the most significant measure of passenger service. The number of passenger-miles, the most universal measure, is convenient for comparisons but usually has less significance than number of trips as a measure of value to travelers.

Deficiencies in quality of data on services rendered by rail passenger systems cause a significant degree of uncertainty in calculations of energy efficiency or energy intensity; therefore, managers of rail systems and government officials responsible for conservation programs may be denied some of the confidence needed for decisive management of an energy conservation program.

Conclusion: Accurate information on services rendered by rail passenger transportation systems is needed. Management information systems and reports should be developed and implemented to satisfy this need.

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III EVALUATION OF ENERGY CONSERVATION MEASURES

Needs

Decisions regarding adoption of energy conservation measures should be based on estimates and comparisons of total, long-term energy demands for alternative programs, and not merely on comparisons of direct demands for electrical power, fuel oil, and diesel fuel. However, because of deficiencies in information regarding energy demands and related matters and a lack of formal methods for evaluations and comparisons of alternatives, the knowledge needed for rational decisions is not available at present. In the short run, this knowledge can be obtained by conducting special studies to estimate the energy impacts of conservation measures and to evaluate and compare alternative programs. In the long run, knowledge for decision-making can be obtained by the development of energy management information systems, standard energy reporting procedures, and formal evaluation and comparison procedures. In this research, the terms "energy management information" and "energy economy study" have been adopted to describe the needed information-gathering procedures and the methods for evaluation and comparison of alternatives.

Definitions of Energy Demands

Total energy demand can be subdivided into three distinct classes: direct, indirect, and capital energy, defined as follows:

- Direct energy is consumed, day by day, to operate equipment and facilities.
- Indirect energy is consumed to supply labor, services, and goods (other than electrical power and fuel) for current operations.
- Capital energy is consumed to create new capital assets for construction, replacement, improvement, extension, and expansion of rail systems, and to create new capital assets required by the public utilities and other industries engaged in the support of rail passenger transportation.

Estimation of Demands

While both practical and theoretical difficulties are encountered in obtaining dependable data on energy demands, approximate data are obtainable and are presented below. However, more complete reports and improvements in estimation procedures are needed.

Direct Energy

To allow comparisons and aggregations of energy data, petroleum fuels (in gallons) and the heating value of those fuels (in Btu) are used, in all cases, as measures of direct energy usage (see Table 3). This practice reflects an assumption, believed to be justified, that substantially all of the energy to be saved by conservation measures in rail passenger transportation will ultimately be realized as reductions in petroleum fuel consumption. Exceptions undoubtedly exist (e.g., where nuclear, hydroelectrical or geothermal sources are used) but have not been identified. It would be desirable to refine this area of analysis. National averages have been used for heating values of fuel oil, for efficiencies of steam generating plants, and for losses and miscellaneous power usages in distribution (except where local conditions are known to be substantially different).

Table 3

ENERGY CONVERSION FACTORS

Electrical power:

$$\begin{array}{lcl} 1 \text{ kWh purchased} & & \\ \text{by a rail system} & = & \left\{ \begin{array}{l} 11,278 \text{ Btu} \\ 0.07739 \text{ gal fuel oil} \\ 1.076 \text{ kWh generated} \end{array} \right. \end{array}$$

$$\begin{array}{lcl} 1 \text{ gal fuel oil} & & \\ \text{consumed at a steam-} & = & \left\{ \begin{array}{l} 145,719 \text{ Btu} \\ 12.92 \text{ kWh purchased by} \\ \text{generating plant} & \text{rail system} \end{array} \right. \end{array}$$

Diesel Fuel

$$1 \text{ gal consumed} = 137,300 \text{ Btu}$$

Published reports and internal documents have been surveyed to obtain information on quantities of energy purchased and used, for all purposes, by rail passenger systems. However, the information obtained in the research does not always include energy used for heating, ventilating, air conditioning, lighting, and operation of maintenance facilities. These demands are often not identified in energy usage reports, and are probably not included in many cases. Efforts to obtain the data during field work were often unsuccessful.

Conclusion: Deficiencies in the quality of data or direct energy demands and in methods of estimation include a degree of uncertainty in calculations of energy intensities, thereby handicapping the management of an energy conservation program. A need exists for the development and use of energy management information systems to account for all direct energy usage in detail and by function. Accurate methods for the

estimation of direct energy usage in terms of basic resources consumed and physical units are also needed. Common measures (such as Btu) are needed to allow aggregation of data and to make comparisons among alternatives. Energy expended to extract, transport, and process fuels also needs to be included. Variations in heating values of fuels, thermal efficiencies of generating plants, and consumption and losses in distribution should be recognized.

Indirect and Capital Energy Demands

Two methods are available for estimation of indirect and capital energy demands. One is based on a detailed analysis of the types and quantities of materials and services required, coupled with estimates of the amounts of energy consumed to produce a unit of each type of resource. Although this method is burdensome, requiring a body of accurate, detailed input data and the expenditure of substantial analytical effort, it is, in theory, more accurate than the alternative method.

