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ENERGY CONSERVATION

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ENERGY STUDY OF RAIL PASSENGER TRANSPORTATION

Volume 2: Description of Operating Systems

Final Report

MASTER

By
Clark Henderson
Hazel T. Ellis
James P. Wilhelm

August 1979

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

Stanford Research Institute International
Menlo Park, California

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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Prepared for:

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

Stanford Research Institute 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

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*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 II of the Rail Passenger Transportation series. The principal author was Clark Henderson. Ms. Hazel Ellis was author of the section on the national rail passenger network. Mr. James Wilhelm was author of sections on Chicago, Philadelphia, Cleveland, Pittsburgh, and Washington, D.C., and the subsection on SEPTA. He participated in the preparation of the description of Muni in San Francisco. Ms. Marika Garskis and Ms. Ruth Ormondroyd assisted.

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I INTRODUCTION

Purpose

This report describes the rail passenger systems of the United States in terms of selected physical, operating, and economic characteristics, and relates services rendered to energy usage and costs.

Diversity of Rail Passenger Systems

Useful descriptions of the rail passenger systems are complicated by the great diversity of the systems themselves. For example, rail passenger transportation exists in four distinct forms: intercity railroads, suburban (commuter) railroads, heavy-rail transit (subways), and light-rail transit (steetcars). Each form varies in technical equipment, design of facilities, operating practices, size of systems, and other characteristics.

Institutional arrangement for planning, ownership, operation, and financing also vary. The roots of rail passenger transportation lie in two different private-sector industries: interstate railroads and urban transit. However, much of the responsibility for rail passenger transportation has shifted to agencies at the federal, state, regional, county, and municipal levels; and the responsibilities of private companies have diminished or ended. Institutional arrangement for joint private-public participation or for full public ownership and control has been tailored to meet the specific needs of each system or region, and there are few similarities among systems.

Scope

The great diversity of systems necessitated separate descriptions for some 30 individual systems or closely related groups of systems. These descriptions treat all but a few small systems in the U.S. and cover substantially all of the rail passenger services presently rendered.

Organization

The intercity rail passenger systems in the U.S. form a national rail passenger network and are described as such. Because of the dominant roles of public institutions, suburban railroads, heavy-rail transit, and light-rail transit systems are grouped by eight city-centered regions. The order of presentation is outlined here:

National Rail Passenger Network

Regional Groups

Boston Region	Philadelphia Region
Chicago Region	Pittsburgh Region
Cleveland Region	San Francisco Region
New York Region	Washington Region

Format

Description of systems are standardized in content and format to the extent possible. The format most frequently used for each system is as follows:

Facilities

Equipment

Energy Usage (kWh, gal, Btu)

Services Rendered (car-miles, seat-miles, passenger-trips, passenger miles)

Energy Intensity (service per gallon of fuel and energy per unit of service)

Economic Data (costs, revenue, deficits, capital outlays)

Readers are cautioned that many obstacles were encountered in efforts to obtain uniform, complete, accurate, and relevant data on these subjects. Consequently, the descriptions presented here should not be regarded as definitive.

Checklist of Energy Demands

Rail passenger systems demand energy in many different ways; consequently, a program of energy conservation and efficiency improvement can respond to opportunities of many kinds. The outline which follows is a partial checklist of direct, indirect, and capital demands for energy related to rail passenger transportation.

Direct Demands

Operation of Vehicles (Data on operation of vehicles can be cross-classified by types of operation and types of consumption, and, if details were known, could be presented in a matrix.)

- Types of operation
  - Passenger vehicles
    - Revenue service
    - Nonrevenue movements of vehicles
      - Deadhead (to and from revenue service)
      - In yards and shops
    - Live storage (with auxiliaries operating)
  - Maintenance and service vehicles
- Types of consumption
  - Propulsion (less energy recycled, if any)
    - Vehicle (empty weight)
    - Payload (passenger weight)
  - Mechanical and aerodynamic friction
  - Power conversion and regulation
  - HVAC (heating, ventilating, and air conditioning)
  - Lighting
  - Compressors
  - Controls
  - Communications

Fixed Facilities

- Power conversion and distribution
- Signals and communications
- Shops
- Yards
- Stations
  - HVAC
  - Lighting
  - Elevators and escalators
  - Communications
  - Fare collection
- Parking lots

Suppliers of Energy

- Production and distribution of fuel to power plants or vehicles
- Losses of heat in electrical power plants
- Losses of electrical energy in distribution and conversion
- Electrical energy consumed by suppliers

Indirect Demands

The energy required to produce and deliver goods and services (other than fuel and power) consumed in current operations of rail passenger systems.

Capital Demands

The energy required to produce, deliver, install, and construct newly acquired capital assets including replacements, improvements, extensions, expansions, and new construction.

Indirect and Capital Demands of Energy Suppliers

Energy (other than basic fuels) required to produce and deliver goods and services consumed by energy suppliers in their current operations; and energy required to produce, deliver, install, construct, and renew the capital assets of energy supply facilities.

Method of Approach

Baselines for Comparisons

Existing systems have been described here for reference purposes but mainly to provide a frame of reference for the identification of possible efficiency improvements. In conducting an energy conservation program, the value of each proposed change in rail passenger systems must be determined by making "before-and-after" comparisons of alternatives. Innovations of many kinds are possible; therefore, a large body of accurate and detailed baseline data will be needed.

Both practical and theoretical obstacles were encountered in the effort to develop adequate baseline descriptions. Practical difficulties were caused by the lack of records on important matters and uncertainties regarding the accuracy and proper interpretation of some available data. Theoretical difficulties arose from the lack of established methods for estimating and relating various causes and effects For example, it was difficult to determine how energy consumption, availability and usage of services, and capital and operating costs will be affected by changes in the design of equipment and facilities, in patterns of operation, in availability and quality of alternative modes of transportation, and other innovations.

Data Sources and Quality*

Rail passenger systems use two formal reporting procedures: railroads are required to report in a manner specified by the Interstate Commerce Commission; transit agencies now report voluntarily in a format prepared by APTA--the American Public Transit Association. (A formal procedure is now being developed cooperatively by APTA and the Urban Mass Transportation Administration.) The two report formats differed

*The Bay Area Rapid Transit system has more and better data on services rendered and energy used than any other system treated here.

in content and neither called for all of the data needed in this research.

Actual reporting practices followed by rail systems were defective in many respects. Some reports were incomplete; some contained data of questionable accuracy. Some reports combined data on suburban railroads in several regions and provided no basis for separation among regions. Some reports combined data on two or more types of rail equipment, and some combined data on light-rail and trolley coach systems. In sum, published statistical data on rail passenger systems provided much less than complete and accurate inputs for baseline descriptions.

Field interviews, inspection of internal reports and documents, correspondence, telephone conversations, and analytical exercises were used to supplement published data. Numerous interpretations of data were made. In a few cases it was necessary to make rough approximations to close data gaps rather than to leave a case study unfinished. For these reasons, readers are urged to pay close attention to comments in the text regarding limitations in the quality of input data.

Direct Demand Estimates

Reports and documents were examined to determine the quantities of energy purchased by each system during the most recent year reported. Quantities obtained in this way did not always include all demands (such as heat for shops and offices). The degree of understatement was not known but was believed to be relatively small. Only BART reported total direct demands.

Since diesel fuel was reported in gallons consumed and electrical power was reported in kilowatt hours purchased, there was a need to devise common measures of energy consumption for comparisons among systems and to allow aggregation of data. Because of concern over depletion of oil, consumption of petroleum fuel was adopted as one common measure and the number of Btus contained in that fuel was used as a second measure. A method was developed for computing the approximate quantity of petroleum fuel that must be burned to produce and deliver the electrical power consumed. While some electrical power consumed actually came from coal, nuclear, hydroelectric and geothermal plants, SRI assumed that transfer of power among electrical systems would allow almost all reductions in electrical power consumed by rail passenger systems to be realized as reductions in consumption of fuel oil. However, we recognized that this would not always be possible (eg., during periods of low demand).

Two statements of energy consumption were made for each system studied: equivalent gallons of fuel oil, and equivalent British thermal units (Btus). The heating values of fuels vary, but detailed data were not available. This report assumed that the diesel fuel said to be typical in the New York region was used everywhere. Its heating value is 137,300 Btus/gal.[1] National statistics for 1974 indicated that the average heat content of oil burned in public utility steam plants was 145,719 Btus/gal. U.S. public utilities produced an average of 1.076 kWh for each 1.0 kWh sold to customers, and used fuel containing 10,481 Btus to produce 1 kWh.[2] These national averages were used to produce the following table of equivalents for electrical energy:

1 gal fuel	=	145,719 Btu, 13.90 kWh produced, or 12.92 kWh sold.
1 kWh produced	=	0.07193 gal of fuel, 10,481 Btu, or 0.9028 kWh sold.
1 kWh purchased	=	0.07739 gal of fuel, 11,278 Btu, or 1,076 kWh generated.

National averages were used except where local conditions were known.

Available information did not permit complete breakdowns for separate elements of direct demand. Such estimates can be made but considerable effort and expense would be required to record, accumulate, and analyze the data. Work at that level of detail was not undertaken in this project.

Indirect and Capital Demands

Capital demand estimates were found in a research report on BART, but not for other systems. A procedure for estimating indirect energy was developed in this study and is illustrated using BART data. Indirect and capital demands for other rail systems and for suppliers of energy were not treated because necessary data were lacking and appropriate methods of analysis had not been developed.

Services Rendered

Estimates of car-miles, seat-miles, passenger-trips, and passenger-miles were valuable as general measures of system effectiveness and as inputs for estimates of energy intensity of a rail passenger system. Railroads generally reported all four service statistics, but often merged several regions in one report. Transit systems usually reported car-mile but not seat-mile data, and passenger-trips but not passenger-mile data.

Transit systems did not record the actual number of passengers entering the system nor the points of entry and exit by individual travelers. Estimates of passenger-trips and passenger-miles were made by analytical procedures based on accounting records of cash receipts from passengers and estimates of the average fare collected per passenger. The process may be somewhat involved because a variety of fares may be used. For example, most adult travelers paid the standard fare, but children and elderly passengers often paid reduced fares. Some travelers used free or term passes. Travelers using some stations paid a premium fare. Free transfers among rail and bus systems were sometimes allowed. Accurate estimates of average fares could be obtained from surveys designed to estimate the number of travelers of each class and the fare paid by each class but this was seldom done.

Reports of the number of passenger-miles of travel via rail transit were based on two inputs: estimates of numbers of passenger-trips and estimates of average trip lengths. In most systems surveys of origins and destinations were made only at long intervals. Consequently, updating estimates of average trip lengths usually required judgement. Published estimates of total passengers and passenger-miles via transit were seldom accompanied by explanations of the estimating methods. Surveys would have to be made to obtain accurate and current data. Readers should keep in mind that any errors in estimating the number of passengers and passenger-miles carried through directly to the estimates of energy intensity and the estimates of the unit of cost of service. The BART fare collection system used magnetic tickets to record accurately both the number of passenger-trips and the inputs needed to compute passenger-miles. From the viewpoint of energy conservation programs, widespread use of such tickets and recording systems would be desirable.

Energy Intensity

Energy intensity is a ratio of energy consumed per unit of service rendered (e.g., Btus per passenger-mile) or of service rendered per unit of energy (e.g., vehicle-miles or passenger-miles per gallon). The measures of energy intensity developed in this study were based upon estimates of annual direct demands for energy and for annual services rendered. Thus, if the quantity of direct energy consumed were accurately known the result would be a "global" average of direct energy intensity for an entire system and an entire year--the system average direct energy intensity. As mentioned above, the energy usage reported by some systems probably omits usage by stations, shops, yard and offices.

This report relates available data on direct energy usage with estimates of service rendered by using several equivalent expressions. The complete format follows:

- Car-miles per gallon of fuel
- Passenger-trips per gallon of fuel
- Passenger-miles per gallon of fuel

- kWh per car-mile
- Btu per car-mile

- kWh per passenger-trip
- Btu per passenger-trip

- kWh per passenger-mile
- Btu per passenger-mile

Electrical energy (kWh) per unit of service was not estimated for systems using diesel electric locomotives.

System average direct energy intensity measures based on annual data are not adequate for all needs in a search for efficiency improvements. For example, the measure obscures differences between seasons of the year, days of the week, times of the day, route structures, technical equipment and variations in operating practices. Also, the measure does not reflect indirect and capital energy demands which may be as large and as subject to control as direct demands. An approach to the treatment of indirect and capital demands is illustrated in the BART system description.

Available input data for compilation of energy intensities was flawed to some extent in nearly all cases, but some cases presented extreme difficulties. For example, a needed input, such as average trip length, was not always available from a dependable source. In some cases, reasoned assumptions were used to fill such gaps. The alternative was to abandon any effort to estimate energy intensity. Consequently, SRI considered it a better practice to make the assumptions and explain the limitations of results in the text.

System average direct energy intensities were often an inappropriate measure to evaluate the impacts of a specific innovation. For example, gaining or losing one passenger (or any other number that does not affect car-miles) would usually have so small an effect on energy consumed as to be undetectable—full trains use little more energy than empty trains. Also, lengthening or shortening a train by one car would usually change total energy consumption significantly less than the system average direct energy intensity per car-mile. Other examples could be cited. Input data for estimation of energy intensities and evaluations of specific innovations were meager even in the best cases. A considerable body of new data must be developed to evaluate the impacts of innovations on energy intensities, services rendered and costs.

Economic Data

Information on total annual costs, revenues, subsidies or losses for each system were collected where available. Reports on economic characteristics were not in standard formats and usually contained little detail. It was not possible to develop a model to explain system costs in terms of services rendered or energy consumed. The diversity of the field made it most unlikely that a single model could be developed to encompass all types of rail passenger service. The best subjects for cost modeling in future research would be a single system, such as BART, where capital assets are mostly new and where modern data processing methods have been used for accounting and operations throughout the history of the system.

The Association of American Railroads and the American Public Transit Association report each year on operating incomes of rail passenger systems for 1975.[3,4] These data were analyzed as follows:

	Operating Income (millions)
Railroads	
National network	$ 241
Suburban	296
Subtotal	537
Rail Transit	
Heavy-rail	517
Light-rail	29
Subtotal	546
Total	$1083

While rail passenger systems have largely become dependant on public agencies for all capital funds and for a substantial fraction of operating funds, there were no standard methods of reporting subsidies and losses. Consequently summary data were not available on capital outlays, long-run average capital costs, and current operating costs of rail passenger systems in the U.S.

A special analysis was made to separate data on suburban and intercity railroad service because near-complete public control of railroad passenger systems has placed suburban and intercity services in different institutional frameworks. Intercity and suburban railroad services are separated on the basis of revenue. Reports of the AAR for 1975 indicated that U.S. rail passenger services were provided by 31 organizations: Amtrak, Auto-Train, and 29 other class I, line-haul railroads. (See Table 1-1.) Total passenger revenue of these railroads for that year was $537 million. However, 15 of these 31 railroads received total revenues of only $2.2 million--less than $500,000 each--and were not listed by name.

Railraods did not report separately on intercity and suburban services but did report separately on three classes of traffic:

- Commutation and multiple-ride tickets
- Other travel in coaches
- Other travel in parlor and sleeping cars.

Table 1-1 indicates the passenger revenues according to these classes of traffic. These data were used to allocate all revenue between intercity and suburban services.

Four systems--Amtrak, Auto-Train, Southern Railway, and Denver and Rio Grande Western--reported revenue of $241.4 million from traffic in coaches, parlor cars, and sleeping cars. This amount was taken as the total revenue from intercity service on the routes that comprised the national rail passenger network. The remaining revenue, $296.1 million, was predominantly suburban in character. This figure included $6 million received by Amtrak and $200.1 received by other railroads for commutation and multiple rides. Single-ticket travel in coaches, parlor cars and sleeping cars for railroads classed as providing predominantly suburban services accounted for $90.0 million in revenue and was believed to be almost entirely suburban travel. For lack of an allocation procedure all of this single-ticket travel was called suburban travel.

Table 1-1

RAILROAD PASSENGER REVENUE (Millions of Dollars)
BY CLASSES OF TRAFFIC[5]
(1975)

System Rank	Commutation and Multiple Rides	Other Travel: In Coaches	Other Travel: In Parlor and Sleeping Cars	Total
National Network				
Amtrak	$ 6.0	$176.6	$29.8	$212.4
Auto-Train	0.0	27.1	1.3	28.4
Southern Railway	0.0	4.1	1.1	5.2
Denver and Rio Grande Western	0.0	1.4	+	1.4
Subtotal	6.0	209.2	32.2	247.4
Predominantly Suburban Services				
Long Island	58.5	40.2	0.1	98.8
Penn Central	55.3	35.6	0.0	90.9
Chicago and Northwestern	26.8	0.0	0.0	26.8
Erie Lackawanna	10.7	3.2	0.0	13.9
Illinois Central Gulf	11.6	0.0	0.0	11.6
Reading	5.0	4.9	0.0	9.9
Burlington Northern	9.3	+	0.0	9.3
Chicago, Milwaukee St. Paul	7.7	0.0	0.0	7.7
Chicago, Rock Island	4.7	0.3	0.0	5.0
Boston and Maine	2.6	2.1	0.0	4.7
Central Railroad of New Jersey	3.1	1.6	0.0	4.7
Southern Pacific	3.5	1.1	0.0	4.6
Other	1.3	0.8	0.1	2.2
Subtotal	$200.1	$ 89.8	$ 0.2	$290.1
Total	$206.1	$299.0	$32.4	$537.5

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II NATIONAL RAIL PASSENGER NETWORK

General

The national rail passenger network includes Amtrak, Auto-Train, the Southern Railway Company, Denver and Rio Grande Western, and several minor lines not analyzed in this research.

During the 19th century, the interstate railroads developed a national network of rail passenger routes that became the dominant mode of intercity travel. In addition, the railroads provided mail, express, and first-class passenger services in cooperation with the U.S. Post Office Department, the Railway Express Agency, and the Pullman Company. For many years, railroads carried most of the nation's express and mail. The dominant role of the railroads in intercity passenger travel, express, and mail continued for at least a century, including World War II and the early postwar years.

Growth in air and automobile travel, especially after World War II, caused a sharp decline in intercity rail travel, and most railroads experienced rapidly mounting financial losses from their passenger operations. In 1958 Congress responded to the railroads' financial problems by amending the Interstate Commerce Act to make it less difficult for railroads to abandon unprofitable passenger routes. As a result, 13 railroads abandoned all passenger service. The number of intercity passenger trains dropped from 1448 in 1958 to 590 in 1968. Passenger traffic decreased 40% in that period and investment in passenger equipment almost ceased.[6] However, the relief hoped for from the 1958 legislation was not sufficient and the railroads continued to suffer losses on their passenger service.

In 1971 two important innovations in intercity passenger service occurred: the creation of the National Railroad Passenger Corporation (Amtrak) by the U.S. Government and the railroads, and the organization of a private company called the Auto-Train Corporation. These two organizations now provide most of the remaining intercity passenger service.

Amtrak

The National Railroad Passenger Corporation (more commonly known as Amtrak) was established by Congress in October 1970 with the enactment of the Rail Passenger Service Act. The purpose of the legislation was to improve and develop the nation's intercity passenger rail service.

In April 1971, 20 railroads entered into agreements under which Amtrak would take over common-carrier responsibility for intercity rail passenger service.[7] These railroads are listed in Table 2-1. The agreements covered all but a few of the intercity passenger lines that were to remain available in the nation. Four passenger carriers did not join Amtrak: Denver and Rio Grande Western Railroad Company; Georgia Railroad and Banking Company; Chicago, Rock Island and Pacific Railroad Company; and the Southern Railway Company.

Table 2-1

RAILROADS THAT SIGNED CONTRACTS WITH AMTRAK[8,9]

The Atchison Topeka and Santa Fe Railway Company
The Baltimore and Ohio Railroad Company
Burlington Northern Inc.
Central of Georgia Railroad Company
The Chesapeake and Ohio Railway Company
Chicago and North Western Transportation Company
Chicago, Milwaukee, St. Paul & Pacific Railroad
Delaware and Hudson Railway Company
Grand Trunk Western Railroad Company
The Mobile & Gulf Railroad Company
Illinois Central Gulf Railroad
Louisville and Nashville Railroad Company
Missouri Pacific Railroad Company
Norfolk and Western Railway Company
Penn Central Transportation Company
Richmond Fredericksburg and Potomac Railroad Company
Seaboard Coast Line Railroad
Southern Pacific Transportation Company
The Texas and Pacific Railway Company
Union Pacific Railroad

The U.S. Secretary of Transportation originally determined the 21 "endpoints" or cities to be served by Amtrak:

Boston
New York
Washington, D.C.
Buffalo
Chicago
Kansas City
St. Louis
Miami
Tampa
St. Petersburg
New Orleans
Norfolk
Newport News
Cincinnati
Detroit
Houston
Seattle
San Francisco
Oakland
Los Angeles
San Diego

Amtrak actually began operation on the following routes:

Boston to New York
New York to Washington
New York to Buffalo
New York to Chicago
New York to Kansas City via St. Louis
New York to Miami and Tampa/St. Petersburg
New York to New Orleans
Washington, D.C. to Chicago
Washington, D.C. to St. Louis
Norfolk/Newport News to Cincinnati
Detroit to Chicago
Chicago to St. Louis
Chicago to Cincinnati
Chicago to Miami and Tampa/St. Petersburg
Chicago to New Orleans
Chicago to Houston
Chicago to Seattle
Chicago to San Francisco/Oakland
Chicago to Los Angeles
New Orleans to Los Angeles
Seattle to San Diego

Many intercity routes were discontinued when Amtrak began in May 1971. In fact, intercity passenger-train mileage was effectively cut in half.