The second method is simple and requires little effort. It employs cost data and a factor relating Btu to dollars of cost. The factor is computed by dividing annual consumption of energy in the U.S. by the gross national product. In 1975, U.S. domestic consumption of energy was 70.85 quadrillion (million billion) Btu; the gross national product was \$1,498 billion. The factor used for estimating the indirect and capital energy for that year was 47,300 Btu/dollar. In theory, the second method offers less precision than the first, but it produces a useful approximation in cases where data are unavailable for the first method.

Energy Management Information

Detailed, dependable information on energy usage and related matters is the most fundamental and universal need for energy conservation in rail passenger transportation. Management information systems can be developed to satisfy this need; however, considerable time and effort are required.

Managers of rail passenger systems are not able to deal effectively with energy problems. They often express concern over the rising costs of fuel and electricity and the prospect of further cost increases. Some also express concern over the long-term possibility that energy shortages may restrict the energy available for rail operation. However, comprehensive programs for conservation and reasonable priorities do not exist.

No management information system provides full details on the quantities of energy consumed for the various functions of rail systems;

further, none includes analytical techniques to estimate all the changes in energy consumption that would result from specific changes in operation. Consequently, managers can neither identify and describe all opportunities for energy savings, evaluate conservation measures, nor establish priorities among measures according to cost-effectiveness criteria.

Government agencies which do not generate primary data, are wholly dependent on operating rail systems for information on energy usage and related matters; consequently, they are also ill-informed regarding energy usage and opportunities for conservation.

Conclusion: A need exists for the federal government to support development of an energy record-keeping system and standards; to require implementation of energy information systems; and to expand the scope of annual reports presently made to federal agencies to include adequate measures of direct energy consumed.

Energy Economy Studies

The needs of decision makers can be satisfied by conducting energy economy studies. Each study would include the definition of alternatives including, usually, the continuations of present programs without change and one or more programs encompassing prospective changes. Energy economy studies can help answer questions such as these:

- Why change the pattern of operation or the design of equipment or facilities of an existing system?
- Why adopt one new system design rather than an alternative?
- Why construct a proposed new system?
- Why follow one schedule for staging the development of a system rather than another?
- Why continue operation of an existing rail passenger system?

Without dependable data and adequate evaluation methods, prospective changes such as these cannot be based on objective evidence.

Conclusion: There is a need for the development and documentation of energy economy study methods, and for their use in evaluating impacts of changes of all kinds on total energy demands and energy intensity. Energy economy studies should ensure that care is exercised in planning, designing, constructing, operating, and renewing or discontinuing rail passenger systems and alternative modes to avoid loss or waste of energy.

Example

One example of the estimation of total annual energy demands was prepared in this research. Using both historical and current data for the BART system, it is offered only to display the results of a methodological exercise.

Estimates for the fiscal year 1975-76 were discussed in Volume II and are presented in Table 4.

Table 4

APPROXIMATE TOTAL ENERGY DEMAND BY BART

	Annual Estimates (Billion Btu)	Energy Intensity (Btu/passenger-mile)
Direct demand	2,630	5,900
Indirect demand	2,606	5,900
Capital demand	<u>1,930</u>	<u>4,400</u>
Total energy demand	7,166	16,200

The estimated total capital energy demand of the initial system, 110,000 billion Btu, was divided by the weighted average service life of all assets, 57 years, to produce an annual estimate.

The BART data are not intended to evaluate and compare BART with other modes of transportation. For such comparisons, only future expenditures of energy are relevant. It is emphasized that the energy embodied in BART's capital assets is "sunk" (i.e., it was expended long ago and cannot be recovered for reuse). Only those estimates of capital energy demands that occur in the future are relevant to decision-making. For established systems such as BART, the relevant estimates would include only the energy demands for replacement and renewal of capital assets. However, for any proposed new systems, the entire capital demand will occur in the future and the entire amount should enter into evaluations and comparisons.

Changes in BART's system design and requirements for capital assets, changes in patterns of operation of the existing system, and changes in patronage would all affect future energy demands. Special studies would be needed to estimate the effects of most changes, but rough estimates can be made for two extreme cases.

First, almost all of direct and indirect demands for energy would end if BART should discontinue operation. That energy amounted to 5,236 billion Btu in fiscal year 1975-76, or 11,800 Btu per passenger-mile. For many reasons, discontinuation of operation is not considered

a reasonable expectation. For one reason, ending rail operation would increase travel via other modes. These modes would, in turn, generate increased demands for direct, indirect, and capital energy. If these alternatives were to be considered, the net change in energy demands (and numerous other effects) would have to be estimated by a special study.

At the other extreme, the marginal energy demand generated by the transportation of one additional passenger aboard the trains now in operation is very small--about 150 Btu per passenger mile. Clearly, the increased usage of the existing fleet of cars to accommodate more passengers (with no change in load factor) would have a much lower energy demand per passenger-mile than the average of 11,800 Btu per passenger-mile in direct and indirect demands. In other words, expected increases in utilization of BART's present capacity and assets tend to improve energy intensities per passenger-mile.