Since 1971 there have been a number of increases and some reductions in the Amtrak network. Originally, all routes were within the United States. The 1972 amendments to the Act required that lines be extended to two cities in Canada and one in Mexico. Legislation provided that states or local governments could require Amtrak to provide service if they paid two-thirds of the losses; by 1975, there were 11 such trains. Experimental lines were authorized, and the Amtrak Improvement Act of 1973 required that at least one experimental route be initiated every year and be operated for at least 2 years.

On April 1, 1976, Amtrak acquired the 450-mile Northeast Corridor line (Washington, D.C. to Boston) from the Consolidated Rail Corporation (ConRail). Congress appropriated funds to rehabilitate the track, to make other improvements in facilities allowing higher speeds, and to improve safety.

Amtrak was set up as a semipublic corporation to provide rail passenger service on a nationwide basis. It is required to operate on a "for profit" basis, but has not done so. Congress has been providing funding for the development of this vast intrastructure in the form of operational support and equipment procurement since the beginning of Amtrak operations.

Congress established that Amtrak shall have a Board of Directors, consisting of 17 individuals, with 8 members selected by the President of the United States and 3 members elected annually by the common stockholders of the four railroad companies (the Penn Central Transportation Company; Burlington Northern, Inc.; Chicago, Milwaukee. St. Paul & Pacific Railroad; and the Grand Trunk Western Railroad Company). Four members are to be elected by the preferred stockholders as soon as practicable after the issuance of preferred stock. Two additional board members, the Secretary of Transportation and the President of the Corporation, serve "ex officio."

For the most part, Amtrak relies on class I railroads to operate its trains. There have been few changes in the railroads participating in the operation, although some names have been changed through consolidation. The Chicago and North Western Transportation Company no longer participates; the Boston & Maine Corporation and the Central Vermont Railway Inc. now operate trains for Amtrak. Amtrak runs its own trains between Washington, D.C. and Boston; between New Haven and Springfield; and from Philadelphia to Harrisburg, Pennsylvania, where it has acquired that right of way.

Routes

Amtrak serves 480 stations and operates over 25,000 miles of road (see Figure 2-1). Most of the roadway is shared with freight trains and, in some cases, by suburban passenger trains. In FY 1975 there were 34 routes. Table 2-2 lists these routes, together with their length and the number of passenger-miles that each route generated in that year. Several routes share certain lines, for example, those between New York and Washington, D.C.

Equipment

Amtrak inherited from the private railroads a great variety of old equipment. It is buying new cars, but the system still consists overwhelmingly of old equipment--about 1,650 out of fewer than 2,000 cars.[12] The average age of the "inherited" railroad cars is more than 25 years. These include coach, sleeper, diner, baggage, and other types of cars. Most of the cars have been overhauled but, because of their age and weight, are being phased out as soon as they can be replaced by new cars.

Amtrak employs 61 "Metroliner" electric, multiple-unit cars between Washington, D.C., and New York. A total of 492 unpowered versions of that design, called "Amfleet" cars, are scheduled for delivery between 1975 and 1977. In addition, Amtrak has ordered 249 bilevel cars from Pullman-Standard to be used in long distance operations.[13] Deliveries began in June 1977 for these bilevel cars and will continue into 1978. Amtrak expects to buy another 35 cars or a total of 284 bilevel cars.[14]

In 1973 Amtrak purchased three turbine-powered trains (14 cars) produced by United Aircraft, and leased two 5-car turbine trains from a French company. In 1974 Amtrak purchased these 2 and 11 additional 5-car turbine trains, 6 from France and 7 from Rohr Industries.

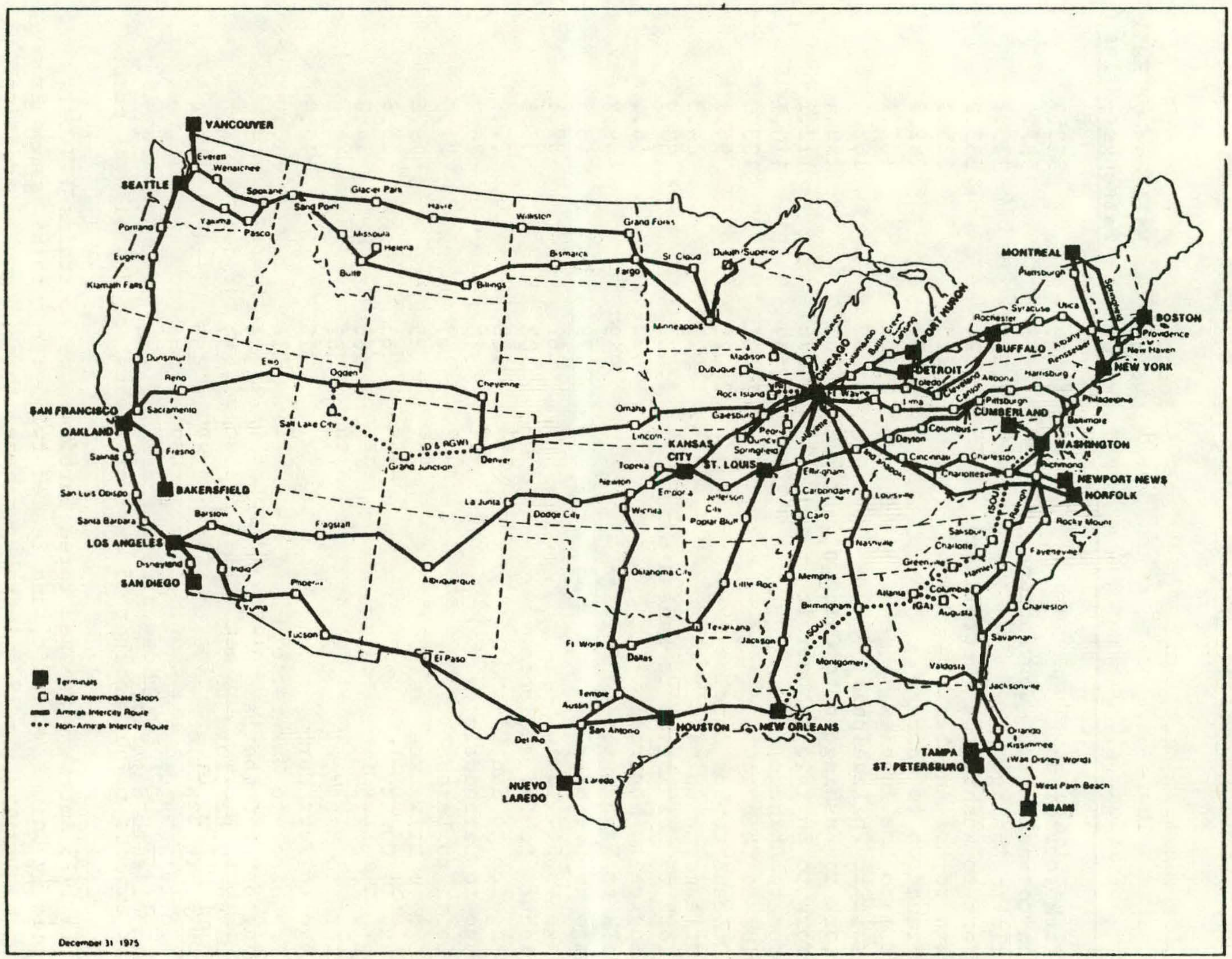

FIGURE 2-1 INTERCITY RAIL PASSENGER ROUTES

National Railroad Passenger Corporation – Amtrak

Table 2-2

NATIONAL RAILROAD PASSENGER CORPORATION ROUTES

Route Length and Ranking by Rail Passenger Miles
(FY 1975)

Route	Route Length (miles)	Millions of Rail Passenger-Miles
New York to Florida	1,388	573.9
Boston to Washington (Conventional trains)	456	537.4
Seattle to Chicago	2,228[a]	335.1
New York to Washington (Metroliner)	224	333.2
Chicago to Los Angeles	2,223	325.2
San Francisco to Chicago	2,409	242.8
Seattle to Los Angeles	1,364	182.1
New York to Philadelphia	90	162.1
New York to Washington to Chicago	961[b]	156.4
New York to Buffalo to Detroit	676	112.2
Houston to Chicago	1,369	110.2
Florida to Chicago	1,601	103.0
New Orleans to Los Angeles	2,022	96.1
New Orleans to Chicago	923	84.3
New York to Washington to Kansas City	1,321	80.9
Washington to Montreal	670	66.1
Norfolk to Washington to Chicago	969[c]	49.2
Chicago to Detroit	279	43.5
Chicago to St. Louis	282	37.1
Harrisburg to Philadelphia	102	35.5
Los Angeles to San Diego	128	27.7
Chicago to Carbondale	310	26.2
St. Louis to Laredo	1,167	21.5
Chicago to Milwaukee	85	19.8
Chicago to Quincy	263	15.8
Seattle to Portland	186	14.0
New York to Montreal	382	12.6
Chicago to Port Huron	318	10.9
San Francisco to Bakersfield	318	10.0
Washington to Cumberland	146	6.1
New Haven to Hartford to Springfield	157	6.0
Vancouver to Seattle	156	4.4
Chicago to Dubuque	182	4.2
Minneapolis to Superior	144	1.2
Special trains		4.1
Route total		3,850.8

[a] The route length is 2,287 miles via Havre on the "Empire Builder."
[b] This mileage is via Rochester, not Washington.
[c] This mileage is via Cincinnati, not Washington.

At the end of 1975, Amtrak had 355 locomotives: 303 diesel, 46 electric, and 6 auxiliary units.[14] About one-half of the fleet was purchased between 1972 and 1975. As is true of the passenger cars, Amtrak has been overhauling the older locomotives, all of which are over 20 years old.

In October 1976, Amtrak staff members listed the following serviceable diesel locomotives:

Number	Model	Horsepower	Nominal Fuel Consumption Rates (gal/locomotive-mile)
150	SDP-40	3,000	2.0
77	E-8	2,250	1.5
25	P 30 CH	3,000	1.9
30	F 40 PH	3,000	1.7
2	FP-7	1,500	1.3
4	FL-9	1,750	1.3
288			

In addition, for heavy demands such as holidays, Amtrak leases locomotives from other railroads such as ConRail for use in the Northeast Corridor.

Most of the new locomotives were adapted from freight locomotives designed by U.S. suppliers because, at present, no U.S. manufacturer of locomotives designs especially for passenger service. These modified locomotives are heavier and consume more fuel than would be required for passenger service.

Service

Aggregate service statistics for calendar year 1975 were as follows:[14,15,16]

88,000 trains (trips)
29,573,718 train-miles
252,938,000 car-miles
7,293 million seat-miles
17.4 million passenger-trips
3,939 million passenger-miles

The following averages computed from these data have limited value in describing so diverse a system as Amtrak but are presented as an aid to perspective:

- The average load factor was 0.54 (passenger-miles per seat-mile)
- The average passenger-trip length was 226 miles.

Trip purposes varied greatly. Consequently, energy intensities per passenger trip were not computed.

Energy Usage

In 1975 Amtrak reported consumption of 79,890,785 gal of diesel fuel and 274,322,779 kWh of electrical energy.[14,15] On the basis of the national average factors explained in Section I, the electrical energy was computed to be equivalent to 21.23 million gal of fuel oil containing 3,094 billion Btu. Using a heating value of 137,300 Btu/gal, the diesel fuel contained 10,969 billion Btu. Total energy consumption was equivalent to 101.12 million gal of diesel fuel and fuel oil, and to 14,063 billion Btu.

Energy Intensity

Total quantities of energy consumed can be related to total quantities of service provided to give global averages or ratios. However, readers should bear in mind that Amtrak operates trains of many kinds under varied conditions. Averages or ratios must therefore be used with caution.

- Service produced per gallon of fuel:
  2.50 car-miles
  72.12 seat-miles
  38.95 passenger-miles
- Energy per car-mile: 66,000 Btu
- Energy per seat-mile: 2,300 Btu
- Energy per passenger-mile: 4,200 Btu

Energy intensity in locomotive-drawn trains is strongly influenced by the match of locomotive power and train length. The composition of Amtrak trains (called "consists") varies by route, time of year, area of the country, and so on. For example, on the Chicago to Los Angeles route (now called the Southwest Limited), the maximum consist is 18 cars: 6 coaches, 6 sleepers, 2 baggage cars, 2 lounge cars, and 2 diners. The usual consist is 14 cars in summer and 10 to 12 cars in winter.

The following discussion treats three train consists and energy usage:[7]

- Old equipment--long-distance service

Cars	Seats
8 coaches (50 seats per coach)	400
2 sleepers (22 seats per coach)	44
1 bedroom car (12 seats per coach)	12
2 baggage cars (no passengers)	--
1 diner (service car)	--
1 lounge car (service car)	--
Maximum number of passengers	456

Power
3 E-8 locomotives

- New equipment--long-distance service

Cars	Seats
6 bilevel coaches (86 seats per coach)	516
1 bilevel coach (104 seats per coach)	104
3 sleepers (22 seats per coach)	66
2 baggage cars (no passengers)	--
1 diner (service car)	--
Maximum number of passengers	686

Power
2 SDP40 locomotives

- New equipment--short-distance (corridor) service

Cars	Seats
5 Amcoaches (84 seats per coach)	420
1 Amcafe (60 seats per coach)	60
Maximum number of passengers	480

Power
1 SDP40 locomotive

Energy intensities for these trains can be computed by assuming that each train experienced the computed average load factor for calendar year 1975 (54%) and consumed fuel at the nominal rates cited above for each locomotive type. The results are:

- Old equipment--long-distance service
  246 passengers at 54% load factor
  2,500 Btu per passenger-mile
- New equipment--long-distance service
  370 passengers at 54% load factor
  1,500 Btu per passenger-mile

  or

  246 passengers at 36% load factor
  2,200 Btu per passenger-mile.
- New equipment-short distance (corridor) service
  259 passengers at 54% load factor
  1,100 Btu per passenger-mile

The comparison of old and new equipment on long-distance routes has been formulated in two ways--each based on an assumption about load factors. If introduction of the new equipment induced an additional 124 persons to use the train, the load factor would remain at 54% and energy intensity would be 1,480 Btu/passenger-mile. If, instead, the new equipment carried the same 246 passengers as the old train, but at a load factor of 36%, energy intensity would be 2,230 Btu/passenger-mile.

Five routes were chosen to illustrate various energy intensities. (See Table 2-3.) The routes reflected some of the variety of equipment in use, the different consists, and the number of routes and stations. The five routes did not represent the worst or the best in terms of energy usage; they represented a diversity of routes and consists from readily available data. (Metroliners had a higher load factor than the Chicago to Los Angeles route shown here; the Oakland to Bakersfield route, for example, experienced a worse load factor than the worst case shown here.) The data, based on a marketing forecast for FY 1976 that was projected from 1974-75 data, were considered conservative.

Given the consists and load factors (and mileage data in the case of the Chicago to Los Angeles route) shown in Table 2-3, the following listing shows the estimated energy intensity for the five routes:

Route	Btu per Passenger-Mile
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

Table 2-3

SAMPLE OF AMTRAK ROUTES, CONSISTS, AND LOAD FACTORS

Route	Miles	Consist	Seats	Load Factor %	Notes
St. Louis to Laredo	1,167	2 E-8 locomotives		51.3	
		2 coaches (@ 48 seats)	96		
		1 sleeper	22		
		1 diner			
		1 baggage dorm			
			118		
Chicago to New Orleans	923	2 P-30CH locomotives		50.0	
		4 coaches	260		
		3 sleepers	34		
		1 diner			
		1 lounge car			
		1 baggage car			
		1 heater car			
			294		
Chicago to Los Angeles	911	2 SDP-40 locomotives		63.4	Chicago to La Junta, Colorado
	1,332	3 SDP-40 locomotives			La Junta, Colorado, to Los Angeles
	450	5 coaches	352		Summer consist:
		3 sleepers (@ 22 seats)	66		Chicago to Kansas City
		2 diners			
		2 lounges			
		2 baggage cars			
			418		
	1,873	1 sleeper[a]	22		Kansas City to Los Angeles
		1 mail car[a]			
			440		

Table 2-3 Continued)

Route	Miles	Consist	Seats	Load Factor %	Notes
New York to Albany	141	1 E-8[b]		47.7	
Buffalo,	438				
Detroit[a]	676	3 coaches (@ 64 seats)	192		
(the "Empire")		1 snack car	50		
			242		
Chicago to St. Louis	282	1 F40PH			
		4 coaches (@ 84 seats)	336	47.7	
		1 Amcafe	56		
			392		

[a] This train terminates at different points.
[b] One FL-9 locomotive is used for 33 miles from Grand Central to Harmon.

Note: These consists are as of October 1976. However, four out of five routes were expected to change consists beginning October 31.

Economic Data

By March of 1976, Congress had authorized $900 million in loan guarantees and $136 million in grants for Amtrak's capital program, of which over $800 million has been spent. In addition, Congress recently appropriated $1.7 billion to renovate the Northeast Corridor. The total amount, including renovation, was $2.5 billion. Federal subsidies of operating expenses since the system's beginning totaled $1.1 billion as of September 30, 1976. Total outlays and commitments to date are more than $3.6 billion.

Financial data for the three recent calendar years are shown below (in thousands of dollars):[14,17]

	1973	1974	1975
Operating revenues	$202,093	$256,910	$252,697
Total expenses	360,720	529,607	605,229
Operating loss	($158,627)	(272,697)	(352,532)

Revenues and expenses per passenger-mile are as follows (in cents):[7]

	1974	1975
Revenue per passenger-mile	6.0¢	6.5¢
Expense per passenger-mile	12.4¢	15.4¢
Federal subsidy (loss per passenger-mile)	6.4¢	8.9¢

These ratios do not reflect state subsidies. As of March 1976, Pennsylvania, New York, Michigan, Illinois, and Minnesota were subsidizing 11 trains.[7]

Table 2-4 shows financial data by route for FY 1975. The routes are ranked by the deficit per rail passenger-mile. These data again show the great diversity among Amtrak routes.

Southern Railway Company

The Southern Railway Company was created in 1894 out of some 30 bankrupt southeastern railroads. Today it comprises 10,500 miles of road in 13 southeastern states, is the sixth largest railroad system in the nation, and is among the most profitable and best maintained railroads in the United States. Its major business is freight, but it also operates one passenger route.

TABLE 2-4

NATIONAL RAILROAD PASSENGER CORPORATION
ROUTE BY ROUTE RANKING BY DEFICIT PER RAIL PASSENGER-MILE[42]
FY 75
($ Millions)

Ranking	Route	Revenue	Fully Allocated Cost[a]	Income/ (Loss)	Millions of Rail Passenger-Miles	Loss per Rail Passenger-Mile
1	New Haven-Hart.-Springfield	$ 0.5	$ 3.0	$ (2.5)	6.0	.4167
2	San Francisco-Bakersfield	0.6	4.1	(3.5)	10.0	.3500
3	Vancouver-Seattle	0.3	1.7	(1.4)	4.4	.3182
4	Washington-Cumberland	0.3	1.8	(1.5)	6.1	.2459
5	Seattle-Portland	0.9	3.9	(3.0)	14.0	.2143
6	Chicago-Dubuque	0.2	1.1	(0.9)	4.2	.2142
7	LA-San Diego	1.5	6.7	(5.2)	27.7	.1877
8	Florida-Chicago	4.5	23.5	(19.0)	103.0	.1845
9	Chicago-St. Louis	2.9	9.3	(6.4)	37.1	.1725
10	Chicago-Milwaukee	1.2	4.4	(3.2)	19.8	.1616
11	Chicago-Pt. Huron	0.6	2.3	(1.7)	10.9	.1560
12	Washington-Montreal	4.5	14.8	(10.3)	66.1	.1558
13	St. Louis-Laredo	1.1	4.3	(3.2)	21.5	.1488
14	NY-Montreal	0.9	2.7	(1.8)	12.6	.1429
15	Harrisburg-Philadelphia	2.0	6.4	(4.4)	35.5	.1239
16	Chicago-Detroit	2.2	7.5	(5.3)	43.5	.1218
17	NY-Washington-Denver	5.2	15.0	(9.8)	80.9	.1211
18	Norfolk-Washington-Chicago	2.3	8.0	(5.7)	49.2	.1159
19	Chicago-Carbondale	1.4	3.8	(2.4)	26.2	.0916
20	Chicago-Quincy	0.8	2.2	(1.4)	15.8	.0886
21	Minneapolis-Superior	0.1	0.2	(0.1)	1.2	.0833
22	NY-Buffalo/Detroit	7.4	16.7	(9.3)	112.2	.0829
23	NY-Philadelphia	7.7	20.8	(13.1)	162.1	.0808
24	NY-Washington-Chicago	10.6	22.6	(12.0)	156.4	.0767
25	Seattle-Chicago	18.8	43.9	(25.1)	335.1	.0749
26	Houston-Chicago	5.6	13.5	(7.9)	110.2	.0717
27	San Francisco-Chicago	14.1	29.3	(15.2)	242.8	.0626
28	Boston-Wash (Conv)	37.4	70.0	(32.6)	537.4	.0607
29	NY-Florida	31.0	65.6	(34.6)	573.9	.0603
30	Seattle-LA	10.4	21.0	(10.6)	182.1	.0582
31	New Orleans-Chicago	3.9	8.4	(4.5)	84.3	.0534
32	New Orleans-LA	4.5	8.6	(4.1)	96.1	.0427
33	Chicago-LA	18.0	33.1	(15.1)	325.2	.0464
34	NY-Wash (Metro)	38.9	43.7	(4.8)	333.2	.0144
35	Special Trains	0.3	0.3	-0-	4.1	-0-
	Route Totals	242.6	524.2	(281.6)		
	State Subsidies	$ 3.9		$ (35.6)		
	Corporate Expense		$ 35.6	$ (35.6)		
	Grand Total	$246.5	$559.8	$(313.3)		

[a]Route allocations represent an allocation of all operating and corporate overhead functional categories with the exception of the general corporate office expense and interest.

Routes

The Southern Railway Company provides rail passenger transportation on a single, 1200-mile route connecting Washington, D.C., and New Orleans. This route, called the "Southern Crescent," serves more than 30 intermediate cities. Until November 28, 1976, Southern also provided passenger service on its "Piedmont" route between Washington, D.C., and Charlotte, North Carolina, a distance of 375 miles.

Equipment

In 1975, Southern averaged 17 locomotives in passenger service. In 1976, Southern had an active fleet of 94 cars for its passenger service: 40 stainless-steel, lightweight coaches; 5 heavyweight coaches; 1 dome coach; 6 coach lounges; 6 diners; 24 sleepers; 3 sleeper lounges; 4 dormitory and baggage cars; and 5 baggage and express cars. For the most part these cars, built in the 1940s and 1950s, are completely refurbished every three years. Most of the cars are required for the regular train consist; the balance are used as replacements while other cars are being repaired or to meet periodic heavier demands for service.[18]

Service

The Southern Crescent runs daily each way between Washington, D.C., and Atlanta, and three days each week between Atlanta and New Orleans. It makes 21 stops between Washington, D.C., and Atlanta, including Charlottesville, Lynchburg, and Danville in Virginia; Greensboro and Charlotte in North Carolina; and Greensville in South Carolina. It makes another 11 stops between Atlanta and New Orleans, including Birmingham, Alabama, and Meridian, Mississippi.

The Piedmont made daily trips each way between Washington, D.C., and Charlotte, North Carolina, until the Interstate Commerce Commission (ICC) allowed its discontinuation. From June 1975 to May 1976, an average of 44 passengers a day rode the train. The average number of passengers aboard the train at any one time was about 22.[19]

In 1975, with both trains in service, Southern Railway reported the following service data:[20,21]

581,768 train-miles
5,503,000 car-miles
234,321 revenue passengers
84,634,117 revenue passenger-miles

The average passenger-trip was 361 miles long.

Energy Usage

The Southern Railway consumed 5,294,500 gal of diesel fuel in its passenger service in 1975.[21] This is equivalent to 727 billion Btu.

Energy Intensity

System average energy intensities for 1975 are as follows:

- Service produced per gallon of fuel:
  1.04 car-miles
  15.98 passenger-miles
- Energy per car-mile: 132,000 Btu
- Energy per passenger-mile: 8,600 Btu

Energy intensity varies considerably with train lengths and loads.

Economic Data

Passenger revenue in calendar year 1975 totaled $5,136,619, or 6.1¢ per passenger-mile.[21] However, operating costs for passenger service exceeded the revenue by a considerable sum. Southern reported in August 1976 that the Southern Crescent was losing about $5.5 million per year, and, according to testimony before the ICC, the Piedmont lost $817,400 in the 12 months ending May 31, 1976.

Auto-Train Corporation

The Auto-Train Corporation was the outgrowth of a three-year study authorized by Congress in 1965 to determine the feasibility of auto-on-train service in the United States. The corporation was formed in 1969 and began operation in December 1971 to provide combined passenger and auto-ferry service for persons who prefer to ride the train and take their automobile with them to Florida.

Routes

At present, the Auto-Train Corporation has two routes; both terminate in Sanford, Florida (between Orlando and Daytona Beach in the eastern central part of the state). One route has its northern terminal at Lorton, Virginia (15 miles south of Washington, D.C.). The Richmond, Fredericksburg and Potomac Railroad handles the northern end of the route to Richmond and the Seaboard Coast Line Railroad takes over for the remainder of the trip. That route is about 850 miles long. The second route has its northern terminal at Louisville, Kentucky, and is about 1,000 miles long. The Louisville and Nashville Railroad handles the trains to Montgomery, Alabama, where Sea-Board Coast Line Railroad again takes over for the remainder of the trip.

Equipment

Auto-Train leases 11 diesel-passenger locomotives and owns 4 diesel switching units. The locomotives are 3,600-hp GE U-36Bs, all built within the past 6 years. They also own 64 passenger-cars and lease 10 from others. The fleet includes the following complement of cars:[22]

Parlor cars	37
Sleeping cars	15
Dining, grill, and tavern cars	16
Nonpassenger carrying cars	6
Total	74

Most of the passenger cars were built between 1948 and 1958, but they have been completely redesigned and refurbished by Auto-Train Corporation.

Auto-Train purchased from Canadian National freight cars of 1956- to 1958-vintage that were converted to auto-carriers. At the end of 1975, Auto-Train had 41 trilevel auto-carrier cars. They have recently borrowed $1.7 million to purchase 20 fully enclosed trilevel cars with increased carrying capacities.

Service

Auto-Train offers daily service in each direction on its Washington, D.C., route. Service on its Louisville route, begun in May 1974, was later reduced from a round trip every third day to once a week (three times a month in the summer). Both trains make nonstop trips. In the spring of 1976, the Louisville run was temporarily suspended because of a shortage of equipment that was caused by two derailments on the Lorton line. In September, Auto-Train signed a trial agreement with Amtrak to attach a 9-car auto-ferry to Amtrak's "Floridian" on the portion of its trip between Louisville and Sanford. This service began on a daily basis in each direction on October 31, 1976. Although Amtrak planned to reschedule the "Floridian," it is likely that stops between Louisville and Sanford will continue with the Auto-Train attachment.

Aggregate statistics for passenger and auto service in 1975 are as follows:[22]

706,317 train-miles
16,741,000 freight car-miles
12,712,000 passenger car-miles
308,662 passenger-trips
267,512,317 passenger-miles

Energy Usage

In 1975, Auto-Train reported consumption of 6,267,742 gal of diesel fuel, or the equivalent of 861 billion Btu.

Energy Intensity

Auto-Train has operated with a fleet of 55 cars but, partially because of the derailments in the spring of 1976, now limits its fleet to 43 cars. Under favorable conditions, trains carry up to 700 passengers and up to 268 autos.[23]

According to statistics published by Auto-Train, it has transported over 1.2 million passengers and 400,000 automobiles since it began operations--an average of approximately 3 passengers for every automobile carried.[24]

The following data reflect energy usage for both passengers and autos:

Service per gallon of fuel:
42.68 passenger-miles plus 14.23 auto-miles.

Energy per passenger-mile and 0.333 auto-mile:
3,200 Btu.

Stated differently, a typical party of three with one auto would travel 14-1/4 miles/gal of diesel fuel. Energy intensity for the entire party of three would be about 9600 Btu per mile. Automobiles of sizes in common use provide similar energy intensities when used by a party of three.

Economic Data

Auto-Train reported passenger and auto revenues of $28,454,750 in calendar year 1975.[20] Its operating revenues were reported by the AAR as $28,967,765 and its operating expenses as $23,905,169. After taxes, its net railway operating income was $1,745,926. Revenue per passenger was reported as $92.19 and revenue per passenger-mile as 10.6¢.[16]

Auto-Train has reported a profit every year except its first.[23] Because of the two expensive derailments in March and May of 1976, however, it lost money in its first fiscal quarter of 1976, which ended July 31.

Denver and Rio Grande Western Railroad Company

The Denver and Rio Grande Western Railroad (D&RGW) operates a 600-mile passenger line between Denver, Colorado, and Ogden, Utah, running one train daily in each direction. Each train makes 12 stops, including one at Salt Lake City.

As of the end of 1975, the railroad owned 40 passenger cars, 31 of which were coaches. Aggregate statistics for 1975 are shown below:[25]

199,143 train-miles
1,302,000 passenger car-miles
238,262 passenger-trips
18,785,123 passenger-miles.

The railroad consumed 532,721 gal of diesel oil in 1975 for its passenger service, equal to 73 billion Btu. Energy intensities were:

- Service produced per gallon of fuel:
  - 2.44 car-miles
  - 35.26 passenger-miles
- Energy per car-mile: 56,000 Btu
- Energy per passenger-mile: 3,890 Btu.

Economic data were not obtained for the D&RGW.

Other Systems

Data on intercity service for the Rock Island cannot be separated from suburban service and is omitted. Data were not obtained on the Georgia Railroad.

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III BOSTON REGION

General

Boston and 79 surrounding communities are served by three heavy-rail transit lines, one light-rail transit network, and two suburban railroads, as well as trackless trolley coaches and buses. At the end of 1975, the rail systems used the facilities and equipment summarized in Table 3-1.[26,27]

Table 3-1

BOSTON REGION FACILITIES AND EQUIPMENT

System	Line Miles	Stations	Cars
Heavy-rail	32.6	44	338[b]
Light-rail	28.9	14[a]	290
Suburban-rail			
B & M	151	50	84 (all RDC)
ConRail	98.6	N/A	119

[a]Plus street stops.

[b]Down from 356 in 1974.

Boston has pioneered the development and use of rail passenger transportation. Horse-drawn streetcars began operation in 1856, electric streetcars were introduced in 1889, and the first subway opened in stages starting in 1897. Most of the present system was constructed before World War II, but expansion and extension projects were resumed in the early 1950s and have continued to the present.

Public control of the transit system began in 1918 and became complete with the formation of the Metropolitan Transportation Authority (MTA) by the State in 1947. MTA became the Massachusetts Bay Transportation Authority (MBTA) in 1964, and its territory was expanded from 14 to 78 communities (now 79).

MBTA operates heavy- and light-rail transit lines as well as buses and trackless trolley coaches. In 1964 and 1965 MBTA entered into contracts to subsidize suburban rail services provided by the Boston and

Maine Corporation and the New Haven Railroad (later Penn Central and now ConRail). MBTA has acquired part of the suburban rail lines and equipment and plans to acquire the remainder.[28]

The Metropolitan Area Planning Council, created by State legislation, represents 101 cities and towns in the Boston area and functions as the project review agency required under the U.S. Office of Management and Budget Circular A-95. The Joint Regional Transportation Committee was organized in 1973 by agreement among five state and regional agencies. In 1975 these agencies entered into a new agreement to serve as the Metropolitan Planning Organization required by the U.S. Department of Transportation.

The Massachusetts Executive Office of Transportation and Construction assumed responsibility for the preparation and annual revision of MBTA's transportation development program in 1975. This responsibility has been delegated to the Central Transportation Planning Staff.[29]

Heavy- and Light-Rail Transit

Routes

Boston's rail transit system has four elements: three heavy-rail lines (Orange, Red, and Blue) and one light-rail line (Green). The four lines use four different kinds of cars and do not interchange equipment. However, all four lines pass through the central business district and intersect one another at four underground stations. Each line intersects two others. Travelers can transfer from line to line without charge. Some travelers have to transfer once or twice to complete a trip.

All four lines cross the central business district and extend to suburban communities in both directions. The Orange and Blue lines have no branches; the Red line branches once; and the Green line branches three times. The three heavy-rail lines have a total length of about 32.6 miles, all in exclusive right-of-way, and 44 stations. The light-rail line has a total length of about 28.9 miles including exclusive right-of-way and line with grade crossing. There are 14 stations and numerous street stops.

Equipment

At the end of 1974 MBTA reported the following distribution of cars to APTA:[23]

Heavy-Rail	No. of Cars
Blue line	88
Orange line	100
Red line	92
	76 Air conditioned
Total	356

Light-Rail	No. of Cars
Green line	290 PCC-type
Grand total	646

Service

Rail transit services are provided about 20 hours each day—from about 5:00 am to about 1:00 am. Headways are generally not longer than 8 to 10 min on weekdays, but are somewhat longer during the early morning and evening hours and on Saturdays and Sundays. Heavy-rail lines operate two- and four-car consists. Light-rail vehicles operate singly on surface routes and in short trains in the downtown subway.[30]

Passenger counts and measurements of trip lengths are not made regularly. However, rough patronage estimates, based on revenue statistics and estimates of average fares,[26] indicate that total annual ridership on the heavy- and light-rail systems was approximately 120 million persons in 1975 (estimated by SRI).

Surveys of trip lengths have not been made since 1963. Estimates of current trip lengths range from 3.1 to 3.68 miles. A consultant to the Central Transportation Planning Staff indicated that an intermediate value (3.4 miles) was a reasonable approximation. On the basis of estimates of patronage and trip length, the heavy- and light-rail transit systems appear to provide about 408 million passenger-miles of service in 1975.

MBTA reported 15,910,047 revenue car-miles in 1975 divided as follows: 5,771,051 miles by PCC cars on surface line, and 10,138,996 miles by PCC cars and heavy-rail cars on rapid transit lines (subways and elevated).[31]

Energy Consumed

MBTA power specialists have estimated that average power consumption per car-mile of revenue service is as follows:[27]

	Average Running Loads (kWh/car-mile)	Car Weights (lb)
Heavy-rail		
Blue line	4.5	48,000
Orange line	5.4	58,000
Red line	8.0	72,000
	10.0 air conditioned	64,000
Light-rail		
Green line	5.0	40,000

The estimated average running loads for the fleet, weighted by number of cars of each type, is 6.0 kWh per car-mile; total energy used by cars in revenue service is estimated at about 95.46 million kWh per year. That is, energy used by cars in revenue service was only about one-half of the total direct energy demand. Energy used by cars in nonrevenue travel and in storage; to operated stations, yards and shops; to generate and distribute electrical power, and for other purposes was about equal to energy used by cars. Separate estimates are not available for each energy use. However, the total amount of energy consumed in generating and delivering power to MBTA can be estimated. MBTA purchases about one-third of the power needed from a public utility company and generates the remainder in two steam plants. In 1975 net purchases of power totaled 70,798,140 kWh.[32] Based on national average heat values, heat rates and losses cited above, the power purchased was equivalent to 5.480 million gal of fuel oil containing 798 billion Btu.

In 1975 the steam power plants consumed 22,160,544 gal of fuel oil with a heat content of 3,191 billion Btu (at 144,000 Btu/gal).* The net output of power to MBTA was 133,125,030 kWh.* The heat rate, 23,970 Btu/kWh,[32] was exceptionally high--more than double the national average for public utilities--and was explained by the fact that the MBTA steam plants are old and of inefficient designs. MBTA plans to retire the steam power plants by 1981. Thereafter, all power will be purchased from the utility company and considerable energy will be saved.

Total power deliveries to MBTA from the public utility and from the steam power plants was 203,923,170 kWh (equivalent to 27.64 million gal of fuel oil containing 3,990 billion Btu). Trackless trolley coaches operated by MBTA are assumed to use 4% of the electrical energy. Rail vehicles account for the following quantities:

26.53 million gal of fuel oil
195.77 million kWh
3,830 billion Btu

---

*MBTA records

Energy Intensity

Because of the lack of detailed data, energy intensities are computed for heavy- and light-rail systems combined. Alternative statements of system average energy intensities are presented here:

- Service per gallon of fuel:
  - 0.60 car-miles
  - 4.52 passenger trips
  - 15.38 passenger-miles
- Energy per car-mile:
  - 12.3 kWh
  - 241,000 Btu*
- Energy per passenger-trip:
  - 1.63 kWh
  - 32,000 Btu*
- Energy per passenger-mile:
  - 0.48 kWh
  - 9400 Btu†

Based on MBTA estimates, the weighted average running load for cars in revenue service was 6 kWh/car-mile. Less than one-half the energy consumed was used by the cars. The difference between 6 and 12.31 kWh is accounted for by conversion and distribution losses and a variety of other energy uses for nonrevenue travel, stations, shops and yards, etc.

Economic Data

MBTA reported costs of transit service and costs per revenue mile in 1975 as follows:[33]

	Total Current Expenses (millions)	Revenue Miles (millions)	Cost per Revenue Mile
PCC cars on surface routes	$ 43.73	$ 5.77	$7.58
All cars on rapid transit routes	72.85	10.14	7.19
Total	$116.58		

*Rounded to thousands

†Rounded to hundreds

Revenue collected was $21.51 million at rapid transit stations and $5.78 million on surface cars, or a total of $27.29 million. Thus, current expenses for rail transit services exceeded rail transit revenues by $89.29 million. Average total cost per passenger-trip via rail transit was about 97¢. Travelers paid average fares of about 23¢. The deficit, an average of 74¢ per passenger trip, was covered by public funds.

Commuter Rail

The Boston and Main Corporation (B&M)[34] operates a suburban rail system serving Boston and suburban communities in the northeast and northwest quadrants of the area. The network radiates from North Station in Boston to some 50 suburban stations and includes four principal lines and several branches. MBTA plans to purchase the rolling stock and some 260 miles of line from B&M. The B&M operates about 973 trains in a typical week: 149 on weekdays, 136 on Saturdays, and 92 on Sundays (and holidays). It carries about 18,000 daily passengers or about 9,000 persons making roundtrips.

Table 3-2

BOSTON AND MAINE, 1975[35]

Road miles operated	151
Cars, self-propelled, RDC	84
Seats, total	9,728
Train miles (000)	1,483
Train hours (000)	45
Car-miles (000)	3,043
Diesel fuel for train operations, gal (000)	2,177
Passenger trips (000)	4,766
Passenger-miles (000)	77,841
Average speed, mph	33.0
Average passenger trip, miles	16.3
Seats per car	115.8
Seat-miles (000)	352,410
System load factor, %	22
Energy consumed, Btu, (at 137,300 Btu/gal)(billions)	299

Alternate statements of energy intensities for the B&M are presented here:

- Service per gallon of diesel fuel:
  - 1.40 car-miles
  - 2.19 passenger-trips
  - 35.76 passenger-miles
- Total energy per car-mile: 98,000 Btu
- Total energy per passenger-trip: 62,900 Btu
- Total energy per passenger-mile: 3,800 Btu

It is noteworthy that the B&M uses only rail diesel cars (RDCs). Consequently, data on energy intensities for the B&M may be the best information available on system average energy intensities for RDC cars. Energy intensity per seat mile is 848 Btu.

ConRail operates a suburban rail system serving Boston and suburban stations south of Boston. Some trains also provide intercity service to Springfield, Massachusetts and Providence. Rhode Island. The network includes four principal lines and one branch, and has a total length of 98.6 miles.[36] MBTA owns 145 miles of rail line on the southside. ConRail operates 25 locomotives, 111 coaches and 8 RDC cars, all owned by MBTA. ConRail operates about 510 trains in a typical week: 94 each weekday, 38 on Saturdays and 2 on Sundays. The system serves about 12,500 daily passengers, or 6,250 persons making roundtrips. Annual patronage is reported by MBTA to be 2,900,000 person-trips or 1,450,000 roundtrips. Data are not available on energy usage by ConRail in the Boston area. Consequently, energy intensities have not been computed.

Economic data, combined for the two railroads, are taken from MBTA's annual report. In 1975 the total patronage was 7.4 million passenger trips and the cost of rail service was $21.9 million. Fares totaled $7.0 million: $4.8 million was collected by B&M and $2.2 million was collected by ConRail. In addition, MBTA paid the two railroad subsidies totaling $14.9 million. Total cost averaged $2.96 per passenger-trip. The average fare was 95¢ and the average subsidy was $2.01 per passenger-trip.

Innovations

MBTA is in the process of replacing PCC cars with newly designed light-rail vehicles. See discussion of vehicles in the San Francisco Region, Section IX.

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IV CHICAGO REGION

General

Chicago and its suburbs are served by one heavy-rail rapid transit system and eight suburban railroad systems, as well as bus lines. At the end of 1975, the rail systems consisted of the lines shown in Table 4-1.*

Table 4-1

CHICAGO REGION LINES

System	Line Miles	Stations	Cars
Heavy-rail			
Chicago Transit Authority	90.2	142	1,093
Suburban rail			
Burlington Northern	38.0	26	124
Chicago & North Western	171	65	280
Chicago, South Shore & South Bend[a]	88.0	n.a.	54
Illinois Central Gulf	62.6	59	165
The Milwaukee Road	106.1	45	103
Norfolk & Western	23.2	10	8
ConRail (Penn Central)[a]	43.6	10	13
Rock Island Lines	46.7	30	93
Suburban rail total	579.2	n.a.	840

[a]Not described in this research.

Mass transportation in Chicago began in 1859 with horse-drawn railcars. The first electric overhead trolley cars went into service in 1890. In 1914 the lines of the numerous private railway companies were coordinated under the management of the Chicago Surface Lines--a milestone in local transportation history--thus making it the largest surface transportation system in the United States.

*Compiled by SRI from various sources. Sources do not always agree regarding lines, stations and cars.

The Chicago Rapid Transit Company, consisting of four elevated lines (the famous "L" system), began operation in 1892 with steam locomotives. The switch to electric power in 1895 on the Metro Line inaugurated the first electrically operated heavy-rail transit system in the world.

The Chicago Surface Lines (CSL) and the Chicago Rapid Transit Company (CRT) were placed in receivership in 1926 and 1930, respectively. Both were purchased by the Chicago Transit Authority (CTA), a municipal corporation formed in 1947, to help solve the financial difficulties of the CSL and CRT. CTA purchased the Chicago Motor Coach Company in 1952. Thus began the changeover in rail passenger transportation from private to public ownership. The CTA has the power to acquire, construct, own, operate, and maintain for public service a local transportation system serving the metropolitan area of Cook County, Chicago and 36 surrounding suburbs.

During 1947 to 1974, the CTA extended the route miles of the surface system and modernized its plant and equipment. Two subways (the State Street and the Dearborn Street subways) were built and financed by the city for the CTA. A third subway, the Congress (West Side) is an extension of the Dearborn Street subway. It was paid for by the city.

The CTA had no taxing power and since the fare box revenue did not keep up with rising costs, CTA was burdened with a rising deficit. To relieve the financial straits of both the CTA and the suburban railroads, as well as suburban bus carriers, the Illinois State Legislature passed the Regional Transportation Authority (RTA) Act in 1974. A referendum gave the Authority power to preserve and improve public transportation in six counties (Cook, Du Page, Kane, Lake, McHenry and Will) through purchase of service agreements, grants to transportation agencies, or operation of systems. The board of Directors of the Authority, composed of appointees by the Mayor of Chicago and the Country Boards, aims to improve transportation in northeastern Illinois by coordinating the various schedules and routes of the city and suburban systems, integrating the various fare systems, providing for optimal ridership at fair rates, and reimbursing the CTA and private transportation companies for losses incurred.