IV DIRECT ENERGY ANALYSIS

This section includes summary data on direct energy usage by rail passenger transportation systems in the United States, and presents information on average direct energy intensities for four types of service, for various systems within each type and, to a limited degree, for variations of intensities within individual systems.

Annual Direct Demands

Table 5 summarizes approximate total direct energy demand in gallons of fuel and Btu for all four types of rail passenger service.

Table 5

APPROXIMATE ANNUAL DIRECT ENERGY DEMANDS

	<u>National Network</u>	<u>Suburban</u>	<u>Heavy- Rail</u>	<u>Light- Rail</u>	<u>Total</u>
Equivalent petroleum fuel (10^6 gal)	113	130	278	9	530
Equivalent thermal energy (10^{12} Btu)	15.7	18.0	39.8	1.2	74.8*

* Minor discrepancy results from rounding.

Direct Energy Intensities by Service Type

Direct energy intensity is the term used here for the ratio of services rendered per unit of direct energy demand and also for the ratio of direct energy demands per unit of service. Service measures are car-miles, passenger-trips, and passenger-miles. Direct energy measures are gallons of petroleum fuel (fuel oil and diesel fuel) and Btu.

Services rendered per gallon of fuel consumed and energy consumed per unit of service are summarized in Table 6 for all four rail passenger services.

Table 6

APPROXIMATE AVERAGE DIRECT ENERGY INTENSITIES

	<u>National Network</u>	<u>Suburban</u>	<u>Heavy- Rail</u>	<u>Light- Rail</u>
Service per gallon of fuel				
Car-miles	2.4	1.3	1.5	1.7
Passenger-trips	0.16	1.91	5.5	10.2
Passenger-miles	38	30	37	37
Energy (Btu) per unit of service				
Car-miles	58,000	104,000	94,000	84,000
Passenger-trips	865,000	72,000	26,000	14,000
Passenger-miles	3,600	4,100	3,900	3,900

The similarity of energy intensities per passenger-mile is misleading. The "global averages" for all four types of rail passenger service fall in a narrow range of 3,600 to 4,100 Btu per passenger mile; however, as shown below, intensities vary greatly among systems of the same type and also vary greatly within systems, by route, time of day, day of week, and so on.

Variation Among Systems

Rail Transit

Table 7 lists heavy- and light-rail systems in declining order of approximate direct energy intensities. The range extends from 2,100 to 9,400 Btu per passenger-mile. The average energy intensities for heavy- and light-rail systems were the same (3,900 Btu per passenger mile). The range of the distribution is extreme and the reason for the large differences observed among systems is not adequately understood.

Electrical power usage per car-mile also varies greatly among transit systems, as illustrated by Table 8.

Partial explanations for some variations in kWh per car-mile are available. For example, MBTA heads the list because of dependence on two old and inefficient steam plants. Plans call for a change to a

Table 7

DIRECT ENERGY INTENSITY VARIATIONS

<u>Region and Name of System</u>	<u>Heavy- or Light-rail</u>	<u>Btu per Passenger-Mile</u>
Boston, MBTA	HR, LR ^a	9,400
Philadelphia, Red Arrow	HR	7,200
San Francisco, BART	LR	5,900
New York, Newark	HR	5,900
Philadelphia, CTD	LR	4,900
Philadelphia, PATCO, Lindenwold	HR	4,800
Cleveland RTD	HR	4,100
New York, PATH	HR	4,000
Average	HR, LR	3,900
New York, Staten Island	HR	3,900
New York, NYCTA	HR	3,700
San Francisco, Muni	LR	3,200
Philadelphia, SEPTA	HR	3,000
Chicago, CTA	HR	2,700
Cleveland, Shaker Division	LR	2,100

Table 8

VARIATIONS IN ELECTRICAL POWER USAGE

<u>Region and Name of System</u>	<u>Heavy- or Light-rail</u>	<u>kWh per Car-mile</u>
Boston, MBTA	HR, LR ^a	12.3
Philadelphia, Red Arrow	HR	11.3
San Francisco, BART	HR	10.4
Philadelphia, Lindenwold	HR	9.7
Cleveland, RTA	HR	8.7
Philadelphia, SEPTA	HR	7.7
Philadelphia, CTA	LR	6.7
Pittsburgh, PAT	LR	7.2
New York, NYCTA	HR	6.8
San Francisco, Muni	LR	6.8
New York, PATH	HR	6.1
Chicago, CTA	HR	5.2
Cleveland, Shaker Division	LR	5.1
New York, Newark	LR	4.6

^a Heavy-rail and light-rail were not separated for MBTA.

public utility source. Intensities will then decline by about one-third. BART's high position on the list is due, at least in part, to its management information system, which records energy usage more completely and accurately than any other in the industry. BART's position in the array might be lower if all other systems reported energy usage with the same thoroughness and accuracy.

Suburban Railroads

Variation in direct energy intensities among suburban railroads shown in Table 9 are also large; the range is 1,900 to 4,300 Btu per passenger-mile, while the average direct energy intensity for all suburban railroads is 4,100 Btu per passenger-mile. Again, very little information is available to explain the variations among systems. Note that regional intensities are used in two cases. Special difficulties were encountered in obtaining primary data for several very large systems in the New York region and also from systems affected by the formation of ConRail, especially in Boston, New York, and Philadelphia.

Table 9

DIRECT ENERGY INTENSITY VARIATIONS AMONG SUBURBAN RAILROADS

<u>Region and Name of System</u>	<u>Btu per Passenger-mile</u>
New York: all systems	4,300
Average	4,100
Boston: Boston and Maine	3,800
Philadelphia: all systems	3,700
San Francisco: Southern Pacific	2,800
Chicago:	
The Milwaukee Road	2,800
Illinois Central Gulf	2,200
Rock Island	2,100
Burlington Northern	1,900
Chicago and Northwestern	1,900

Conclusion: Differences in energy intensities among systems of similar type are generally not explained by available information. Technical and operational analyses are needed to relate energy usage to the physical and operational characteristics of existing systems, to explain the reasons for differences among systems, and to provide a basis for planning conservation programs.

Variations Within Systems

Variations in energy intensities within systems (i.e., by time of day, day of week, or route) have been explored in only a few cases. Three examples follow:

- An analysis of NYCTA operations at 3:30 am on one line indicates that energy intensity was about 15,300 Btu per passenger-mile. At 8:30 am, energy intensity was about 720 Btu per passenger-mile. The range is a ratio of more than 20:1. Average direct energy intensity for NYCTA is 3,700 Btu per passenger-mile, more than five times the minimum and about one-quarter of the maximum observed on the line studied.
- A detailed analysis of San Francisco's Southern Pacific suburban service indicated the following distribution of direct energy intensities:
 - The train with the lowest energy intensity used 780 Btu per passenger-mile.
 - The system average energy intensity was 2,800 Btu per passenger-mile.
 - One-quarter of all trains having the highest energy intensities averaged 6,700 Btu per passenger-mile.
 - The train with the highest energy intensity used 41,300 Btu per passenger-mile.
- A sample of five Amtrak routes shows the following variations in energy intensities:

<u>Route</u>	<u>Btu per Passenger-mile</u>
St. Louis to Laredo	6,800
Chicago to New Orleans	3,600
Chicago to Los Angeles	2,600
New York to Detroit	1,800
Chicago to St. Louis	1,200

Conclusion: Although variations in energy intensities within systems are strongly influenced by load factors, other factors are present as well. Detailed analyses of causes of variations are needed to plan measures to avoid excessively high intensities.

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V. ENERGY ECONOMY MEASURES

This section outlines measures that could be adopted as elements of an energy conservation program. As indicated earlier, improvements in data and methods of analysis are regarded as essential to success. Various specific improvements are of sufficient importance to warrant thorough energy economy studies. Discussions and illustrations of many of the measures appear in Volume IV.

Design and Operations

Deficiencies in the design of rail equipment and facilities are common and diverse in nature. These deficiencies are, by far, the most serious causes of nonproductive and inefficient operating practices and waste of energy. Most energy losses can only be avoided by design improvement and acquisition of appropriate capital assets, often at considerable expense.

Some operating practices that waste direct energy are accepted by managers as the lesser of unattractive alternatives, especially when the cost of labor and other resources needed to avoid the energy waste would exceed the cost of the energy wasted. Undoubtedly, some waste of energy also results from inefficient management, but the detailed observations that would be needed to estimate such losses were not made in this project.

Examples of Wasteful Conditions

Case studies of some 30 rail passenger systems described in Volume IV reveal many examples that contrast energy conservation and wasteful conditions. The following comments summarize observed conditions that are notable for their waste of direct energy:

Deadhead Travel

More than 12% of the total vehicle mileage (and a similar fraction of operator labor-hours) of the San Francisco Muni light-rail system is expended in deadhead travel (i.e., movements between the storage yard and the five revenue lines). Some rail systems have less than 1% deadhead mileage. Muni's practice is made necessary by poor location of the car storage yard. Correction would entail construction of several additional yards in appropriate locations, requiring large capital investments.

Terminal Movements

The design of some systems requires a waste of energy (and other resources) by changing directions of travel at the terminals of revenue routes, forming trains, and adjusting train lengths. Locomotive-drawn trains with conventional controls must switch the locomotive from one end of the train to the other to change directions. BART's car design and yard locations make it relatively burdensome, in time, cost, and energy, to form trains and change train lengths. These wasteful practices can be avoided by use of push-pull controls for locomotive-drawn trains and by use of double-end controls for multiple-unit transit cars.