The RTA Act did not specifically place control of the CTA under the RTA; however, as a practical matter, the RTA is now the CTA's sole source of operating money over and above system-generated revenue. The RTA also extends its protective umbrella over six privately owned suburban railroads that provide commuter service to downtown Chicago from as far away as Kenosha, Wisconsin, and South Bend, Indiana. However, jurisdiction of the RTA ceases at the state line. The Rock Island Lines receives 100% deficit funding from the RTA; the other six railroads all receive some financial assistance. Because of the lack of data, the Chicago, South Shore and South Bend lines and the ConRail (Penn Central) lines have not been analyzed in this research.

Heavy-Rail Transit

Routes

The CTA operates seven routes during peak travel hours and has a total of 89.4 miles of revenue line and 0.8 mile of nonrevenue lines.[37] Of these 10.1 miles are underground, 39.5 miles are elevated, and 40.6 miles are at grade.[37] Most of the line is double track. There are 142 stations with an average spacing of 0.63 miles.[38]

Equipment

The 1976 CTA car fleet consisted of 1,093 cars from six different series, as shown in Table 4-2.

Table 4-2

CHICAGO TRANSIT AUTHORITY CAR FLEET

	1947-48	1950-59	1959-60	1964	1969-70	1976
Number	4	708	47	180	150	4[a]
Series	51,53 54,75	6001-6722	4-50	2001-2180	2201-2350	2401-2600[a]
Weight	92,700 to 94,800	42,700 to 44,350	46,800 to 48,500	48,400	45,000	50,500
Length	88' 7-1/2"	48'0"	48'0"	48'0"	48'0"	48'0"
Width	9'4"	9'4"	9'4"	9'4"	9'4"	9'4"
Height	12'2"	11'10"	11'10"	12'0"	12'0"	12'0"
Seats	96	50[b]	46	49[b]	49[b]	47[b]
Horse-power	440	220	220	400	400	440

[a] 200 being built; 4 cars in test revenue service in 1976

[b] Per car average

In general, the CTA cars are small and lightweight when compared to most heavy-rail rapid transit cars. Short cars are required because the track layout includes turns of small radius, especially on the elevated structure over streets and alleys within the Central Business District (CBD). Seven hundred fifty one cars--series 4-50 and 6001 to 6722 except two pairs--were converted from PCC streetcars to their heavy-rail design. Four cars (51, 53, 54, and 75) are three-compartment, articulated units. Cars 2001-2180, 2201-2350, and 6001-6722 (1039 cars) are permanently coupled in married pairs. The CTA is purchasing 200 new cars (numbered 2401-2600) most of which will be delivered in 1977. Three hundred thirty series 2000 and 2200 cars are airconditioned. The 200 new cars will also be airconditioned. All single cars and married pair cars are double-ended, i.e., have cabs at each end of each car or pair. All cars have cab signal and speed control equipment except for 86 cars which are used in the middle of trains. All cars draw 600 Vdc power from the third rail except for approximately 2 miles of overhead catenary at the end of the Stokie Swift route.

Service

Heavy-rail rapid transit service is provided on seven routes (Table 4-3).[37]

Table 4-3

CTA RAPID TRANSIT SERVICE

Route	Route Length (1/2 Roundtrip Length)[a]	Number of Stations	Average Spacing Between Stops[e] (miles)
North-south	23.7[b]	42	0.55
West-northwest	27.4	42	0.59
West-south	21.4[c]	28	0.77
Ravenswood	9.6[d]	27	0.47
Stockie Swift	4.9	2	4.93
Evanston	3.9	22	0.49
Loop elevated	2.0	9	0.22

[a]Includes turnback travel

[b]This includes ½ mile on the loop. SRI estimate.

[c]This includes 1 mile on the loop. SRI estimate.

[d]This includes 2.0 miles on the loop. SRI estimate.

[e]For service with the most stops. Trains do not stop at every station.

The heavy-rail system operates 24 hr a day but some routes are discontinued during off-peak periods. Most routes have A and B trains. A trains stop at some stations but not at others; B trains stop at all stations not served by A trains, plus some that are served by A trains. During peak hours, the Evanston route runs express trains to the Loop. Average train headways vary from 2.4 min during peak periods on one route to 45 min in early morning on another route. Train lengths vary from a maximum of eight cars during peak periods to one car or a married pair during off-peak periods. During weekday peak periods in September 1976, 916 cars were in service; during base periods, 298 cars were in service.

In 1975, CTA generated 49.50 million revenue car-miles at an average service speed of 25.13 mph. Nonrevenue car-miles consisted of 226,000 car-miles or 0.5% of total car-miles. On each weekday of 1975, an average of 922 rail cars operated 162,196 car-miles. During 1975, the system transported 166 million passengers with an estimated average person trip length of 6.9 miles. Total passenger-miles was about 1,078 million. (Operating statistics are summarized in Table 4-4.)

Table 4-4[39,40]

CTA OPERATING STATISTICS

	CY 1975
Revenue car-miles	49,496,982
Service car-miles	225,835
Total car-miles	49,722,817
Revenue passengers	89,000,000[a]
Transfer passengers	54,000,000[a]
Nonrevenue passengers	5,000,000[a]
Total passengers	148,000,000[a]
Average passenger trip length (miles)	6.9[b]
Total passenger-miles	1,078,000,000
Average passenger load per car	21.7
Average load factor @ 49 seats/car	44%

[a] CTA, Rail System Operating Facts, OP-X76336, 19 October 1976.

[b] SRI estimate based on CTA Operating Data--1974, OP-X75264.

In November 1975, a CTA survey counted 527,300 passengers on a typical weekday, 249,000 passengers on a typical Saturday, and 138,000 passengers on a typical Sunday. The three larger routes (i.e., north-south, west-northwest, and west-south) carried 86% of the weekday passengers. A 24-hr traffic check in 1970 indicates that patronage distribution by time of day is:

Owl	12:00 pm - 6:00 am	4%
AM rush	6:00 am - 9:00 am	32%
Midday base	9:00 am - 3:00 pm	20%
PM rush	3:00 pm - 6:00 pm	32%
Evening	6:00 pm - 12:00 pm	12%

Two-thirds of all rides occur during six hours--i.e., during the two 3-hr rush periods.

Energy Usage

Total ac energy purchased was 260,152,061 kWh for CY 1975. Electrical energy used for operation of the passenger vehicles was 228,899,047 dc kWh (see Table 4-5). The CTA purchases its power from Commonwealth Edison, which uses coal to produce about 65% of its energy and nuclear energy to produce the balance. However, to compare the systems, energy consumption has been expressed as equivalent quantities of fuel oil and as the heating value of that fuel oil.

Table 4-5

ENERGY USAGE[40]

Total energy purchased, ac	260,152,061 kWh
Net kWh, dc, for operation of cars	228,899,047
Fuel equivalent to total energy purchased	20.13 million gal
Equivalent heat content	2,934 billion Btu

Based on national average heat rates and losses (11,278 Btu/kWh) and equivalent fuel oil required (0.07739 gal/kWh), in 1975 the CTA used electrical energy equivalent to 20.13 million gal fuel oil or 2,934 billion Btu.

According to CTA engineers, about 5% of the energy purchased (13 million kWh) is used by fixed plants, including stations, shops, and maintenance crews. About 7% of the remainder (18.2 million kWh) was lost in ac to dc conversion in 1975.[36] CTA engineers estimate that conversion losses have been reduced about 50% by installation of silicon controlled rectifier substations.

The RTA reports that the "loss in transmission from power plant to the CTA is 6.7% as compared to the national average at 8.0%[41] This suggests that the equivalent calculations used in this analysis may slightly overstate actual energy usage. However, a correction was not made.

Energy Intensity[40]

Based on total energy purchased, the system average energy intensities have been compiled and are stated, in equivalent terms, as follows:

- Service per gallon of fuel oil:
  - 2.47 car-miles
  - 7.35 passenger trips
  - 53.55 passenger-miles
- Total energy per car-mile
  - 5.23 kWh
  - 59,000 Btu
- Total energy per passenger trip:
  - 1.76 kWh
  - 20,000 Btu
- Total energy per passenger-mile:
  - 0.24 kWh
  - 2,700 Btu

Energy intensities vary by time of year. RTA has estimated that energy used by cars averaged 4.7 kWh (dc) per car-mile over the entire year and varies as follows: 6.2 kWh per car-mile in January, 4.1 kWh per car-mile in May, and 3.9 kWh per car-mile in August.[41] The use of heaters in the cars and longer car warmup time probably explains the higher winter figure.

Energy intensities also vary with load factors and route conditions. The RTA[41] estimates that the lowest energy intensity for operation of cars is 0.050 kWh dc per passenger-mile based on crush loading of vehicles on a line with long station spacing and little curvature. This is one-fifth the system average of 0.21 kWh dc per passenger-mile.

There are undoubtedly significant differences among cars. The newer cars (class 2000 and 2200) are heavier than the older cars and may therefore have higher energy consumption per car-mile. Airconditioning of new cars also increases energy intensity per car-mile during warm weather. Detailed studies would be required to assess the energy impact of car weights, load factors, breaking, air conditioning and station spacing on energy usage for car operation.

The CTA purchases ac power at its substations and converts to dc at an efficiency of 93%. RTA reports that "energy losses in the CTA distribution system, which links trains with substations can be considered negligible.[41]

Economic Data

The following economic data are taken from CTA reports to the American Public Transit Association (APTA). The 1974 financial data are used because, for 1975, CTA reported only total revenue and did not separate rapid transit revenue from bus revenue.

	1974
Revenue	
Passenger revenue	$46,292,000
Other operating revenue	952,000
Total operating revenue	47,244,000
Operating expense	90,484,000
Operating loss	43,240,000
Operating expense per car-mile	$1.85
Average fare by revenue passengers	0.32
Average cost per passenger trip	0.61
Loss per passenger trip	0.29

Losses are covered by subsidies, but the CTA does not separate rail subsidies from total (rail plus bus) subsidies. In 1974 total subsidy was $62.6 million to cover a $64.3 million loss. In 1975 the total CTA subsidy had increase to $91.3 million and total loss had increased to $93.8 million. Energy cost in 1974 was $4.66 million, which was 5.2% of operating expense.

In 1975, CTA purchased ac power at an average cost of 2.05¢ per kWh. The operational and maintenance cost of substations is relatively high. As a result, dc power had an average cost of 2.89¢ per kWh, an increase of 41%.

Innovations

The CTA currently has an Urban Mass Transportation Administration Section 9 grant to do a yards and shops study. One objective is to limit deadhead car-miles, but the CTA reports that deadhead mileage is relatively low because yards are located at the end of most lines. The CTA is also converting 14 rotary and 2 mercury-arc substations to silicone rectifiers. This change will increase conversion efficiency and reduce both energy usage and cost of dc energy.

Burlington Northern (RTA)

Suburban Rail

Routes

The Burlington Northern operates suburban service from Chicago Union Station to Aurora, Illinois, 38 line miles west. Most of the line is 3-track. The line has 26 stations with an average spacing of 1.52 miles.

Equipment

In 1975, the annual report to the Interstate Commerce Commission showed that 124 coaches were assigned to suburban service, although the report lists a total of 165 passenger coaches in service. It is understood that 41 coaches are for sale or conversion. All but 5 of the 124 coaches in suburban service are stainless steel, bilevel coaches. The bilevel cars are electrically heated and air-conditioned, seat 148 passengers, weigh approximately 122,000 lb, and were manufactured between 1950 and 1973.

All of the BN suburban trains operate in the push-pull mode, in which locomotive units push inbound trains and pull outbound trains. Twenty-six coaches contain control cabs. The number of locomotives recorded in the annual report to the ICC for 1975 was 25. The locomotives contain an average hosepower of 2,376.

Service

The Burlington Northern operates an extensive weekday schedule, based heavily on serving the suburban workers commuting to and from Chicago. Over one-half of the daily trains operate in the morning and afternoon commuting periods and most of these operate in the peak directions, i.e., inbound in the morning and outbound in the afternoon. In 1974, 64 trains were operated per day with 31% between 7 and 9 am and 30% between 4:25 and 6:35 pm.

Service in the am and pm peak directions is at intervals of approximately 20 min. Midday service and "reverse" direction service in peak hours is operated every 60 to 75 min. There is a 90-min service gap at the noon hour. Evening service is operated every 2 hr inbound and every 75 min outbound.

On Saturdays and Sundays, the number of trains scheduled are about one-third and one-half, respectively, of weekday service. Saturday service to Chicago is operated on headways varying from 90 min to 2 hr and from 1 to 2 hr on outbound trips. On Sunday, 10 roundtrips are operated between Union Station and Aurora at 2-hr intervals.

Throughout the week, service begins at 5:00 am and continues until 2:15 am the following morning, providing almost continuous service.[42]

Service statistics are presented in Table 4-6.

Table 4-6

BURLINGTON NORTHERN COMMUTER SERVICE FOR 1975[43]

Car-miles	3,915,000
Revenue passenger trips	12,294,067
Average passenger trip length, miles	18.71
Total passenger-miles	229,991,833
Average passenger load per car	58.7
Average load factor @ 119 seats per car	49%
Average number of cars per train	5.5

Energy Usage

In 1975, the BN purchased 3,186,593 gal of diesel fuel for passenger operations.[43] This is equivalent to 438 billion Btu of energy. Other energy usage data was not reported.

Energy Intensity

Based on diesel fuel used, the system's energy intensities have been compiled and are stated in equivalent forms, as follows:

- Service per gallon of fuel:
  1.23 car-miles
  3.86 passenger trips
  72.17 passenger-miles
- Total energy
  112,000 Btu
- Total energy per passenger trip:
  36,000 Btu
- Total energy per passenger-mile:
  1,900 Btu

Economic Data

Economic data for 1975 was not obtained. In 1973 the BN commuter operation received $7,705,000 in passenger revenue and $7,755,000 in operating revenue. Operating expenses were $9,249,000, leaving an operating deficit of $1,494,000. In 1975, the BN expended $913,134 for diesel fuel at 28.7¢/gal.

Chicago & North Western

Suburban Rail

Routes

The Chicago and North Western (C&NW) is the largest suburban road in the Chicago metropolitan area in terms of route miles, revenues, and passengers carried. Suburban service is provided on three separate lines originating at Chicago's Madison Street Station. The North line runs to Kenoska, Wisconsin; the Northwest line runs to Harvard, Illinois with a fork branching off to Richmond, Wisconsin; and the West line runs to Geneva, Illinois.[44]

The number of stations for the combined three lines is 65 and the average spacing between stations is 2.67 miles. C&NW reports the line miles for the three routes to be 171. Some of this mileage is in Wisconsin. RTA does not have jurisdiction over Wisconsin tracks and does not report data for that part of the service. ICC data reflects all service provided by the C&NW.

Most of the system is double track or triple track. There is 2.9 miles of four-track line out of the Chicago Terminal and approximately 18 miles of single track on the Richmond Branch of the Northwest line.

Equipment

The commuter fleet consists of 59 diesel locomotives and 280 coaches.[45] The locomotives vary from 1500 hp to 2250 hp and weigh about 190 tons. The bilevel coaches, made between 1955 and 1970, weigh an average of 125,000 lb. Seating capacity is 160. Sixty-four of the coaches contain control cabs for push-pull operation. The locomotives have been modified to provide electric power to heat, light, and air-condition the coaches.

Service

The North and Northwest lines offer services approximately from 6:30 am to 2:00 am. The West line operates approximately from 5:30 am to 10:30 pm. During peak-hours on the North and Northwest lines, most stations are served every 15 to 20 min, while stations on the West line are served every 20 to 25 min.

In 1974, 192 trains were operated each weekday. About 53% of all trains operate during peak hours--between 7 and 9 am and 26% between 4:30 and 6:30 pm. In 1975, there was an average of 11,700 passenger trips per day on about 59 trains on the West line, 18,900 passenger trips on about 67 trains per day on the Northwest line, and 11,700 passenger trips on about 66 trains per day on the North line.[44]

Only two round-trip suburban trains operate on weekdays to the Lake Geneva, Richmond branch. Speed of operation over all C&NW lines averages 27 mph.

Service statistics are presented in Table 4-7.

Table 4-7

C&NW SERVICES FOR 1975[45]

Car-miles	11,106,000
Revenue passenger trips	25,076,129
Average passenger trip length (miles)	21.19[a]
Total passenger-miles	531,311,661
Average passenger load per car	47.8[a]
Average load factor @ 160 seats per car	30%[a]
Average cars per train	4.8

[a]Derived

Energy Usage

In 1975, the C&NW purchased 7,376,363 gal[45] of diesel fuel for passenger service (equivalent to 1,013 billion Btu). Data on other energy usage was not reported.

Energy Intensity

Based on diesel fuel used, the system's average energy intensities have been compiled and are stated, in equivalent forms, as follows:

- Service per gallon of fuel:
  1.51 car-miles
  3.40 passenger trips
  72.03 passenger-miles
- Total energy per car-mile:
  91,000 Btu
- Total energy per passenger trip:
  40,000 Btu
- Total energy per passenger-mile:
  1,900 Btu

Economic Data

Economic data for 1975 were not located. Economic data for 1973 were used instead, although it is not representative of 1975 operations. In 1973, the C&NW commuter operations had a surplus, but in 1975 it had a loss. In 1973, the C&NW commuter operations received passenger revenue of $23,236,000 and total operating revenue of $24,278,000. Operating expenses totaled $20,363,000, leaving an operating surplus of $3,915,000.

Illinois Central Gulf

Suburban Rail

Routes

The Illinois Central Gulf provides suburban rail service on two separate lines: the Commuter Division, which is the main line of the system, and the Joliet Line. Two spurs provide service from the main line to South Chicago and Blue Island. The main line is 17 miles long and includes 14.5 miles of single track and 2.5 miles of double track. The South Chicago spur starts about 9 miles from downtown and has 4.3 miles of double track. The Blue Island spur starts about 15 miles from downtown and has 4.3 miles of single track. The Commuter Division has a total of 25.6 miles of line and 49 stations with an average spacing of 0.8 mile. The Joliet line has 37.2 line miles and 10 stations with an average spacing of 4.1 miles. The ICG has a total of 62.6 miles of suburban line and 59 stations.[46]

Equipment

The fleet consists of two 1,500 hp diesel locomotives, and 165 cars (3 coaches, 32 old MU electric cars, and 130 MU electric bilevel cars). The bilevel cars, made in 1972, are air-conditioned, seat 156 passengers, and weigh 132,000 lb. The 32 old MU coaches seat 84 passengers and weigh 90,200 lb. The coaches seat about 100 passengers.* The total ICG car fleet averages 140.8 seats per car.

Service

The ICG provides more frequent service during peak and non-peak periods than any other suburban commuter rail service in the Chicago area. The schedule in peak and off-peak periods is also more balanced than those of others in the region, with 40% of ICG trains operating the peak periods, compared to 50% on other Chicago railroads.[46]

In 1974, 202 trains were run each weekday: 200 on the Commuter Division and only 2 on the Joliet line. The morning peak schedules (7 to 9 am) includes 21% of the trains and the evening peak (4:30 to 6:30 pm) includes 19%[47] Service begins at 4:20 am with a north-bound train and continues until 3:00 am when the last southbound train departs, seven days a week. In the direction of peak load traffic service is frequent, with 10- to 15-minute headways. "Reverse" direction trains in the morning peak operate on headways of 30 min or less, while headways of "reverse" direction trains in the evening peak are 60 min. Midday schedules are on 30-min headways and evening schedules are hourly.[47]

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*SRI estimate.

Saturday service at midday is every half-hour, and in the evening every hour; fewer trains operate during the peak periods. Sunday and holiday service operates hourly. The current system load factor for the morning peak averages 94.9% During the "peak of the peak" some trains have load factors as high as 125%.

The ICG's report to the ICC indicates that the total car-miles for 1975 was 4,664,000. (See Table 4-8.) The car-miles reported include some nonpassenger car-miles (mail cars etc.,) but it is assumed that the mileage of these nonpassenger cars is negligible. Service statistics are presented in Table 4-8.

Table 4-8

IGC SERVICE STATISTICS[41,46]

Car-miles	4,664,000
Revenue passenger trips	14,473,727
Average passenger trip length, miles	19
Total passenger-miles	277,807,377
Average passenger load per car	60[a]
Average load factor @ 140 seats per car	0.43
Average number of cars per train	3.0

[a] Reported 62.9 for 1974.

Energy Usage

Electric power purchased for car operation in 1975 was 52,436,449 kWh ac. Based on national average heat rates and losses, the ICG used a total energy equivalent of 4.06 million gal of fuel oil or 591 billion Btu. The diesel fuel used by the ICG in 1975 was 106,064 gal at a cost of $32,780.[41] Energy usage and results of equivalence conversions are summarized in Table 4-9.

Energy Intensity

In 1975, electric cars operated 4,608,000 car-miles and consumed 52,436,449 kWh ac. This is an average of 11.4 kWh ac purchased per car-mile.[41]

The average vehicle mile per kWh dc for recent years was reported to be 11.57.[46] In January the average car-mile-per-dc-kWh was 14.14 miles, while in August it dropped to 10.07 car-miles per dc kWh. Presumably, the difference is explained by an excess of heating energy over air-conditioning energy.