Excess Passenger Capacity

Many passenger trains contain more capacity than is required to accommodate the passenger loads carried, thereby wasting energy. The most extreme cases involve use of excess cars. For example, the Long Island Rail Road operates 7-car trains after midnight on a route where the average train load is 12 passengers. This practice is deemed necessary because car couplers are unreliable. Other systems, such as the New York City Transit Authority and Port Authority Trans-Hudson, do not shorten trains below half-length. This practice is said to be justified by the arrangement of switches, third-rails, and power collectors in cars, and by the need for several cars to allow a train to continue in operation with a malfunctioning car. Correction of these wasteful design features would probably justify expenditure of considerable amounts of money. BART must use two A cars in each train to provide a control cab for each direction of travel. On the other hand, systems with double-end controls for each car, or married pair, such as Lindenwald, use trains of any length, from one car upward, and frequently vary train lengths to match loads.

Although loads are often very light at the outer ends of lines, most systems operate all trains over the entire length of passenger lines. Others avoid nonproductive travel by turning some trains back at intermediate stations.

Self-powered rail diesel cars could be substituted for locomotive-drawn trains during periods of slack demand.

Measures requiring research and development could be exploited to better match train capacities to loads. One scheme would use automatic controls and other appropriate equipment and facilities to add or remove passenger cars at each station, according to need. (This technique has been developed for automated guideway transit systems.)

Special passenger cars could be developed to provide energy-efficient transit service on electrified lines during periods of low demand. For example, BART's 450-car fleet of 72-passenger A and B cars

might be augmented by adding a few dozen "A-A" cars designed with double-end controls and with seats for, say, 24 passengers. BART's minimum train would then have 24 rather than 144 seats. To achieve further energy savings, the special cars might be designed to perform at lower than standard accelerations and speeds. Furthermore, the special cars could be self-powered to allow shutdown of the third-rail power supply system in slack periods. The power for train operations could come from low-pollution diesel engines designed for operations in tunnels--an advance over existing rail diesel cars. A highly advanced propulsion system, using a hydrogen compound for fuel, a hydrogen-oxygen cell on the vehicle to produce electrical power, and a flywheel aboard the vehicle to store energy regenerated during braking, can also be envisioned.

Lightweight Car Design

Rail passenger cars vary in empty weight per unit of capacity. Clearly, excessive weight wastes energy each time the car is accelerated. However, costs and penalties are associated with design, manufacture, operation, and maintenance of lightweight equipment. An evaluation of alternative designs is needed.

Locomotive Design

Energy could be saved by designing locomotives in a variety of sizes to match the loads imposed by passenger trains; by designing engines that can be restarted quickly and safely, thus avoiding the need for prolonged idling; and by using superchargers and other equipment to improve the efficiency of the engine and electrical propulsion system. Since locomotives consume about 30% of the direct energy consumed in rail passenger transportation, locomotive design is important. However, rail passenger systems use only about 850 units of some 26,000 used by the railroads. As a result, suppliers give relatively low priority to improvements in the design of locomotives for passenger use. For example, Amtrak's first large order for modern locomotives was filled by a modified version of a freight locomotive design.

Propulsion and Braking

The solid-state propulsion control equipment successfully used in BART and several new rail systems is not used in some 9,000 older transit cars. Solid-state control is said to require about 10% less energy for acceleration than is used by cam control resistors. The quantity of electrical energy that would be saved by conversion to solid-state control is not known. Solid-state control equipment for regenerative braking produces electrical energy in usable form. Up to 30% of the kinetic energy of the train is said to be recyclable; however, actual reuse of the energy presents additional problems. The energy must either

be transmitted instantly to another train or load (via the third rail and electrical supply system) or it must be stored in flywheels, batteries, or other equipment aboard the train or by the wayside. Considerable work will be needed before the economic and technical problems of recycling braking energy are solved.

Train Operations

In comparison with stops at every station, some rail systems employ skip-stop operations to reduce the number of times each train stops along a route. Savings in energy for acceleration are realized and average speeds are increased, although passengers experience additional delay waiting for trains and some additional burden for transfers between trains. No evaluation of the benefits and penalties was found.

It appears that significant amounts of energy can be saved by changing speed-distance profiles. Generally, the changes include reducing accelerations, reducing top speeds, and coasting (with power off) during part of the run between stations. These changes, while saving energy, tend to reduce equipment productivity and to increase travel times. A complete evaluation of energy savings and other impacts was not found.

Ice

Significant amounts of energy are used during severe winter weather to prevent formation of ice on the track, third rails, and switches. Research and development on energy-efficient means to prevent icing is needed.

Idle Equipment and Facilities

Large amounts of energy are wasted for heating, ventilating, air conditioning, lighting, and operation of electrical and mechanical equipment in idle equipment and facilities. This is especially common in the more modern systems where relatively sophisticated equipment is used. In some cases, it is said that turning power off and on again each time a train or station goes out of service is excessively costly.