Table 4-9

ICG ENERGY USAGE

Electric:	
Energy purchased for car operation, ac	52,436,449 kWh
Net energy applicable to cars, dc	49,800,000 kWh
Equivalent fuel oil consumed	4,060,000 gal
Equivalent heat value of fuel oil	591 billion Btu
Diesel:	
Diesel oil purchased	106,064 gal
Equivalent heat value	15 billion Btu
Totals:	
Equivalent fuel consumed (electric & diesel)	4,170,000 gal
Equivalent heat value	606 billion Btu

Locomotive-drawn trains operated 56,000 car-miles and 18,796 diesel locomotive miles, and consumed 106,064 gal of diesel fuel. This is equivalent to 1.89 gal/car-mile and 5.64 gal/locomotive mile.

Based on electrical energy and diesel fuel used, the system's average energy intensities have been compiled and are stated, in equivalent forms as follows:

- Service per gallon of oil:
  1.12 car-miles
  3.47 passenger trips
  66.62 passenger-miles
- Energy per car-mile
  130,000 Btu
- Energy per passenger trip
  42,000 Btu
- Energy per passenger-mile:
  2200 Btu

Economic Data

Economic data for 1975 was not located, but an RTA report specified that FY 1973 passenger revenue was $10,468,000 and total operating revenues were $10,946,000. Total operating expenses were $16,053,000, creating a $5,107,000 operating deficit. Subsidies of $777,000 were received.

In 1975, $32,780 was spent on diesel fuel, an average 30.9¢/gal. Fuel cost was 59¢/passenger-coach mile or $1.74/locomotive-mile. Also in 1975, $1,776,196 was spent for electrical power for car operation, an average of 3.39¢/kWh. Power cost 38.6¢/car-mile for the electric cars.

The Milwaukee Road

Suburban Rail

Lines and Equipment

The Milwaukee Road (Chicago, Milwaukee, St. Paul and Pacific Railroad Company) provides commuter service between Chicago and Elgin, Illinois (West line) and between Chicago and Walworth, Wisconsin (North line). The West line consists of 36.6 miles[48] of double track; 7.0 miles are elevated and the balance is at grade. There are 20 stations[49] with an average spacing of 1.9 miles.

The North line consists of 32 miles of double track and 41.5 miles of single track.[48] Nine miles are elevated and the balance is at grade. Of the elevated mileage, 4 miles near the downtown terminal are common to both North and West lines. The North line has 25 stations, with an average spacing of 3.06 miles. The North and West lines combine to give a total of 106.1 line miles.[49] (The 4-mile common section is counted only once.)

The suburban rail fleet consists of 77 diesel electric locomotives and 103 bilevel coaches.

Of the bilevel coach fleet, 62 coaches were built between 1961 and 1965 and 41 were built in 1974. The entire fleet is air-conditioned. The average number of seats per passenger car is 153.7.[50] Thirty-four coaches contain cabs and are push-pull control units. These cars have 147 seats and weigh 107,100 lb. The remaining 69 cars have 157 seats each and weigh 103,200 lb.

Fifteen EMD diesel electric locomotives were manufactured in 1974 and seven EMD diesel electrics were manufactured in 1961. The diesel locomotives have been modified to generate electrical energy to light, heat, and air-condition the coaches.

Service

Both lines of the Milwaukee Road suburban service are heavily orientated toward serving commuters traveling to and from Chicago, About one-half of the daily trains operate in the morning and afternoon peak periods, most in the peak direction. In 1974, 81 trains were scheduled each weekday with 37% operating between 7 and 9 am and 38% between 4:30 and 6:30 pm.[48]

Service in the peak directions on the North and West lines is provided at intervals of 20 to 30 min at most stations. Service in the "reverse" direction during peak hours is operated at 1-hr headways and the frequency of midday service varies from 45 min to 3 hr. Evening service headways range from 1 to 2 hr.[48]

Saturday, Sunday, and holiday service are also provided with headways ranging from 1 to 4 hr. The number of trains scheduled is about one-third to one-half as many as are scheduled for weekday service. Service begins at 5:00 am and continues until 1:30 am the following morning on weekdays and Saturdays. Sunday and holiday service begins at 6:30 am and continues until 1:30 am the following morning.[48]

The Milwaukee Road equipment is interchangeable on the North and West lines. As shown below, 19 engines and 90 passenger coaches are required during peak commuting periods. On Saturdays, 16 coaches and 8 locomotives are required and Sundays require 8 coaches and 4 locomotives.[48]

Average service speed on the North line is 30 mph and on the West line about 27 mph.

Service statistics for 1975 are presented in Table 4-10.

Table 4-10

MILWAUKEE ROAD 1975 SERVICES (RTA)[50,51]

Car-miles	3,636,952
Revenue passenger trips	7,867,515
Average passenger trip length, miles	23.15
Total passenger-miles	182,140,489
Average passenger load per car	50.1
Average load factor @ 153.7 seats per car	33%

Energy Usage

In 1975, the Milwaukee Road used 3,782,446 gal of diesel fuel for suburban train operations (equivalent to 519 billion Btu energy).

Energy Intensity

Based on train operation used, the system's average energy intensities have been compiled and are stated in equivalent forms as follows:

- Service per gallon of fuel oil:
  0.96 car-miles
  2.08 passenger trips
  48.15 passenger-miles
- Energy per car-miles
  143,000 Btu

- Energy per passenger trip:
  66,000 Btu

- Energy per passenger-mile:
  2,800 Btu

Economic Data

In 1975, the Milwaukee Road operating revenue for passenger operations was $14,058,000. Information on passenger operating expenses was not located for 1975. In FY 1973, the Milwaukee Road suburban system earned $6,342,000 in passenger revenue and $6,355,000 in total operating revenue. Operating expenses in 1973 totaled $7,964,000, creating a $1,609,000 operating deficit. Subsidies received totaled $354,000 in 1973.

In 1975, diesel fuel cost $1,179,411, an average 31.2¢/gal. The fuel expense equalled 8.4% of operating revenue. On the average, the fuel costs 32¢/car-mile, 15¢/passenger-trip, and 0.65¢/passenger-mile.

Norfolk and Western

Suburban Rail

Lines and Equipment

The Norfolk and Western (N&W) operates a 23.2 mile suburban line running southwest from Chicago to Orland Park. It is the smallest of the Chicago commuter railroads. The 10 stations along the route have an average spacing of 2.6 miles.

In 1975, 18 coaches and 1 dining car, plus 3 postal cars and 1 other nonpassenger carrying car were in service. The average seating capacity of the coaches is 69 passengers. It is believed that 8 coaches are used for suburban service.

Service

The N&W operates two trains in each direction daily. Service data are presented in Table 4-11.

Table 4-11

1975 N&W SERVICES[52]

Car-miles	210,000
Revenue passenger-trips	314,007
Average passenger-trips length, miles	13.85
Total passenger-miles	4,348,623
Average seating capacity per car	69
Average passenger load per car	20.7
Average load factor @ 69 seats per car	30%

Energy Usage

Although ICC statistics from the N&W Railroad include nonpassenger carrying cars, energy consumed by these cars is assumed negligible. In 1975, the N&W purchased a total of 37,355 gal of diesel fuel for passenger operations. This is equivalent to 5 billion Btu energy.

Energy Intensity

Based on total energy used, the system's average energy intensities have been compiled and are stated in equivalent forms, as follows:

- Service per gallon of fuel oil:
  5.62 car miles
  8.41 passenger trips
  116.41 passenger-miles
- Total energy per car-mile:
  24,000 Btu
- Total energy per passenger trip:
  16,000 Btu
- Total energy per passenger-mile:
  1,200 Btu

These results are suspect: the energy intensities are among the lowest observed even though load factors are low. There was no opportunity to recheck input data.

Economic Data

For 1975, the N&W reports operating revenues of $207,569 and operating expenses of $350,101, yielding a $142,532 operating deficit. Subsidies, if received, were not reported. Revenues averaged $0.66/passenger and expenses averaged $1.11/passenger.

Train fuel amounted to $10.057 for FY 1975, 4.8% of operating revenue. For CY 1975, $11,146 of fuel oil was purchased at 29.8¢/gal average. Fuel cost averaged to 5.3¢/car-mile, 3.5¢/per revenue passenger-trip, and 0.26¢/passenger-mile.

Rock Island (RTA)

Suburban Rail

Line and Equipment

The Rock Island, a medium sized suburban railroad in terms of route miles, revenues, and passengers carried, offers commuter service from downtown Chicago's La Salle Station to Joliet, Illinois, 40.2 line miles southwest of Chicago. A branch line, approximately 6 miles long, termed the "suburban" line diverges from the main line at the Gresham Station (approximately 10 miles from La Salle Station) and rejoins the main line at the Blue Island Station. The entire system has 46.7 miles of line and 30 station stops with an average station spacing of 1.6 miles. Most of the station stops are between the La Salle Station and Blue Island, less than one-half the distance of the line. There are only seven stops between Blue Island and Joliet. The line includes about 10 miles of triple track from the La Salle station to where the "suburban" line starts. The remaining line is double track.

The Rock Island report to the ICC for 1975 specified 233 miles of road operated for passenger trains, considerably more than the 46.7 miles used under RTA commuter service. This is explained by the fact that the Rock Island operates both intercity and suburban passenger services. Two intercity trains are operated each day (one to Peoria, Illinois, and one to Quad Cities, Illinois).

In 1975, the Rock Island had 28 diesel locomotives of 1,750 to 2,250 hp in service and 119 coaches. It is believed that 93 coaches are used for suburban service. The average seating capacity for the 119 coaches is 110.[53] Two dining cars and three nonpassenger carrying cars were also in service. In 1974, 48 coaches were air-conditioned; of these, 30 were 160-seat, bilevel coaches. All other coaches had 100 seats per car. Ten bilevel coaches had control cabs for push-pull operations.

Service

The Rock Island weekday schedule emphasizes service for workers commuting between southwestern suburban communities, the Beverly Hill and Morgan Park areas of Chicago, and the Loop. Slightly less than one-half the daily trains operate in the morning and afternoon peak periods, and most of these trains operate in the peak direction.[54] Only two trains in both the morning and afternoon peak periods operate in the nonpeak directions.

In 1974, peak period headways in the peak direction varied from 15 to 30 min at stations between Joliet and Blue Island, and from 5 to 10 min on the stations between Blue Island and La Salle Street Station.

Midday and evening service headways vary from 1 to 2 hr, with some of the stations on the main line between the Blue Island and Gresham stations receiving no service at all.[54]

Saturday service headways vary between 1 and 2 hr, while those on Sunday are between 2 and 3 hr. The number of weekend trains scheduled is about one-half of those scheduled for weekday service; also, fewer stations are served. Service begins at 5:15 am on weekdays, 5:30 am on Saturdays and 6:10 am on Sundays and holidays. Service ceases at 1:55 am in the morning, seven days a week.[54]

Equipment requirements for suburban service are: 18 locomotives and 94 passenger coaches for weekdays, 5 locomotives and 16 coaches on Saturday and 2 locomotives and 4 coaches on Sunday. The Rock Island has an "old" locomotive fleet and an equally "old" coach fleet. Less than one-half of the coaches are equipped for push-pull operation.[54] The average scheduled speed is 25 mph. The RTA indicated actual average service speeds are slower on the Rock Island operation.

Data for 1974 and 1975 suggest that the Rock Island uses about 90% of its coach fleet for Chicago commuter service. It is assumed that the intercity service is small in relation to suburban service. Consequently, data reported for the total passenger operation is used in this section as well as the Energy Usage section. Rock Island's report to the ICC indicates that the total car-miles for 1975 was 2,970,000. Some nonpassenger car-miles (mail cars, etc.) are included but the mileage generated by these nonpassenger-carrying cars is assumed to be negligible. (See Table 4-12.) Presumably, these procedures lead to some overstatement of energy consumption; however, there was no opportunity to improve the inputs.

Table 4-12

ROCK ISLAND STATISTICAL DATA[53]

Locomotive miles - road service	933,966
train switching	8,103
yard switching	47,575
Total locomotive miles	989,644
Car-miles	2,970,000
Revenue passenger trips	5,831,912
Passenger-miles	108,775,366
Average passenger trip length, miles	18.65
Average passenger load per car	36.6
Average load factor @ 110 seats per car	33%

Energy Usage

The Rock Island purchased a total 1,629,779 gal of diesel fuel in 1975 for passenger trains (equivalent to 224 billion Btu).

Energy Intensity

Based on diesel fuel used, the system's average energy intensities have been compiled and are stated, in equivalent form, as follows:

- Service per gallon of diesel fuel:
  1.82 car-miles
  3.58 passenger trips
  66.74 passenger-miles
- Energy per car-mile:
  75,000 Btu
- Energy per passenger trip:
  38,000 Btu
- Energy per passenger-mile:
  2,100 Btu

Economic Data

A Rock Island report included the following economic data for 1975. The Rock Island suburban service obtained operating revenue of $4,731,692, all from passenger service. Total suburban operating expense was $8,909,017. The operating deficit was $4,177,325, which was partly recovered by subsidies of $2,755,107.

Average cost per passenger trip was $1.53 and average fare was 81¢. Subsidies averaged 47¢ per passenger trip.

Fuel costs were $542,834 or about 6% of total operations expense. Fuel costs was 18¢/car-mile and 50¢/passenger-mile.

V CLEVELAND REGION

General

Cleveland and its suburbs are served by heavy- and light-rail transit systems. A commuter railroad operation was discontinued in early 1977. At the end of 1976, the rail systems consisted of the following:[56]

Table 5-1

CLEVELAND REGION FACILITIES AND EQUIPMENT

System	Line Miles	Stations	Cars
Heavy-rail			
Regional Transit Authority, Cleveland Division	19	18	116
Light-rail			
Regional Transit Authority, Shaker Division	13	29	57
Suburban-rail			
ConRail-Erie Lackawanna	66	12	3

The suburban rail operation which provided only one daily roundtrip serving an estimated 200 passengers, will not be described. The heavy- and light-rail operations of the Regional Transit Authority (RTA) are described below.

Rapid transit rail service in Cleveland began in 1913 when the first cars started operating on what was originally called the "Shaker Lakes Line," running from downtown Cleveland to a newly developed suburb known as Shaker Heights. Construction was carried out by two railroad companies: the Cleveland & Youngstown Railroad and the Cleveland Interurban Railroad.

In 1930, the Cleveland Interurban Railroad opened up a new right-of-way and high-speed line from East 34th into the newly built Cleveland Union Terminal, thereby avoiding street traffic, decreasing running time between downtown Cleveland and Shaker Heights and, consequently, enhancing the growth of the suburb. The entire Shaker Heights system, consisting of a main line with two branches, was purchased by the City of Shaker Heights in 1944.

In 1955, the first 13-mile line of the Cleveland Transit System (CTS) heavy-tail transit system was opened from downtown Cleveland to the east and west. The line was extended two miles further west in 1958 and was extended again to the Cleveland Hopkins International Airport in 1968. The initial financing for the CTS came through a $29,500,000 loan granted by the Reconstruction Finance Corporation. In 1972 the CTS was unable to make payments on its debt. It appealed to the City of Cleveland for aid and received a loan to redeem the bonds.

The Regional Transit Authority, formed in 1975, acquired control of both the heavy- and light-rail systems. They are now known as the Shaker Division and the Cleveland Division.

Heavy-Rail Transit

Route

The RTA operates one heavy-rail rapid transit line 19.04 miles long of which 0.375 mile is below grade at the city center. The line runs from the Cleveland Hopkins International Airport through the city center to Windermere with a total of 18 stations spaced an average of 1.12 miles apart. The shop and yard are located at Windermere.

Equipment

In 1976, the RTA had 116 heavy-rail cars of two basic types: the "Blue" cars made by St. Louis Car Company and the newer "Airporters" made by Pullman-Standard:

	Blue Cars	Airporters
Number	87	29
Year	1954-55-58	1967, 1970
Weight	56,000	64,775
Length	48'6"	70'
Width	10'	10'5"
Height	11'9"	13'6"
Seats	54 double/ 52 single	80
Horsepower	220	400

Forty-six cars are single units with operator cabs at both ends. Seventy of the Blue cars are married pairs. All cars have MU connections for operation in trains. The 29 Airporters are air-conditioned. An overhead wire provides 600 Vdc power.

Service

Heavy-rail rapid transit service is provided on one route. No express trains are run; however, from 6 am to 9 am and from 4 pm to 6 pm on weekdays, some extra trains are run on 10.11 miles of the line and are used to serve selected stations from Cleveland Union Terminal (downtown) west. Service is provided 24 hr a day. Headways are 6 to 7 min from about 6 am to 7 pm on weekdays and 30 min during other hours each day. Train lengths vary from one to six cars.

Service statistics for 1975 are presented in Table 5-2. Average service speed is 29 mph.[57] There are very few nonrevenue car-miles per year. Based on a 1975 ridership survey, the average passenger-trip length is 7.8 miles on the heavy-rail rapid transit system.

Table 5-2

CLEVELAND HEAVY-RAIL RAPID TRANSIT SERVICE[58]

	1975
Total car-miles	3,559,267
Revenue passengers	10,884,995
Average passenger trip length	7.8 miles
Total passenger-miles	84,900,000
Average passenger load per car	23.9
Average load factor @ 60 seats per car[a]	40%

[a]Weighted average number of seats per RTA heavy-rail car.

Four ride counts by RTA between October 1975 and August 1976 indicate that the heavy-rail system carries an average of 41,500 passengers each weekday, 16,000 passengers each Saturday, and 7,800 passengers each Sunday. A 1975 survey of weekday traffic indicates percent patronage by time of day to be:

5:00 - 6:59 am	12%/2 hr
7:00 - 8:59 am	41%/2 hr
9:00 - 11:59 am	9%/3 hr
12:00 - 3:59 pm	12%/4 hr
4:00 - 5:59 pm	23%/2 hr
6:00 - 8:59 pm	2%/3 hr
9:00 - 11:59 pm	1%/3 hr
12:00 - 4:59 am	1%/5 hr

Two-thirds of all rides occur during the 2-hr morning and afternoon peak periods. The RTA schedules 85 cars for the peak periods, 16 for the day base period, 6 for the 8 to 12 pm period, and 3 for early morning. The system generates 12,620 car-miles per weekday. Saturday schedules use 9 cars in the day, 6 in the evening, and 3 in the early morning--a total of 4,040 car-miles. Sunday schedules use 6 cars all day, except 3 in early morning, for a total of 3,198 car-miles.

Energy Usage

Electrical energy purchased was reported by RTA to be 30,929,100 kWh ac for CY 1975.[59] The RTA purchases its power from the Cleveland Electric Illuminating Company, which uses oil to produce about 98% of its electrical energy and coal to produce about 2%. Based on national average heat rates and distribution losses (11,278 Btu/kWh) and equivalent fuel oil required (0.07739 gal/kWh), in 1975 the RTA heavy-rail system used energy equivalent to 2.39 million gal of fuel oil or 349 billion Btu.

Energy Intensity

The system average energy intensities have been compiled and are stated in equivalent forms as follows:

- Service per gallon of fuel oil:
  1.49 car-miles
  4.55 passenger trips
  35.5 passenger-miles
- Energy per car-miles:
  8.69 kWh ac
  98,000 Btu
- Energy per passenger-trip:
  2.84 kWh ac
  32,000 Btu
- Energy per passenger-mile:
  0.36 kWh ac
  4,100 Btu

In summer, 1975, the RTA measured the power consumption of cars for full route trips over several days. The power consumption was measured in kWh dc by watt-hour meters installed on the cars. Most auxiliary equipment (including heaters, airconditioners, and lights) was not operating and there was no passenger load. Power consumption averaged 2.55 kWh dc per car-mile for the Blue cars and 5.5 kWh dc car-miles for the Airporter cars. The heavier weight and the much larger motors on Airporter cars accounted for most of the greater power consumption of these cars. Average power consumption for the fleet (weighted by the number of cars of each type) was 3.3 kWh dc per car-mile. This figure is less than one-half of the 8.7 kWh ac per car-mile figure derived above as the system average energy intensity. Most of the difference--5.4 kWh per car-mile--is believed to be due to these demands: operation of auxiliary equipment while cars are in service, and while idle but connected to the power; ac-to-dc conversion losses (estimated to be 3.2%); lines losses; energy used in shops, stations, and offices; energy used for substation heating and lighting; snow melters; and the additional power needed to transport the weight of passenger loads. The RTA reports relatively low power loss in the copper overhead distribution wire in comparison with a conventional third rail.

Economic Data

The RTA reported to APTA the following operating revenues and operating expenses for the heavy-rail system in calendar year 1975:

Passenger revenue	$3,534,204
Other operating revenue	26,023
Total operating revenue	3,560,227
Total operating expense	4,771,277
Net operating loss	1,211,050

Operating expense averaged $1.34/car-mile and 44¢/passenger trip. Fares averaged 32¢/passenger trip. The deficit was about 12¢/passenger trip. Operating subsidies covered most of the RTA operating loss for 1975, but were not separated by Division.

Electrical energy cost reported for 1975 was $675,000, which was 14% of operating expense. Average energy costs were 19¢/car-mile and 0.8¢/passenger-mile.

Light-Rail Transit

Routes

The RTA light-rail system contains 13.05 miles of line and two routes, Shaker and Van Aken. Both routes share a 5.98-mile line from the Cleveland Union Terminal to a branching of the two routes. The shared line included 5.88 miles of fully grade-separated line and five stations, plus 0.10 mile of line at-grade with two grade crossings. The Shaker branch has 3.80 miles of line, 11 grade crossings, and 11 stations. The Van Aken has 3.27 miles of line, 11 stations, and 11 grade crossings.

Route	Line Length (miles)	Stations
Shared line	5.98	7
Shaker branch	3.80	11
Van Aken branch	3.27	11
Total system	13.05	29

The average station spacing is about ½ mile for trains in service. However, the average station spacing on the branch lines is much closer than on the route section common to both lines.

The heavy-rail system also shares 2.62 miles of line, near the downtown terminal, used by the light-rail system. A convenient transfer can be made between the two systems at East 34th station, about midpoint in the common section.

The 1976 RTA light-rail car fleet consisted of 57 PCC cars of five basic series (see Table 5-3).

Table 5-3

CLEVELAND RTA LIGHT-RAIL FLEET

Year	1946	1946-7	1946-7	1947-8	1949
Number	10	5	15	25	2
Series	41-50	51-55	56-70	71-95	450-451
	St. Louis MU	St. Louis	St. Louis MU	Pullman-Std. MU	St. Louis
Weight	37,900	36,420	37,990	43,100	42,000
Length	46.5'	46.5'	46.5'	50'	53'
Width	9'	9'	9'	9'	9'
Height	10'0"	10'2"	10'2"	10'2"	10'0"
Seats	60	60	60	62	59

All cars have single-ended cabs with backup capability. An overhead wire supplies 600 Vdc power to the cars. Fifty cars are set up for multiple unit operation, 5 are limited to single unit configuration, and a married pair (450 and 451), can be single or multiple. Each car has four 55-hp motors and dynamic braking. Governing limits the top speed to 45 mph.

RTA has initiated a program to replace these cars, but the present fleet is expected to continue in use until about 1980 or later.

Service

Light-rail transit service is provided on two routes, 24 hr a day, 7 days a week. Branch line headways vary from about 5 min during peak hours to 20 min during weekday base periods. During early morning hours and all day Sunday, branch line headways are limited to 1 hr. Headways on the shared line are one-half that of the branch lines. The minimum headway is 2 min. Train lengths vary from one to three cars in operation, although six car trains are possible. Platforms are limited to four cars on the Van Aken branch and three on the Shaker branch.

Service statistics are presented in Table 5-4. Note that nonrevenue car-miles were only 16,500 miles. This is less than 2% of the total

Table 5-4

RTA LIGHT-RAIL SERVICES[52]

	CY 1974
Revenue service car-miles	1,017,965
Nonrevenue car-miles	16,531
Total car-miles operated	1,034,496
Revenue passenger trips	
Shaker line	1,397,610[a]
Van Aken line	2,329,351[a]
Total passenger trips	3,726,961
Average passenger trip length, miles	
Shaker line	8
Van Aken line	7
Weighted average	7.4
Passenger-miles[b]	
Shaker line	11,200,000
Van Aken line	16,300,000
Total	27,500,000
Average passenger load per car	26.6
Average load factor @ 61 seats per car	44%
Average service speed, mph	29[57]

[a]RTA estimates that 3/8 of patronage is on the Shaker route and 5/8 is on the Van Aken route.

[b]Derived

car miles and indicates an efficient logout of lines and yards. RTA has estimated the average trip length to be 8 miles on the Shaker line and 7 miles on the Van Aken line with an estimated patronage split of 3/8 on the Shaker line and 5/8 on the Van Aken line. The weighted average trip length--7.4 miles--was used to estimate passenger-miles.

The system average load factor for 1974, was 44%, which is attractive. Since establishment of the RTA, patronage of the Cleveland light-rail system has increased, with very little change in service due to greatly reduced fares and free transfers. RTA statistics on cumulative rides for a year through August, 1976, indicates the light-rail system has increased ridership by 37% over the same period in 1975. System average load factors are probably about 60% for 1976.

Starting September 20, 1976, on an average weekday, the RTA scheduled two cars in owl service (1 am to 7:30 am), 45 cars in morning rush service (7:30 am to 9:00 am), 6 cars in base period (9:00 am to 4:30 pm), 43 in late afternoon rush service (4:30 pm to 8:00 pm), and 4 cars in evening service (8:00 pm to 1:00 am). On Saturday, five to six cars were scheduled for about 6:30 am to 8:00 pm, with two cars at all other times. On Sundays, two cars were scheduled for the whole day.

Energy Usage

The APTA report shows purchases of 4,400,000 kWh for vehicle operation in 1974.[59] Based on other data from RTA, it was estimated that total energy purchased was 5.27 million kWh.

The Shaker Division has three convection-cooled silicon rectifier substations with 97% ac-to-dc conversion efficiency and one rotary rectifier substation of much lower efficiency which is only used at peak load periods. One rectifier is on track shared with the heavy-rail system. The RTA estimates that about 1% of vehicle purchased power is used for substation heating and lighting.

The RTA purchases its power from the Cleveland Electric Illuminating Company, which uses coal to produce 98% of its power and oil to produce 2%. To compare the systems, the entire fuel input is expressed in terms of equivalent amounts of fuel oil.

Based on national average heat rates and distribtuion losses and equivalent fuel oil required in 1974 the RTA used an energy equivalent of 50 billion Btu or 340,000 gal of fuel oil.

The RTA reported that the light-rail system used 4.5 million kWh ac for vehicle operation in 1975, a very slight increase. Similarly, the Cleveland Electric Illuminating Co^pany states that the amount used in 1976 was not significantly greater than in 1975.

Energy Intensity[59]

Based on total energy used, the system average energy intensities have been compiled and are stated in equivalent forms as follows:

- Service per gallon of fuel oil:
  2.54 car-miles
  9.13 passenger trips
  67.40 passenger-miles
- Energy per car-mile:
  5.1 kWh ac
  57,000 Btu
- Energy per passenger trip:
  1.41 kWh ac
  16,000 Btu
- Energy per passenger-mile:
  0.19 kWh ac
  2,100 Btu

In summer, 1975, the RTA measured the power consumption of the PPC cars by installing dc watt-hour meters on board on test cars. Most auxiliary equipment (including heaters and lights) was not operating and there was no passenger load. The average energy intensity from the test was 1.78 kWh dc/car-mile, less than one-half of the 4.25 kWh ac per car-mile figure calculated for the entire system. Consequently, about 2.5/kWh/car-mile of energy is used to operate auxiliary car equipment, to transport the extra weight of passengers, and in substations (conversion losses), line losses, shops, stations, and offices.

The 37% increase in patronage in 1976, and the near negligible increase in energy for vehicle operation will improve energy intensities. Energy intensities may be as low as 9,100 Btu/passenger-trip and 1240 Btu/passenger-mile in 1976. This will probably be the most favorable system average energy intensity to be found in U.S. rail passenger transportation. The RTA expects patronage to be even higher in 1977, with no increase in service (i.e., car-miles).

Economic Data

Economic data are not available for 1975. Operating revenues and operating expenses for the light-rail system for calendar year 1974 were:[59]

Passenger revenue	$1,971,196
Other operating revenue	50,980
Total operating revenue	2,022,176
Total operating expense	2,218,066
Net operating loss	195,890
Taxes	208,847
Operating subsidies (city)	94,282
Net loss	310,455

In 1974, operating expense averaged \$2.14/car-mile and 60¢/passenger-trip. The average fare per passenger was 53¢ and operating loss per passenger-trip was \$.053. A subsidy averaging \$.025 per passenger-trip was received.

The cost of power plus operation and maintenance of power was \$214,000 (9.6% of total expense). Power cost 21¢/car-mile and .8¢ per passenger-mile.

VI NEW YORK REGION

General

New York City and suburban communities in New York, New Jersey, and Connecticut are served by a large, complex, and varied rail passenger network, including three heavy-rail systems, one light-rail system, and three groups of suburban rail lines. At the end of 1975, the systems used the facilities and equipment listed in Table 6-1.

Table 6-1

NEW YORK REGION FACILITIES AND EQUIPMENT

Facilities	Line Miles	Stations	Cars
Heavy-rail			
NYCTA	230.6	461	6681
SIRTOA	14.6	22	52
PATH	13.9	13	298
Total	259.1	496	7031
Light-rail			
Newark	4.2	11	30
Suburban rail			
Long Island	319	150	1047
New Jersey	480	N/A[a]	755
New York and Connecticut	263.7	100	1436

[a]Data not available

Rail service with horse-drawn cars began in lower Manhattan in 1832 and continued past 1900. Steam, cable and a prototype pneumatic system played minor roles during the late 19th century. An electric streetcar line was established on Long Island in 1887, and an extensive street railway system was built over the next 20 years. The first subway, started in 1900, began service in 1904 and was an instant success. The Hudson and Manhattan Railroad (now PATH) began service in 1908. The suburban railroads began operations in the 19th century.

New York City participated in the planning and construction of the first subway in the area and acquired ownership of the entire system in 1940. The New York City Transit Authority (NYCTA) was created later by the state to operate the system under a lease.

The Metropolitan Transportation Authority (MTA) was created in 1968 "to continue, develop, and improve" transportation in New York City and several suburban counties. MTA now controls four rail passenger systems:

- The NYCTA heavy-rail system is leased from the city
- The Staten Island heavy-rail system is leased from the city
- The Long Island Railroad is wholly owned
- The Hudson Harlem and New Haven Division of ConRail supply suburban passenger services under contract with MTA.

MTA receives funds from the State of Connecticut to aid in subsidizing services in New York and Connecticut on the New Haven Line. MTA contributes funds to aid New Jersey in subsidizing rail lines in New Jersey and New York, west of the Hudson River. MTA controls toll bridges and tunnels in New York City as well as airfields and other facilities.

The Port Authority of New York and New Jersey, a bistate agency, acquired the bankrupt Hudson and Manhattan Railroad in 1962 and has modernized the entire system. The Port Authority also owns the Hudson River toll crossings between Manhattan and New Jersey, bus terminals, commercial airports of the region, and numerous other facilities.

New Jersey provides financial support and furnishes equipment for a suburban rail complex connecting New York with a number of New Jersey communities. Two commuter lines extend from New Jersey into New York state west of the Hudson River. (MTA provides financial aid to one of these lines.) Before creation of ConRail, these services were provided by the Erie-Lacawanna, Penn Central, Central Railroad of New Jersey, and other railroads. New Jersey also subsidizes the light-rail system in Newark. A private firm, Transport of New Jersey, owns and operates the light-rail system as well as a large urban bus fleet.

<u>NYCTA Heavy-Rail Rapid Transit Systems</u>

The NYCTA is one of the largest heavy-rail transit systems in the world and greatly surpasses any other in the United States. In fact, it accounts for almost one-half of the heavy-rail rapid transit lines and more than three-quarters of the heavy-rail transit service in the United States.

Lines and Equipment

In 1975, there were 230.6 miles of line (including 137 miles underground), 461 stations, and 6681 cars. The system was designed as three separate parts--IND, IRT, and BMT--and the network is exceptionally complex. Many lines have four tracks and provide both local and express service. The network was designed to reduce traveler transfers on foot and to ease the burdens of transfers by across-the-platform transfers when possible. This design pilosophy made it necessary to merge and separate routes at many points and greatly complicated operation and control of the system.

Since coming under common ownership, the three parts have been integrated, to the extent possible. Integration cannot be complete for numerous reasons. Perhaps most important of these is the fact that the tunnels of Division A (IRT) have a smaller cross section than the tunnels of Division B. The differences in tunnels are reflected in the existence of two families of cars: 2350 in Division A (IRT) and 4320 in Division B (IND-BMT). Within each family there are many lots of cars purchased at various times and kept in service to the present.

Cars used by Division A are 51 ft 4 in. long, 8 ft 9 in. wide, and 11 ft 10.37 in. high. Weights vary from 69,100 to 78,700 lb. Older cars on Division B are 60 ft 6 in. long, 10 ft wide and 12 ft 1.75 in. high and weigh 68,000 to 85,000 lb. Several years ago, NYCTA made minor changes in tunnel clearances to allow 75-ft cars on Division B. Two lots of long cars have been purchased: 352 cars under Contract R-44 and 754 cars under Contract R-46. Their weights are 83,000 and 86,000 lb, respectively. Delivery of the R-44 cars was complete in 1973. R-46 cars are being delivered in 1975-1977. The new cars have larger capacities, more powerful propulsion systems, and higher speeds than any others in the fleet. Cars purchased before World War II are being retired as new cars are delivered. More than 900 NYCTA cars are air conditioned.

Service

Heavy-rail transit service is provided on about 25 express, local and shuttle routes. Some routes are discontinued or shortened during off-peak hours, nights, and weekends, but 24-hr, 7-day service is maintained throughout the system. In the fiscal year ending June 30, 1975, NYCTA generaged 302.8 million revenue car-miles and transported 1,077.6 million revenue passengers. Tri-State staff members estimate that the average trip length on NYCTA is 7.0 miles.[60] Total revenue service was more than 7.5 billion passenger-miles. (See Table 6-2.)

Table 6-2

NYCTA SERVICE STATISTICS

Revenue car-miles, millions	302.8
Nonrevenue car-miles, millions	2.7
Total car-miles, millions	305.5
Revenue passengers, millions	1,077.6
Average length of person trip-miles	7.0
Revenue passenger-miles, millions[a]	7,543

[a]Derived

Energy Consumption

Total energy purchased was 2,048.8 million kWh. The supplier, Consolidated Edison, has an average heat rate of 12,341 Btu/kWh, and average internal usage and losses of 9.8%. Thus, fuel having a total heating value of 13,680 kWh was consumed for each kWh delivered to NYCTA and a total of 28,030 billion Btu was consumed during the year. Based on the national average heating value of 145,719 Btu/gal of fuel oil, NYCTA required 192.3 million gal of fuel oil. (See Table 6-3.)

NYCTA reports that energy consumption for the operation of cars was 1,679.3 million kWh and that revenue and nonrevenue miles of travel totaled 305.5 million car-miles. The average energy consumption for the operation of cars was 5.50 kWh/car-mile. Data are not available to

Table 6-3

NYCTA ENERGY USAGE[62,63,64]

Total electrical energy purchased, kWh, millions	2,048.8
Energy for operation of cars, kWh, millions	1,679.3
Consolidated Edison heat rate, Btu/kWh	12,341
Consolidated Edison distribution efficiency, %	90.2
Heat valve, Btu/gal, U.S. average	145,719
Btu/kWh purchased by NYCTA	13,680
Equivalent Btu consumed to supply NYCTA, billions	28,030
Equivalent fuel oil consumed by Consolidated Edison, gal, millions	192.3

separate consumption by propulsion and auxiliaries. However, an NYCTA staff member estimated that the division was about 10% and 90%, or about 0.5 kWh/mile for auxiliaries and 5.0 kWh for propulsion.

Energy Intensity

Alternative statements of energy intensities are presented here:

- Service per gallon of fuel:
  1.57 revenue car-miles
  5.60 passenger trips
  39.22 passenger-miles
- Energy per revenue car-mile
  6.87 kWh
  93,000 Btu
- Energy per passenger trip
  1.90 kWh
  26,000 Btu
- Energy per passenger-mile
  0.27 kWh
  3,700 Btu

The system average energy intensity of 6.8 kWh/car-mile is greater than the 5.5 kWh/car-mile because of the need to operate stations, yards, and other fixed facilities.

The energy intensity per passenger-mile varies greatly from time to time throughout the day, depending on the number of passengers carried by cars. This is true of all rail passenger systems but can be illustrated by an example based on one NYCTA line. The weight of passengers has only a small influence on energy usage and is often neglected; most of the energy consumed by cars is devoted to the movement of the car and the operation of its machinery rather than to the movement of passengers. In this exercise, allowance is made for the weight of passengers by approximate factors. A car having an empty weight of 75,000 lb is assumed to have a gross weight of about 82,500 lb under average load conditions (say, 50 passengers) and a maximum gross of about 90,000 lb when heavily loaded. The car is assumed to use 5.5 kWh/car-mile for operations under average conditions and somewhat less (say, 5.2 kWh) when empty, and somewhat more (say, 5.9) when heavily loaded.

Data from a survey made annually by Tri-State[65] was used to show how energy intensity per passenger-mile varies on one line during a 24-hr period. The survey indicates the loads carried by inbound local trains on the Lexington Avenue line at 60th Street. At 3:30 am, trains carry average loads of 4.2 passengers per car, while at 8:30 am, trains carry loads of 101.2 passengers per car.

If the lightly loaded train at 3:30 am requires the expenditure of 5.2 kWh of electrical energy per car-mile to transport 4.2 persons/car, energy intensity is 1.24 kWh/passenger-mile. Based on factors cited above, the power company would burn fuel containing 15,300 Btu/passenger-mile to power this train. At the other extreme, energy intensity is very low when large passenger loads are carried. If the 8:30 am trains with 101.2 passengers/car consume energy at the rate of 5.9 kWh/car-mile, the energy intensity is only 719 Btu/passenger-mile. The comparison emphasizes the variation within systems and the economics of scale.

It is noteworthy that the 3:30 am trains usually contain four cars. If it were technically feasible for NYCTA to operate one-car trains, the energy intensity at 3:30 am would be reduced to about 3820 Btu per passenger-mile which is near the system average. This analysis suggests that substantial amounts of energy would be saved if it were possible to shorten trains in slack periods. However, that change may not be feasible without costly technical changes in equipment. Also, adjusting train lengths several times each day might involve unacceptable labor costs in yards. Changes of this kind have not been evaluated in detail.

Economic Data[61]

For the fiscal year ending June 30, 1975, NYCTA reported total operating revenues of $380.6 million and total operating expenses and rentals of $713.0 million. The loss from operations was $332.4 million. The average fare was about 35¢. Costs per revenue passenger was 66¢ and the average operating loss was 31¢. (Fares have since been increased to 50¢.)

Operating revenues average $1.26/car-mile. Operating expenses average $2.35/car-mile. Of the latter figure, about $1.62 is expended for operation of cars, power, and maintenance of equipment. Thus, it appears that the practice of shortening trains in slack periods, as discussed above, would reduce certain operating costs as well as car-mile energy.[62]

Staten Island Rapid Transit Operating Authority (SIRTOA)

The Staten Island heavy-rail rapid transit system is part of the MTA complex. It is a single line system, 14.6 miles in length, double-tracked and electrified. One end of the line is at the ferry terminal that provides water transportation to Manhattan. The line extends west through a number of suburban communities and contains 22 stations. The system uses 52 air-conditioned cars of the R-44 type originally purchased for NYCTA.

The following data, provided by SIRTOA (or derived), cover all of 1975 (service was interrupted by a three-week strike).

Total electrical power, kWh	14,109,664[a]
Operation of cars	13,330,000[b]
Fixed Plant	775,000[a]
Passenger trips	4,589,458[a]
Average trip length, miles	9[a]
Passenger-miles	41,300,000[b]

[a]SIRTOA
[b]Derived

Information presented by SIRTOA appears to have understated car mileage for 1975. The reported figure was 623,487 car-miles. This would work out to be about 12,000 miles/year/car, much lower than the annual mileage for similar cars used by NYCTA. Energy intensity would be about 21.4 kWh/car-mile, again much higher than NYCTA experiences. These results are considered unreliable and are not used.

Total electrical power consumption is equivalent to 1.09 million gal of fuel oil or 159 billion Btu (based on national averages explained above). Energy intensities are:

- Service per gallon of fuel:
  4.20 passenger trips
  37.83 passenger-miles
- Energy per passenger trip:
  3.07 kWh
  35,000 Btu
- Energy per passenger-mile:
  0.34 kWh
  3900 Btu

In 1975, SIRTOA had a total revenue of $1.71 million: $1.61 million from passengers, and $0.1 million from other sources. Operating expenses totaled $5.90 million and the loss on operations was $4.19 million. This loss is covered by subsidy payments from the city and state.

The average fare collected was 35¢. (The standard adult fare is now 50¢.) The average cost per passenger trip was $1.29 and the average subsidy was 94¢/passenger trip.

Port Authority Trans-Hudson Corporation (PATH)

History

Efforts to construct what is now PATH began in 1874, but service did not begin until 1908. The Hudson and Manhattan Railroad owned and operated the system but experienced severe financial difficulties. In 1962 the system was acquired by PATH, which is a subsidiary of the Port Authority of New York and New Jersey.

Routes

PATH operates a heavy-rail rapid transit system connecting two parts of Manhattan with transporation terminals and suburban communities in New Jersey. The network can be diagrammed as the capital letter "H." Newark and the World Trade Center are at the ends of the left bar, Hoboken and Herald Square are at the ends of the right bar, and the cross bar is on the New Jersey side of the Hudson.

The system contains 13.9 miles of double-track, electrified line; 7.8 miles are underground and 6.1 miles are at grade. There are 13 stations: 6 in Manhattan and 7 in New Jersey. Two tunnels cross the Hudson River. One line has a single Manhattan station at the World Trade Center. The other has five Manhattan stations and terminates at 33rd Street near Herald Square.

In New Jersey, one line terminates at Hoboken and provides a major interface with commuter railroads. Another terminates at Newark. The Journal Square station on the Newark line is part of a newly constructed transportation center and is a major transfer point for travelers using buses and autos.

Equipment

The system uses 298 cars purchased in four lots in 1958, 1965, 1967, and 1973. All cars are air conditioned and all are 50 ft long. All cars purchased since 1958 are 111 in. wide.

The newest cars (Model PA-3) weigh 59,000 lb fully loaded. The design capacity is 140 passengers: 35 seated and 105 standing. With crush loading, an additional 25 passengers can be carried.

Service

PATH operates about 1200 trains on a typical week day, providing service on five routes, as follows:

- Newark - World Trade Center
- Journal Square - World Trade Center
- Journal Square - 33rd Street
- Hoboken - World Trade Center
- Hoboken - 33rd Street

Service frequencies are 3 to 6 min during peak hours, 10 to 15 min in off-peak periods, and 20 to 30 min in the early morning hours (about 12:30 am to 5:30 am. Weekend services are at 15- to 30-min intervals and some services are combined.

In 1975, PATH reported 10,656,600 car-miles and 468,220 hr of car operations. The derived average speed is 22.76 mph. Nonrevenue travel was not reported. PATH reported 38,339,587 revenue passenger trips and estimated that the average trip length was 4.8 miles. The derived total service is 184 million passenger-miles.

Energy Consumption

Electricity used to operate vehicles was reported to be 63,574,560 kWh. Staff members estimated that energy consumption was 55.94 million kWh for propulsion (88%) and 7.63 million kWh for auxiliaries (12%). PATH staff members estimated that an additional 1.30 million kWh (2%) was used for fixed installation. Based on these data, total consumption was estimated to be 64.87 million kWh.