Power Supply and Conversion

Several rail passenger systems (e.g., MBTA and NYCTA) rely on inefficient sources for electrical power and thereby waste energy. Fortunately, plans have been made to change to more efficient sources of supply.

Rotary converters and mercury rectifiers remain in service for ac-dc conversion. This equipment wastes up to 10% of the energy consumed -- two to five times as much energy as solid-state converters. Again, most of the obsolete equipment will be replaced as capital funds become available.

Availability of Service

Some rail passenger systems provide 24-hour, 7-day service. Others close down during part of the night and on weekends and holidays. Undoubtedly, costs per unit of service and energy intensities are high for services provided during periods of very low demand. On the other hand, the lack of round-the-clock availability of service on a route tends to discourage dependence on public transportation, to reduce patronage at other times as well, and to reduce the value of rail passenger systems. Special efforts should be made to develop economical, energy-efficient means to provide relatively frequent service on all major routes at all times.

Conclusion: Energy wasteful conditions and practices are many and varied in rail passenger transportation. Avoidable waste has not been estimated in detail but is likely to be more than 20% and may be as high as 40%. A comprehensive program is needed to identify and assess the magnitude of various conservation measures and to evaluate each measure in terms of energy savings and other impacts.

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VI ROLES OF LOCAL INSTITUTIONS

Rail passenger transportation institutions have experienced revolutionary transformations, especially during the past decade. The institutional structures have not yet reached the levels of maturity, uniformity, stability, and economic strength necessary for independent execution of programs to change operating patterns, equipment, and facilities. The deficiencies of institutional structures are serious obstacles to the development of long-term, coherent programs of all kinds.

History

Rail passenger systems have roots in two private-sector industries, both of which began in the 1830s: the steam railroad and the horse-drawn, street railway, which later came to be called "transit properties." By the early 1900s, two distinct subdivisions of each industry had emerged: railroads provided intercity and suburban services, and transit systems provided streetcar and subway services. Recently, the names, but not the substance, of some services have changed. In this research, services by railroads are classed as the national rail passenger network and the suburban railroads. Transit services are classed as heavy-rail and light-rail.

Privately owned and operated systems were the dominant modes for intercity travel and for urban travel in large cities for many decades. Competing modes were generally slower and more costly or less attractive to travelers. However, private systems did not always enjoy prosperity and private ownership did not have universal approval. Early in the 20th century (1900 in New York and 1912 in San Francisco), municipal agencies began to take responsibility for the construction or operation of urban systems. Several cities provided financial aid for the construction of systems when private industry lacked capital. Some cities took full control of existing systems to prevent discontinuation of service by bankrupt firms. During the Great Depression and after World War II, numerous government agencies--federal, state, regional, county and local--committed financial resources for construction, continuation of service, and improvement of rail passenger systems of all types.

Shift from Private Control

Since the late 1960s, public agencies at all levels of government have greatly expanded their responsibilities for financial support, operation, and ownership of rail passenger systems. In 1975, less than

5% of the rail passenger service, measured by operating income, remained entirely under private ownership and control (see Table 10). A single system, Auto-Train, was the largest private firm (with less than 3% of the total income) and was the only U.S. rail passenger system that reported profitable operations. The other all-private passenger services (e.g., Southern Railway and Southern Pacific) reported losses on passenger services and were, in effect, using cross-subsidies from freight customers to provide passenger service.

Table 10

OPERATING INCOMES OF
RAIL PASSENGER SYSTEMS
(millions of dollars)

<u>Rail Passenger Services</u>	<u>Private Sector</u>	<u>Public Agencies or Mixed</u>	<u>Total</u>
Railroads			
National network	35	206	241
Suburban	<u>10</u>	<u>286</u>	<u>296</u>
Subtotal	45	492	537
Rail transit			
Heavy rail	--	517	517
Light rail	<u>--</u>	<u>29</u>	<u>29</u>
Subtotal	--	546	546
TOTAL	<u>45</u>	<u>1,038</u>	<u>1,083</u>

Dominance of Public and Mixed Systems

All heavy-rail systems are owned and operated by public agencies. All but one of the small light-rail systems are owned and operated by public agencies and the one surviving private system receives public financial aid. One major suburban system, the Long Island Rail Road, is owned and operated by a public agency. Other public agencies responsible for suburban rail services generally contract with railroads to operate trains, but often own the rolling stock and all or part of the track and stations.

Subsidies

The public and mixed systems are only able to continue operations because subsidies are received from government agencies (federal, state,

regional, special districts, counties, and municipalities). In some cases, publicly owned rail systems receive cross-subsidies from profitable activities within the same agency; the most common source is surplus income from toll bridges. The operating incomes shown in Table 10 (\$1.04 billion in 1975) are by no means the total cost of capital, operation, and maintenance for rail passenger transportation in the United States. In fact, accurate estimates of the annual outlays and the long-run average costs of these systems are not known and could be estimated only with great difficulty.

Limited Ability to Innovate

The institutional structures for the rail passenger systems in the U.S. have been developed by trial and error in response to pressing problems. None of the systems enjoys a high degree of independence or command of resources for innovative programs.