Based on national averages discussed in Section 1, total electrical energy consumed was equivalent to 5.02 million gal of fuel oil or 31.6 billion Btu.

Energy Intensity

Alternative statements of energy intensities are presented here:

- Service per gallon of fuel:
  2.12 car-miles
  7.64 passenger trips
  36.65 passenger-miles
- Energy per car-mile:
  6.09 kWh
  69,000 Btu
- Energy per passenger trip:
  1.69 kWh
  19,000 Btu
- Energy per passenger-mile:
  0.35 kWh
  4,000 Btu

Economic Data

In 1974, PATH reported total railway operating revenue of $12.19 million; total railway operating expense of $35.67 million; and a net operating loss of $23.48 million. Taxes of $2.14 million increased the deficit to $25.62 million. Further adjustments (not explained) increased the deficit to $32.32 million, which is the amount of operating assistance received. Passengers paid average fares of 30¢. Total cost averaged $1.16/passenger trip, and operating assistance averaged 86¢/passenger trip.

Newark Light-Rail System

Newark, N.J., is served by the light-rail transit system described here, as well as by PATH, suburban railroads, and buses. The owner of the system is a private firm, Transport of New Jersey (TNJ), which also operates a large bus fleet. The firm receives an operating subsidy from the state of New Jersey.

Routes and Equipment

The system contains one double-track line about 4.2 miles long, including 1.3 miles in subway and 2.9 miles at grade. There is a single grade crossing on the surface line. The 11 stations all have full platforms. The system employs 30 PCC cars, all built in the late 1940s and now approaching 30 years in age.[66] The reported vehicle capacity is 180 passengers (55 seated and 125 standing).[67]

Service

In 1974, the system reported 577,207 car-miles, all in revenue service. Vehicles were in revenue operation 40,633 hr. The derived system average speed was 14.2 mph. The system transported 2,450,824 passengers; 2,208,000 paid full fares; 234,000 paid special fares; and 8,000 traveled free.

Average trip lengths were not reported by TNJ. In the calculations presented below, an estimate of 2.2 miles, which has been employed by Tri-State,[63] was used. Derived annual service was 5.39 million passenger-miles.

Energy Use

Electrical energy for the operation of passenger vehicles was reported at 2,659,770 kWh (APTA)[68] in 1974. Energy used for other purposes was not reported. It has been assumed that the energy used for fixed installation is 5% of that used for vehicles (about 140,000 kWh) and that total electrical energy purchased was about 2.8 million kWh/year. (The effect of an alternative assumption is explored below.) Based on national average heat rates and distribution losses explained in Section 1, this is equivalent to 0.22 million gal of fuel oil or 32 billion Btu.

Energy Intensity*

Alternative statements of energy intensities are presented here:

- Service per gallon of fuel:
  - 2.66 car-miles
  - 11.31 passenger trips
  - 24.87 passenger-miles
- Energy per car-mile:
  - 4.8 kWh
  - 55,000 Btu
- Energy per passenger trip:
  - 1.14 kWh
  - 13,000 Btu
- Energy per passenger-mile
  - 0.52 kWh
  - 5,900 Btu

The results cited above reflect the assumption that total energy purchased was 5% greater than energy reported for the operation of cars, and that the average trip length was 2.2 miles. Different assumptions can be made. For example, one could assume that the energy reported as used for operation of cars was, in fact, the total electrical energy purchased and that the average trip length was, say, 2.0 miles rather than 2.2 miles. The changes tend to have offsetting effects but would alter the end result from 5900 Btu/passenger-mile to 6100 Btu/passenger-mile--a net increase of 3%. This exercise demonstrates the kind of errors to be expected where estimates of energy intensity are based on data of uncertain quality. Approximation of the kind used here are often the best that can be done at present. Uncertainties regarding energy intensities will remain until new procedures are developed for accurate and complete record-keeping.

Economic Data

Transport of New Jersey is a private company. In 1974 the firm reported total railway operating revenue of $1,168,000 including operating revenue of $918,000 and operating subsidies (paid by the state of New Jersey) of $250,000. Railway operation expense was $1,090,000. After tax payments of $98,000, the company incurred a loss of $20,000.

*See discussions of assumptions.

Operating expense per car-mile was $1.89. Total cost of the service, including taxes, average 48.5¢/passenger trip. The average fare paid by revenue passengers was about 38¢. The subsidy was equivalent to 10¢/rider and the company's loss was about 0.8¢ rider.

Suburban Rail Service

New York City and suburban communities are served by three groups of suburban passenger lines. The Hudson, Harlem and New Haven divisions of ConRail provide service between Grand Central Station in Manhattan and suburban communities to the north and northeast in New York and Connecticut. The Long Island Rail Road provides service between New York City and suburbs on Long Island. Elements of ConRail that were formerly parts of Penn Central, Erie Lackawanna, and Central Railroad of New Jersey provide service from suburbs in New Jersey to Manhattan, either directly to Penn Station or with transfers to PATH.

Hudson, Harlem, and New Haven Divisions of ConRail

Suburban rail lines originally owned by the Pennsylvania, New York Central, and New Haven railroads were acquired by Penn Central and later by ConRail. In 1971 and 1972, the Metropolitan Transportation Authority entered into agreements to provide financial support needed to continue services that were then under threat of discontinuation because of financial difficulties. Day-to-day operations are conducted by ConRail. MTA has assumed responsibility for funding the deficits and certain other costs of furnishing service on the Hudson and Harlem divisions, and in an equal partnership with the Connecticut Transportation Authority, on the New Haven division. MTA pays ConRail fees totaling $225,000/year and has leased or purchased much of the physical plant. MTA is financing major modernization and equipment replacement programs.

Routes

Suburban rail service is provided to about 100 stations. The Hudson Line provides service to Poughkeepsie, a distance of 73.6 miles. The Harlem line provides service to Dover Plains, a distance of 76.6 miles. The New Haven line provides service to New Haven, a distance of 72.3 miles and also serves three branches, New Canaan, Dunbury, and Waterbury, a total distance of 58.4 miles. All three lines share 5.4 miles of track north of Grand Central on the Hudson Line and two lines share an additional 6.4 miles of track on the Harlem line. Total line is 263.7 miles of which 159.1 is in New York and 104.6 is in Connecticut. About 128 miles of the line is electrified and 136 miles is nonelectrified. Both ac and dc power are used.

Equipment

In 1975, MTA owned the following equipment used on the Hudson, Harlem, and New Haven lines:

Diesel locomotives	52
Dual-powered locomotives	43
Total	95
Rail diesel cars	34
Locomotive drawn cars	357
Electric powered multiple-unit cars	1045
Total cars	1436

The mix of nonelectrified and electrified lines, and ac and dc power, greatly complicates operations and equipment requirements. For example, the dual-powered units are diesel locomotives equipped to pick up electrical power from the wayside. These units are needed for trains that must travel underground to reach Grand Central Station and also on nonelectrified lines. Standardization of power supply, extensions of electrification, and purchase of dual-powered turbine electric cars have been considered to avoid these problems.

Service

During 1975 the three divisions carried 39.3 million passengers a total of 1.07 billion passenger-miles. The average trip length was 27.2 miles. Vehicle travel was 5.56 million train-miles and 25.78 billion car-miles.

Long Island Rail Road (LIRR)

The Long Island Rail Road began operations in the 19th century and has had a great influence on the development of Long Island and New York City. It was part of the Pennsylvania Railroad until 1966, when financial difficulties threatened to end service. The system is now wholly owned by MTA and receives substantial public subsidies for capital programs and operations.

LIRR is a class I railroad, providing a small amount of freight service but mainly engaged in suburban passenger service. Service is provided between three terminals and numerous stations in New York City and suburban communities throughout most of Long Island.

Lines and Equipment

LIRR serves about 150 stations. In 1975, LIRR reported 319 miles of line in use for passenger service. About 136 miles of heavily traveled route at the western end of the network are electrified; the remainder is diesel powered. At the end of 1975, LIRR reported the following passenger cars in service:[69]

800	multiple-unit electric cars
202	locomotive-hauled coaches
145	locomotive-hauled parlor cars
1047	

According to Tri-State,[70] the average car is 10 years old. All cars are air conditioned, and the average seating capacity is 118 passengers/car. The system uses 65 locomotives for freight and passenger service.

The combination of diesel and electric operation causes operating problems and degrades service by making it necessary for travelers to change between diesel and electric trains. Extensions of electrification are being considered, as is the use of dual-powered turbine-electric trains that can operate on nonelectrified and electrified lines. Four prototype dual-powered cars are being demonstrated.

Servic-[69]

In 1975, LIRR reported 1.851 million passenger-miles and 67.17 million passenger trips. Average trip length was 27.56 miles. In that year, the system generated 55.82 million car-miles. Service by electric trains accounted for 5.570 million train-miles and 45.30 million car-miles, indicating an average consist of 8.13 cars/train. Road service by locomotive-drawn trains accounted for 1.688 million train-miles and 10.53 million car-miles, indicating an average consist of 6.24 cars/train.

A survey conducted by Tri-State indicates that LIRR does not shorten trains in slack periods. For example, 19 trains operating to Manhattan between midnight and 5:00 am included 142 cars (an average 7.47 cars/train) and carried 209 passengers (an average of 1.47 passengers/car). During the morning peak hours, 67 trains with 613 cars (an average of 9.15 cars/train) carried 60,371 passengers (an average of 98.48 passengers/car). These data suggest that considerable energy might be saved by adjusting the length of trains from time to time during the day. However, technical and economic reasons may justify existing practices.

New Jersey Suburban Trains

Information on suburban railroad operations in the New Jersey suburbs of New York is not complete.

Lines and Equipment

In 1972, three railroads provided significant amounts of service: Penn Central, Erie Lackawanna, and Central Railroad of New Jersey. Passenger line totaled about 480 miles.

In 1975,[70] the following equipment was in use on these lines:

	Penn Central	Central Railroad of New Jersey and Reading	Erie Lackawanna	Total
Cars:				
Electric MU	120		230	350
Locomotive hauled	92	144	151	387
Self-propelled, RDC	___	18	___	18
Total cars	212	162	381	755
Air conditioned	194	115	151	460
Average seats	93	86	90	
Average age	24	30	29	
Locomotives				
Electric	13			13
Diesel	25	13	32	70
Total	38	13	32	83

Service

Both the Penn Central and the Erie Lackawanna provided service in areas other than New Jersey and it is difficult to isolate the separate parts in current reports. A study by Tri-State provides useful data on the New Jersey traffic for the year 1972.[63] It was estimated that the three railroads carried passengers in the area as follows:

Penn Central	12,252,000
Erie Lackawanna	16,594,000
Central of N.J.	5,857,000
Total	34,703,000

Regional Energy Analysis

This research has not discovered complete and up-to-date estimates of service provided and energy usage by each of the three suburban rail complexes in the New York area. However, a good picture of conditions for the entire region for the year 1972 is available from a report prepared by Tri-State in 1975.[63]

That report treats suburban service provided by the Long Island Rail Road; the Erie Lackawanna; the Central of New Jersey; and the Hudson, Harlem, New Haven, and New Jersey services then operated by Penn Central. Aggregate statistics from the Tri-State report are recapitulated here:

Service:

127,019,267 car-miles
132,596,690 passenger trips
3,086,665,061 passenger-miles

Energy used:

42,102,001 gal diesel fuel, plus
633,073,664 kWh
95,758,060 equivalent grand total gallons of fuel
13,147,581 million Btu

Energy intensities have been computed from those data and are stated in alternative forms here:

- Service per gallon of fuel:
  1.33 car-miles
  1.38 passenger trips
  32.23 passenger-miles
- Energy per car-mile:
  103,500 Btu
- Energy per passenger trip:
  99,000 Btu
- Energy per passenger-mile:
  4,260 Btu

Regional Economic Data

MTA's annual report for 1975 indicates that passenger revenues for the LIRR and the Hudson, Harlem, and New Haven divisions totaled $179.3 million and that the systems lost $181.8 million. Some of the loss of the LIRR ($128.6 million) would likely be attributed to freight operations if LIRR were a private firm. However, if all losses are considered incidental to the continuation of passenger services, passengers' fares are covering only one-half of the cost of services.

Economic data were not received for the New Jersey suburban rail systems.

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VII PHILADELPHIA REGION

Philadelphia and suburban communities in Pennsylvania, New Jersey, and Delaware are served by three heavy-rail rapid transit systems, an extensive light-rail transit network, and two suburban railroads, as well as trolley coaches and buses. Two regional agencies provide rail passenger service.

The Delaware River Port Authority, through its subsidiary, the Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO), provides heavy-rail rapid transit service in the Lindenwold line. The Southeastern Pennsylvania Transportation Authority (SEPTA) provides all other heavy- and light-rail transit service and manages the suburban rail services operated by ConRail for SEPTA. SEPTA's rail operations are organized in three divisions: the City Transit Division (CTD), the Red Arrow Division (RAD), and the Commuter Rail Division.

At the end of 1975, the combined rail passenger transportation resources of the Philadelphia region were as shown in Table 7-1.

Table 7-1

PHILADELPHIA REGION EQUIPMENT AND FACILITIES

	Routes	Miles of Line	Stations (Stops)	Cars
Heavy-Rail				
PATCO	1	14.2	13	75
SEPTA City Transit Division	2	24.5	54	490
Light-Rail				
SEPTA City Transit Division				
- Subway-surface lines	5	21.4	181	290 (subway-surface and streetcar lines combined)
- Streetcar lines	7	52.8	519	
SEPTA Red Arrow Division	3	24.8	73	61
Commuter Rail				
Penn Central commuter lines	6	149.7	101	258
Reading commuter lines	7	264.6	116	188

History

Rapid transit in Philadelphia grew from several omnibus and horse-car companies that originated in the late 1820's. Suburban railroads began service in Philadelphia in 1832 with the Chestnut Hill Railroad Company. By 1902, the Philadelphia Rapid Transit Company (later the Philadelphia Transportation Company) had acquired most of the companies operating in the metropolitan Philadelphia area. The City of Philadelphia joined with the PRT in 1907 to construct rapid transit facilities. In 1907, these were joined with the interurbans run by the Philadelphia and West Chester Traction Co. (later Red Arrow), which had operated the West Chester Turnpike since 1848. A new railroad company, the Philadelphia and Western, founded by the Goulds, joined the PRT and PWCT at Upper Darby that same year (the Norristown Red Arrow Line). Meanwhile, by 1900, the Pennsylvania Railroad and Reading Railroad had absorbed all the other Philadelphia railroads, except the Baltimore & Ohio.

In 1964, SEPTA was created "to acquire, consolidate and operate the transit system in the metropolitan area." SEPTA's territory included five counties: Bucks, Chester, Delaware, Montgomery, and Philadelphia. Its first task was to stabilize a deteriorating suburban rail situation. In 1958, purchase of service agreements had been made between public agencies (predecessors of SEPTA), Penn Central, and Reading Railroads (now part of ConRail). The purpose of the agreements was to continue service on 13 suburban rail lines. SEPTA assumed that responsibility and, in 1970, leased the suburban rail facilities for 99 years. Under the Rail Reorganization Plan, SEPTA began to manage and regulate the tariffs of the ConRail suburban services, both within its constituent country region and in the following areas: Schuylkill, Berks, and Northampton Counties in Pennsylvania; Mercer County in New Jersey; and New Castle County in Delaware. SEPTA also obtained operating agreements among itself, ConRail, and AMTRAK for operation of SEPTA-ConRail services over AMTRAK's Northeast Corridor and Harrisburg Corridor Lines.

In 1968, SEPTA acquired the Philadelphia Transportation Company, now the City Transit Division (CTD), which operates 2 heavy-rail lines and 12 light-rail lines. In 1970, SEPTA purchased the Red Arrow system and its three suburban rail lines to complete the public takeover of all the rail systems it now controls.

PATCO's Lindenwold Hi-Speed Transit Line opened in 1968. It interfaces with SEPTA rail lines in downtown Philadelphia, crosses the Delaware River to Camden, New Jersey on the Benjamin Franklin Bridge, and continues along a former suburban railroad right-of-way through several suburban communities to Lindenwold, New Jersey. The line interfaces with ConRail suburban rail lines in New Jersey which, in turn, serve other suburban and seashore communities in New Jersey. The Lindenwold line is successor to a number of older transportation services in the area. In 1854, ferries connected Philadelphia and Camden and rail lines linked the ferry with numerous suburban and seashore communities in New Jersey. The Benjamin Franklin Bridge was built in 1926 to provide a highway link between Philadelphia and Camden. The bridge contained provisions for both light-rail and heavy-rail lines. A light-rail line has not been installed. A heavy-rail system, called the Bridge line, was opened in 1936 and connected Philadelphia and Camden. It had only light patronage, except during World War II, but its existence encouraged studies of a longer and more useful system. In 1962, a plan was adopted to develop the Lindenwold line. When the line opened in 1968, it replaced the older heavy-rail system and a suburban rail route to Lindenwold, New Jersey. The line interfaces with the SEPTA rail network in Philadelphia and with the ConRail lines, which have long served suburban communities and the seashore. New Jersey DOT subsidizes the ConRail service and owns the suburban rail equipment.

The Lindenwold line is owned by the Delaware River Port Authority and is leased and operated by PATCO. The parent authority owns other transportation facilities in the region, including the toll bridge between Philadelphia and Camden used by the transit system.

PATCO Heavy-Rail Transit System

Routes[71]

The Lindenwold line is 14.2 miles long and is double-tracked. It includes 13 stations: five in Philadelphia, three in Camden and one each in Collingswood, Westmont, Haddenfield, Ashland, and Lindenwold. The average distance between stations is almost 1.2 miles.

Equipment

PATCO now owns 75 cars and plans to procure 46 new cars to meet growing demands. Each car is 67 ft 10 in. long, 10 ft 1.5 in. wide, and 12 ft 4 in. high and weighs about 78,000 lb. The average seating capacity is 77-1/3 passengers/car. The cars, built by Budd and powered by General Electric, are of two types: 25 have control cabs at each end and can operate as married pairs. Trains can be of any mix of cars and can be of any length up to six cars.

Service

The system operates 24 hr a day, every day of the year. This practice indicates that policy makers consider constant availability of service to be important. Many other rail systems discontinue operations part of each day.

Service is frequent during most hours of the day and never longer than 1 hr between trains. On weekdays, the headway interval is 5 to 10 min from 5 am until midnight, and then drops to 30 min or 1 hr until

5 am. On weekends and holidays, headways are somewhat longer than weekdays, but never exceed 1 hr. The system operates more than 300 trains on the typical weekday and more than 100,000 trains during a year. Most trains operate from one end of the line to the other and stop at all stations. However, some trains make short runs and some skip certain stations.

In 1976, the diurnal distribution of patronage on a typical weekday was as follows:

12:00 pm - 6:30 am	4.0%
6:30 am - 9:30 am	36.8%
9:30 am - 3:30 pm	13.4%
3:30 pm - 6:30 pm	33.9%
6:30 pm - 12:00 pm	11.9%

Note that 6 hr of peak-traffic during the morning and afternoon account for more than 70% of the day's patronage. Another 6-hr period after midnight accounts for 4%.

The capacity of the system is varied throughout each day by changing the frequency of service and the length of trains. This practice saves money and energy. The distribution of train length on a typical weekday is as follows:

Cars per Train	Trains	Percent of Trains
1	52	15
2	134	38
3	78	22
4	16	5
6	72	20
	352	100

More than one-half of the trains contained only one or two cars. The Lindenwold line is outstanding among U.S. heavy-rail systems in this respect. Two design characteristics facilitate changes in train length: first, the storage yard is conveniently located just beyond the last station at the suburban end of the line; and second, the physical process of coupling and uncoupling cars is relatively easy. Obviously, these design features and the practice of varying train lengths are highly desirable from the viewpoint of energy conservation. Even so, in the early morning hours and during other slack periods, the short trains have more capacity than needed.

Maximum train speed is 75 mph, with acceleration at 3 mph/sec and braking at -3 mph. The typical train makes the full 14.2 mile run with stops at all 13 stations in 24 min; the average speed is 36 to 38 mph.

During periods of heavy traffic, the train is said to be much faster than bus or auto or parallel routes. The typical traveler making a roundtrip by rail saves 30 min each day compared to private auto and 1 hr each day compared to bus.

PATCO provides parking lots at suburban stations to increase the attractiveness of transit service to those riders who could commute by auto. There are 9500 parking positions and most travelers gain access to the service via auto. Of the parking spaces, 40% are always usable without charge and the remainder are free after 10:00 am.

In 1975, patronage on a typical workday was about 42,000 passenger trips or about 21,000 roundtrip patrons. Fares range from 40 to 90¢, depending on distance.

During 1975, the system generated 4,192,790 car-miles and transported 11,120,000 passengers. PATCO estimates that the average trip length was 8.5 miles. Total service was approximately 94.52 million passenger-miles.

The system generated 324,242,000 seat-miles and had a systems average load factor of 29%.

Energy Usage

PATCO reported energy consumption of 40,526,380 kWh in 1975. This amount is assumed to be total energy purchased, although that is not certain. Based on national average heat values, heat rates and losses explained in Section I, this is equivalent to 3.14 million gal of fuel oil and 457 billion Btu.

Energy Intensity

The alternative statement of energy intensities for the Lindenwold lines is presented here:

- Service per gallon of fuel:
  1.34 car-miles
  3.54 passenger trips
  30.14 passenger-miles
- Energy per car-mile:
  9.66 kWh
  109,000 Btu
- Energy per passenger trip:
  3.64 kWh
  41,000 Btu
- Energy per passenger-mile:
  0.43 kWh
  4,800 Btu

Economic Data

In 1975, expenses were reported at $13.4 million, including $6.1 million for the rental of leased facilities from the parent corporation and $7.30 million for materials, services, and labor. Power cost $1.4 million, or about 10% of the total. Income was $6.6 million, including $6.3 million from fares and $0.2 million from parking. Net loss for the year was $6.8 million. The loss is covered by the parent corporation. In fact, all but $0.7 million of the loss is covered by foregoing the rental payment.