Conclusion: Rail passenger systems are generally unable to spend significant amounts of their own money to change operations or to design and acquire equipment and facilities to conserve energy. This is true even when reductions in energy cost would eventually repay the cost of the investment. The federal government cannot require significant changes in rail operations or system design without new legislation and procedural mechanisms for planning, evaluating, and financing changes.

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VII INDUSTRY FUTURE

The future of rail passenger transportation in the United States depends as much on external forces such as public policy, legislation, and appropriations of public funds, as it does on conditions within rail systems, such as operating efficiency and technical design of systems. Consequently, ordinary forecasting methods based on historical trends, costs, and modal splits would not produce meaningful results. On the other hand, it is possible to identify forces that tend to establish boundaries on the scale of rail passenger transportation (i.e., conditions that prevent severe curtailments of service and conditions that tend to prevent large growth).

Rail-Dependent Cities

Some cities experienced their major growth and development during the period of rapid growth of rail transit and suburban rail systems (mainly from 1890 to about 1930). New York, Boston, Philadelphia, Chicago, and Cleveland are vitally dependent on rail transportation; rail patronage in these regions is high. These cities have high population densities and high job densities in downtown areas. Discontinuation or severe curtailment of rail transportation service in those cities would drastically affect economic activity and life style. The value of commercial and residential property, levels of commercial activity, and employment would decline; automobile traffic would quickly overload streets and highways; and many families would find it necessary to relocate residences, change jobs, or move to other cities. In sum, for the foreseeable future, continuation of rail passenger services (without radical changes) appears to be near certain in those cities. Historical evidence supports this belief. Each time one of the major urban or suburban systems has faced financial disaster and closure, public agencies have come to the rescue.

Some of the same reasoning applies to continuation of heavily traveled links of the national rail passenger network between major cities. However, the adverse impacts of discontinuing intercity rail services would be less severe.

Conclusion: It is reasonable to expect that the operation of rail transit, suburban rail, and heavily traveled intercity routes will continue for the foreseeable future. Thus, investments and changes made to promote energy conservation in those systems are likely to remain in use until the end of the normal service lives of capital assets. Measures to improve these systems offer the best prospect for large-scale

and long-term energy savings. Because of age and basic defects in the original designs of old rail systems, this area also appears to offer the richest opportunities for significant energy savings.

Projects in Progress

National Network

Amtrak, which comprises almost all of the national rail passenger network, is making very substantial advances in facilities and equipment. The largest element is the \$1.7 billion program for improvement of facilities in the Northeastern Corridor, from Washington to Boston. Amtrak will also benefit greatly from the improvements in facilities being made as an outgrowth of the ConRail reorganization. In addition, Amtrak is purchasing modern rolling stock to replace part of the existing fleet of old and obsolete equipment. These programs affect only a relatively small fraction of the 26,000-mile network but have long-term impacts on operations and energy usage. On the other hand, it is difficult to visualize modernization of Amtrak's low-volume routes, which now incur large operating losses. It is likely that some low-volume routes will be dropped.

Rail Transit

At present, there are about 700 miles of heavy- and light-rail line, about 946 stations (plus street stops), and about 10,530 passenger cars. Rail transit construction, expansion, and improvement programs are in progress or being planned in Atlanta, Baltimore, Boston, Buffalo, Chicago, Cleveland, Miami, New York, Philadelphia, Pittsburgh, San Francisco, and Washington, D.C. A report in the New York Times (September 13, 1977) indicated that construction of at least an additional 260 miles of heavy- and light-rail line is in progress or planned by local agencies. If completed, total mileage would change from 700 to 960, a growth of 37%.

In the same news story, however, officials of the U.S. Department of Transportation stated that, principally because of the high cost and limited effectiveness of rail systems, completion of the planned rail lines is by no means assured. This view is easily understood when total cost estimates are examined. Recent experience suggests that rail transit system costs might average \$50 million per mile and that the total cost of constructing 260 miles might be \$13 billion.

The capital costs for such a program are staggering in relation to the small geographical areas and relatively small populations served. The capital energy demands are equally staggering. Estimates based on the factor cited above (47,300 Btu per dollar) indicate that capital energy demands for the program would total 5.6×10^{15} Btu (i.e.,

5.6 quads). This is almost 8% of total U.S. domestic consumption in 1975.

Conclusion: Completion of all planned construction of new rail transit systems will not occur because of great capital costs and enormous capital energy demands. Few additional cities will initiate rail transit construction programs.

Shifts Away From Auto Dependence

Cities developed under the influence of the automobile--including most of the urban growth of the past 40 to 50 years--do not display the densities of population, jobs, retail stores, and other activities needed to justify capital-intensive rail transit systems. Revolutionary changes in densities of land use or reductions of costs for transit systems would be required to change most U.S. cities from their present auto-dependent status to a new transit-dependent status.

Shifts away from auto dependence toward transit dependence have been predicted by some urban transportation authorities. However, the changes envisioned would occur in special transit-pedestrian districts comprising only a small fraction of urban areas. Existing rail systems and low-cost transit systems of conventional or advanced design would be used rather than new heavy- or light-rail systems.

The development of transit-pedestrian districts would tend to increase the value of existing regional rail networks but would rarely justify major new construction projects.

Conclusion: Prospects for rail passenger system are mixed. Existing systems will be preserved and improved, and may enjoy increased patronage, but construction of new systems will be limited. This suggests that energy conservation programs should focus on the rehabilitation and improvement of existing systems, where large savings are possible.

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VIII THE FEDERAL ROLE

Present Role

The role of the federal government in rail passenger transportation has grown immensely during the past decade as subsidy programs of various types have been initiated and enlarged.

Amtrak, a major beneficiary of government financial aid, has received appropriations totaling \$3.6 billion: \$2.5 billion for capital improvements and \$1.1 billion for operating subsidies. In addition, Amtrak benefits from research and development programs conducted by the Federal Railroad Administration.

Public agencies responsible for rail transit and suburban rail services receive aid of several kinds from the Urban Mass Transportation Administration. Among these are advances in technical equipment from UMTA's R&D programs, financial aid in the conduct of technical planning studies and demonstrations, capital grants covering up to 80% of the cost of approved investments, and operating subsidies covering up to 50% of operating losses. In addition, the Federal Highway Administration has programs to aid in financing parking garages and improvements in transportation systems management aimed, in part, at encouraging rail travel.

Inability to Innovate

It is a remarkable fact that the federal government has assumed the largest share of responsibilities for financing rail passengers transportation but has retained very little power to plan and execute innovative programs affecting operations or systems designs. Instead, the primary role in initiating changes has been reserved for operators of rail transportation. However, local agencies must seek federal approval of proposed programs. Although agencies of the federal government do not exercise power by directing desired actions, they can influence behavior by withholding approval of unwanted actions.

Conclusion: Federal agencies lack the power to plan and execute energy conservation programs in rail passenger transportation as well as the power to require rail systems to take desired actions. The power to disapprove undesirable plans submitted by local agencies can block unwanted actions but will not produce early, large-scale energy conservation measures. New mechanism are needed to allow federal agencies to establish directions and priorities.

Research and Development

Federal agencies should support research and development in those areas where significant opportunities for energy conservation are perceived and where industrial suppliers and rail system owners are unlikely to take prompt action. It should be recognized that rail systems and industrial suppliers have a tradition of cooperation in the development and testing of new equipment and of advances in facility design. When rail systems have adequate funds for capital improvements, market forces are sufficient to stimulate and guide most of the needed research and development. However, government support of research and development is needed where the potential value of an innovation program, as an energy conservation measure, is not adequate to stimulate prompt action by rail systems and suppliers. Examples are basic research on innovations without a short-term market potential such as development of high tensile-strength fiber flywheels for energy storage; and system-level research aimed at exploiting innovations of several kinds and in several industries such as the public utility companies, suppliers of heavy fixed electrical equipment, and suppliers of on-board equipment for power conditioning, propulsion and braking, and energy storage. In these cases, the federal government needs to assume leadership in research and development to encourage early exploitation of energy conservation measures that might otherwise be delayed until severe energy shortages are at hand.

Full Subsidy of Approved Conservation Measures

Requirements

The federal government could greatly increase its influence over the planning and execution of energy conservation measures by making three changes in present subsidy programs and administrative procedures:

- Establish methods and procedures for the conduct of energy economy studies to evaluate possible changes in rail operations or system design
- Establish criteria for evaluating the worth of energy savings in the justification of capital outlays for energy conservation
- Obtain legislative authority and appropriations to allow DOE to participate with DOT in subsidy programs for rail passenger transportation in those cases where energy conservation is a major objective. For example, DOE and DOT, together, might pay the full cost of technical studies dealing with energy conservation. In those cases where energy conservation criteria are met, DOE might pay 20% of the cost of capital assets (to relieve the rail system of that cost), while DOT would continue to pay 80% of the capital cost, as at present.

Goal

These changes would not alter the fact that local agencies are the prime movers in rail system innovations, but it could have a radical effect on the priorities given by local agencies to energy conservation measures. Congress has required local agencies to pay part of the cost of technical studies and of capital assets to help avoid ill-considered and wasteful programs. However, a side effect of that policy is that sponsors of energy conservation measures in local agencies must compete with sponsors of many other investments for the limited amounts of local funds available each year. Energy conservation often has a low priority, at the local level of government, because the changes are not visible or tangible and appear remote from service quality. Consequently, conservation measures that could be planned and executed within a fairly short period of time are scheduled for execution over long periods or are postponed indefinitely. Conversely, energy conservation is recognized as a high priority objective by the federal government. It appears likely that DOE could justify an increase in financial aid to local agencies to remove energy conservation programs from competition for local funds and to encourage prompt action.