Power cost was 30¢ per car mile, 0.43¢/seat-mile, and 1.48¢/passenger-mile. The average cost per passenger trip was $1.20 and the average fare was 57¢. The net loss averaged 63¢/passenger trip.

Proposed Expansion

Studies have been made for additions and improvements to the PATCO system. One new intermediate station is being added to the existing line and 46 new cars are being procured. Consideration has been given to extending the existing line and adding two branches.

One alternative among several was studied from the viewpoint of energy intensity. It would add 38 miles of double-track line, 20 new stations, and 146 cars at a total cost of $681 million. The additional system would cause the following additions to services provided:

80,440 daily passengers
17.3 million car-miles
415 million passenger-miles
24% load factor

The load factor for the incremental service is less than the 29% now experienced. Generally, reducing the load factor tends to increase energy intensity per passenger-mile. On the other hand, the energy required on the extension per car-mile would probably be less than the present system average because of relatively long spaces between stations. These factors tend to offset one another, and it is likely that the new services would experience an energy intensity per passenger-mile not much different from the system average energy intensity now observed.

SEPTA Energy Allocation

In 1975, SEPTA purchased 189,388,800 kWh of electrical power at a total cost of $6,040,290. A special analysis was required to allocate energy usage among the electrically powered systems operated by SEPTA.

SEPTA has reported that slightly more than 82% of the energy purchased was delivered to substations designed primarily for the operation of vehicles, and has provided a breakdown by system type. The remaining cost of energy purchased, almost 18%, was assumed to have been used primarily for fixed facilities, such as stations, yards, shops and offices, and was allocated among systems in the same proportions as energy for the operation of vehicles.[76] The following tabulation outlines the procedure used and the results of the analysis.

Table 7-2

SEPTA ENERGY ALLOCATIONS

	Amount	Percent[a]	Allocation[a] of Total Electrical Energy Purchased kWh (000,000)
Transit Vehicle Operation			
City Transit Division			
Heavy-rail	$2,925,923	59.06	111.856
Light-rail	1,254,525	25.32	47.959
Trackless trolley[a]	313,631	6.33	11.991
Red Arrow Division	459,949	9.29	17.583
Subtotal	4,954,028	100.00	
Facilities	1,086,262[a]		
Total	$6,040,290		189.389

Sources: SEPTA except as noted

[a]Derived

SEPTA City Transit Division Heavy-Rail Transit System

Routes

SEPTA City Transit Division (CTD) operates two heavy-rail rapid transit lines: the Market-Frankford line and the Broad Street line, which includes the Broad-Ridge Spur. The two lines combine for a total of 24.5 miles of line with 54 stations.

	Line (Miles)	Stations	Average Station Spacing (Miles)
Market-Frankford	13.03	28	0.48
Broad Street	9.90	22	0.47
Broad-Ridge Spur	1.57[a]	4	0.52
Total Heavy-rail	24.5	54	0.49

[a]Derived

The Market-Frankford line is double-track throughout with 0.55 mile at grade, 3.79 miles in subway, and 8.69 miles elevated. The Broad Street line is double-track throughout except over nine stations in the middle of the line where four tracks have been provided for express services. It has 0.23 mile of line at grade and 9.67 miles in subway. The Market-Frankford line is broad gage.

Equipment

The 1976 SEPTA heavy-rail car fleet consisted of 490 cars. Each line has its own car series, as shown in Table 7-3.

No cars have air conditioning although the Market-Frankford cars may have this feature added soon. Cabs are placed at both ends of each single car and each two-car married pair. The Market-Frankford line cars have 400 hp per car and the Broad Street line cars have 420 hp per car. All cars pick up 630 Vdc power from a third rail.

Service

Heavy-rail rapid transit service is provided on three routes: the Market-Frankford line, the Broad Street line, and the Broad Street-Ridge Spur. The two main routes operate 24 hr a day, 7 days a week. The Broad-Ridge Spur operates from 5:30 am to 9:00 pm weekdays, from 6:30 am to 9:00 pm Saturdays, and is closed on Sundays and holidays. Express or skip-stop trains are run on both main routes during peak hours.

During 1976, headways on the Market-Frankford line were 2 min during peak hours, 7-1/2 min during the base period, and 10 to 15 min during night hours. The Broad Street line had the same headways except peak period headways were 3-1/4 to 4 min. The broad-Ridge Spur headways varied from 9 to 30 min during the day. On the total heavy-rail system, a maximum of 334 cars are operated in morning peak service, a maximum of 352 cars in evening peak service, and a minimum of 126 cars during weekday base period.

Table 7-3

SEPTA HEAVY-RAIL CAR FLEET

Line	Market-Frankford	Broad Street		
Series	601-646, 701-924	151-200	1001-1026	1-150
Number of Cars	45 singles 222 in married pairs	50	25	148[a]
Year	1960-1	1938	1936	1928
Weight, lb	51,300 - singles 48,730 - doubles	90,000	90,000	90,000
Length (over anti-climbers)	55'0"	67'6"	67'6"	67'6"
Width	9'1"	10'3-1/2"	10'3-1/4"	10'3-1/2"
Height	12'9-7/16"	12'4"	12'4"	12'4"
Seats	54 singles 56 doubles	71	67	67
Average Seats	55.66		67.90	

[a]Derived

In calendar year 1975, SEPTA's heavy-rail transit lines moved 84,638,000 passengers an average 4.95 miles/passenger trip and provided total service of 417.2 million passenger-miles. The systems generated 14.56 million car-miles at an average service speed of 16.5 mph.[72] Nonrevenue cars-miles were less than 1% of the revenue car-miles. See Table 7-4.

SEPTA statistics indicated that patronage averages approximately 347,000 passengers/weekday, 156,000 passengers/Saturday, and 75,000 passengers/Sunday. The Market-Frankford line carried 62% of the total passengers and generated 63% of the total car-miles. During a weekday morning period, the average Market-Frankford line car carried 58 passengers (a load factor of 1.04--i.e., 1.04 passengers/seat) and the average Broad Street line car carried 47 passengers (a load factor of 0.69). SEPTA reports load factors can reach 2.0 at peak hours and 0.85 at base hours for the Market-Frankford line and 1.8 and 0.55, respectively, for the Broad Street line.[72] The fewer seats per car on the Market-Frankford line compared to the Broad Street line cars contribute to the greater load factor. On both lines, over one-half of all weekday rides occur during the two peak periods.

Table 7-4

CY 1975 SERVICES FOR SEPTA

	Market-Frankford Line	Broad Street Line	Total Heavy-Rail
Total car-miles	9,129,000	5,431,000	14,560,000
Revenue passengers	36,906,000	20,670,000	57,576,000
Transfer passengers	15,041,000	11,698,000	26,739,000
Free passengers	204,000	119,000	323,000
Total passengers	52,151,000	32,487,000	84,638,000
Average trip length	5.77	3.58	4.95
Total passenger-miles	300.91 million	116.30 million	417.2 million
Average passenger load per car	33.0	21.4	28.8
Average load factor	0.59 (at 55.7 seats/car)	0.32 (at 67.9 seats/car)	0.48 (at 60.3 seats/car)

Energy Usage

In 1975, total electrical energy usage by the heavy-rail system was 111.856 million kWh ac. (See SEPTA Energy Allocation, above.) Of this, about 91.720 million kWh ac was used mainly for operation of vehicles and the remainder was used by fixed facilities. However, SEPTA reports that in rail operations about 13.5% of power purchased at substations designed for vehicle operations is actually used for nontraction purposes. An additional 10% is lost in ac-to-dc conversion. Thus, the energy finally delivered and used for vehicle operation is derived to be 71,410,000 kWh dc. (See Table 7-5.)

Table 7-5

SEPTA HEAVY-RAIL ENERGY USAGE FOR CY 1975

Total energy purchased, kWh ac	111.856 million
Fixed facilities	
Most shops, stations, offices, etc.	20.134 million
Auxiliary power from substations	12.382 million
ac-to-dc conversion losses	7.934 million
Energy used to operate the vehicles, kWh dc	71.406 million
Equivalent gallons fuel	8.66 million
Equivalent thermal energy, Btu	1,262 billion

The SEPTA heavy-rail system consumed energy equivalent to 1,262 billion Btu or 8.66 million gal of fuel oil. (See Section I for equivalency factors.)

Energy Intensity

Alternative statements of system average energy intensities for the SEPTA heavy-rail lines are presented here:

- Service per gallon of fuel:
  1.68 car-miles
  9.78 passenger trips
  48.40 passenger-miles
- Energy per car-mile:
  7.68 kWh
  86,700 Btu
- Energy per passenger-trip:
  1.32 kWh
  15,000 Btu
- Energy per passenger-mile:
  0.267 kWh
  3,000 Btu

SEPTA City Transit Division Light-Rail Transit System

Routes

At the end of 1975, the CTD had 12 routes and 74.2 miles of double-track line--71.4 miles on city streets and 2.8 miles underground; there are 8 stations and 692 car stops. The track is broad gage and power is drawn from 630 Vdc overhead trolley lines.

The five subway-surface lines share the subway but branch at the surface for a total of 21.4 miles of line. In addition, seven surface routes operate on 52.8 miles of line. The light-rail lines are distributed throughout Philadelphia and extend short distances into suburban communities.

Equipment

In November 1976, CTD had 290 PCC-type cars. Details on the fleet are available for 1975 when there were 304 cars. The 1975 fleet was made up of five series of PCC cars made in 1940-2, 1946, 1947, and 1948. The cars are 46 ft 0 in. to 46 ft 5-3/8 in. long (over the bumpers), 8 ft 5-1/4 in. to 8 ft 5-3/8 in. wide and from 10 ft 5/8 in. to 10 ft 3-3/8 in. high. The cars weigh about 38,000 to 39,000 lb each. The five series had 53, 53, 51, 47, and 45 seats/car for an estimated weighted average of 49 seats/car.

All the cars operate as single units with cabs at one end only. Each car has 220 hp. None have air conditioning.

Service

Some CTD light-rail routes operate 24 hr a day, 7 days a week while others are discontinued from about 1:30 am to about 5:00 am. The average headway is 6.4 min. At the end of 1975, 201 cars were in operation during morning peak service and 189 during evening peak service.

SEPTA supplied average passenger-trip lengths for each light-rail line, which averaged to 3.74 miles on the subway surface lines and 1.89 miles on the surface lines, giving a combined average trip length per light-rail line of 2.8 miles.

In CY 1975, the SEPTA CTD light-rail systems generated 6,263,000 car-miles while moving 39,658,464 passengers a total of 111,044,000 passenger-miles.[74] See Table 7-6.

Table 7-6

CY 1975 SEPTA CITY TRANSIT DIVISION LIGHT-RAIL SERVICES

Total car-miles	6,263,000
Revenue passenger trips	26,167,464
Revenue transfer passenger trips	9,191,000
Nonrevenue passenger trips	4,300,000
Total passenger trips	39,658,464
Average passenger-trip length, miles	2.8
Total passenger-miles	111,044,000
Average passenger load per car	17.73
Average load factor (at 49 seats/car)	36%

Energy Usage

SEPTA spent $1,568,156 to obtain power for their substations for light-rail car and trackless trolley coach operation (figures supplied by SEPTA). SEPTA estimates approximately 20% of this power was used by the trackless trolley coach system. The total energy purchased for the CTD light-rail systems is calculated to be 47,959,000 kWh ac (see Table 7-7). This total is equivalent to 541 billion Btu or 3.71 million gal of fuel oil.

Table 7-7

SEPTA LIGHT-RAIL ENERGY USAGE FOR CY 1975

Total energy purchased, kWh ac	47,959,000
Energy purchased at substations	39,326,000
Fixed facilities	
Most shops, stations, offices, etc.	8,633,000
Auxiliary power from substations (13.5% of power to substations)	5,309,000
ac-to-dc conversion losses (10% of remainder)	3,402,000
Energy used to operate the vehicles, kWh dc	21,982,000
Total energy purchased, Btu	541 billion
Equivalent gal of fuel of total energy purchased	3.71 million

Energy Intensity

Alternative statements of energy intensities for the SEPTA light-rail lines are presented here:

- Service per gallon of fuel:
  1.69 car-miles
  10.68 passenger trips
  29.91 passenger-miles
- Energy per car-mile:
  7.6 kWh
  86,000 Btu
- Energy per passenger trip:
  1.21 kWh
  14,000 Btu
- Energy per passenger-mile:
  0.43 kWh
  4,900 Btu

Economic Data[73] for SEPTA City Transit Division

SEPTA's City Transit Division includes the heavy-rail system, two groups of light-rail lines (subway-surface and street), and trackless trolley coach lines. The services provided by each system in 1975 are summarized here:

	Passengers	Car-Miles
Heavy-rail	84,638,000	14,560,000
Light-rail	39,658,464	6,263,000
Trolley coach	12,779,000	1,987,000
	137,075,464	22,810,000

In their reports, SEPTA does not separate economic data for the different services provided by CTD. No suitable method has been found for allocating revenue, cost, and subsidies among these services. Economic data for the entire City Transit Division is presented in Table 7-8.

Table 7-8

ECONOMIC DATA FOR CITY TRANSIT DIVISION

Passenger revenue		$30,959,756	
Other revenue		704,770	
Total operating revenue			31,664,526
Total transportation expenses		18,337,514	
Total other operating expenses		35,390,006	
Total operating expenses			53,727,520
Net operating loss			22,062,994
Taxes			0
Operating subsidies	- federal	4,028,320	
	- state	12,878,108	
	- county	25,446	
	- city	2,920,499	
	- Total		19,852,373
Unexplained			-2,210,621

SEPTA Red Arrow Division, Light-Rail Transit System

Routes

SEPTA's Red Arrow Division (RAD) operated three light-rail lines just outside the city of Philadelphia in the Western suburbs: the Norristown high-speed line, the Media rail line, and the Sharon Hill rail line. The Media and Sharon routes have 2.3 miles of common track. Details on the lines are shown in Table 7-9.

Table 7-9

RAD FACILITIES SUMMARY

	Line Length (miles)	Number of Stops	Average Stop Spacing (miles)
Media/Sharon Hill common	2.3	11	0.23
Media	6.3	24	0.27
Sharon Hill	3.0	16	0.20
Norristown	13.2	22	0.63
Total RAD light-rail	24.8	73	0.35

All lines are on exclusive right-of-way except for about a 3/4 mile segment at the end of the Media line. The Norristown high-speed line is grade-separated with no crossings. The Media and Sharon Hill routes share the line between the 69th Street terminal and Drexel Hill Junction, a distance of about 2-1/4 miles, which includes 11 stops and 10 crossings. The remainder of the Media line has 16 crossings and the remainder of the Sharon Hill line has 19 crossings. All of the crossings are protected and controlled by the rail system or tied into the traffic signal cycle. The majority of crossings occur at passenger stops.

All of the Norristown line is double-track except about 0.7 mile of single-track at the Norristown end. All of the Media line is double-track except about a 1-3/4-mile single-track section on the outer portion of the line. All of the Sharon Hill line is double-track except about 9/10-mile single-track at the end of the line.

The Norristown line (Table 7-10) owns three types of cars. All are standard gage, are powered from a third rail, and have multiple-unit control.

The Media and Sharon Hill routes (Table 7-11) use four types of cars. All are wide gage and are powered from overhead conductors.

The Bullets, which were constructed almost entirely of aluminum, were built to be aerodynamically streamlined and lightweight. The Liberty Liners are four-car articulated trains with airconditioning. Because of the large amount of current the Liberty Liners draw when starting, only one of the two trains is used at a time; during 1975, this usage was limited primarily to the evening rush (4:00 to 5:30 pm). The series 77-86 cars were used primarily during rush hours in 1975. Most of the current car fleet is expected to continue in service for at least the next few years.

All cars are double-ended, since all lines dead-end without turnaround track, except the Upper Darby terminal of the Media/Sharon Hill line.

Table 7-10

RAD EQUIPMENT SUMMARY, NORRISTOWN

Series	160-168	200-209 Bullet	Liberty Liner[a]
Number	9	10	2 (4-car sets)
Year	1924-29	1931	1941
Weight, lb	60,200	52,290	210,500
Length	50'6"	55'2"	156'
Width	9'0"	9'2"	9'2"
Height	11'10"	10'6-1/4"	12'11"
Seats	52	52	140
Power, hp	260	400	500
Top speed, mph	70	90	85

[a]Not in revenue service.

Table 7-11

RAD EQUIPMENT SUMMARY, MEDIA AND SHARON HILL

Series	77-86	73-75	1-9 Brilliners	11-24 Trolley
Consist capability	--	MU	--	MU
Number	10	2	9	13
Year	1932	1926	1941	1949
Weight, lb	41,552	49,000	42,350	49,000
Length	49'2"	47'10"	48'8"	50'5"
Width	8'10"	8'7"	8'10-3/8"	9'0"
Height	10'6"	12'5"	10'1/8"	10'0"
Seats	61	62	58	58
Power, hp	200	200	300	300
Top speed, mph	55	N/A[a]	60	65

[a]N/A: data not available

Service

The Norristown line operates from about 5:00 am to 1:45 pm weekdays, 5:30 am to 1:45 am Saturdays, and 6:00 am to 12:45 am Sundays; the Media line operates from about 5:15 am to 12:00 pm weekdays and Saturdays and from 7:00 am to midnight Sunday; the Sharon Hill line operates from about 5:15 am to 12:30 am weekdays and Saturdays and from 7:00 am to midnight Sundays. Weekday headways in 1975 were 15 min during rush periods (5 am to 9 am and 3:30 pm to 6:30 pm), 15 to 20 min in the base period, and 20 to 30 min in the evenings. Scheduled vehicles varied from 40 in the morning rush to 8 in the late evening. Total vehicle miles were 5105 per weekday, 3029 per Saturday, and 1856 per Sunday.

During 1975, SEPTA's Red Arrow Division light-rail system moved 5.71 million passengers a total of 27.6 million passenger-miles for an average 4.8 miles/passenger-trip, while operating 1.55 million car-miles. (See Table 7-12.) Average service speeds were 30.5 mph for the Norristown route, 17.2 mph for the Media route, and 14.5 mph for the Sharon Hill route.*

Table 7-12

CY 1975 RED ARROW DIVISION SERVICES[73]

Total car-miles	1,550,000
Total passenger trips	5,711,900
Average trip length (miles)	4.8[a]
Total passenger-miles	27,622,770
Average passenger load per car	17.84
Average load factor (at 59.7 seats/car average)	30%

[a]Derived

SEPTA statistics indicate that patronage averages about 20,300 passenger trips per weekday, 9900 passenger trips per Saturday, and 3950 passenger trips per Sunday or holiday. Average passenger-trip lengths reported by SEPTA were 6.7 miles for the Norristown route, 4.3 miles for the Media route, and 2.7 miles for the Sharon Hill route. These figures are one-half the one-way route lengths. The Norristown route carried 41% of all passengers, the Media route 31%, and the Sharon Hill route 28%.

SEPTA estimates deadhead car mileage at about 20 car-miles per weekday on the Norristown route, 45 car-miles per weekday on the Sharon Hill route, and zero on the Media route.

Energy Usage

In the subsection entitled SEPTA Energy Allocation, the Red Arrow Division was estimated to use 17.583 million kWh ac in 1975. This figure disagrees with some reported data, but the differences could not be reconciled. Based on the equivalence factors discussed in Section I, this electrical energy is equivalent to 1.361 million gal of fuel or 198 billion Btu.

Energy Intensity

Alternative statements of energy intensities for SEPTA's Red Arrow Division light-rail lines are presented here:

- Service per gallon of fuel oil:
  1.14 car-miles
  4.20 passenger trips
  20.30 passenger-miles
- Energy per car-mile:
  11.34 kWh
  128,000 Btu
- Energy per passenger trip:
  3.08 kWh
  35,000 Btu
- Energy per passenger-mile:
  0.64 kWh
  7,200 Btu

Economic Data[73]

Operating revenue and operating expenses for the RAD light-rail system during CY 1975 are presented in Table 7-13.

Table 7-13

ECONOMIC DATA FOR RAD LIGHT-RAIL SYSTEM

Passenger revenue	$1,763,669	
Other revenue	520,183	
Total operating revenue		2,128,852
Total transportation expenses	1,112,137	
Total general expenses	694,271	
Total operating expenses		4,315,580
Net operating loss		2,186,728
Taxes		0
Operating subsidies - federal		392,360
- state		1,373,855
- county		214,448
Total		1,980,663
Unexplained		206,065

Philadelphia Suburban Rail System

Routes

SEPTA's Commuter Rail Division operates the suburban rail system under purchase-of-service agreements with ConRail. The railroad continues suburban service short distances beyond SEPTA's five-county service area. In 1975, Penn Central had 101 stops on 149.7 miles of line, of which 129.0 miles are within SEPTA territory; the Reading had 116 stops on 264.6 miles of line, 148.7 of which were within SEPTA territory. All track is electrified except for the outer portions (151.7 miles) of three Reading branches.

As of December 31, 1975 the Penn Central fleet (Table 7-14) consisted of 258 cars and the Reading fleet consisted of 188 cars.

The Reading also had three 1500-hp diesel locomotives to pull the six nonpowered coaches.

In 1976 and 1977, SEPTA retired about 60 older suburban railcars and purchased more Silverliner IV cars and Rail Diesel cars. At the end of 1977 the fleet is expected to be:

	Philadelphia Div	Reading Div	Total
Silverliner IV	130	102	232
Silverliner	57	17	74
Rail diesel car	0	21	21
Total	187	140	327

Although most cars can go faster, the maximum operating speed allowed is 70 mph on the Reading track and 85 mph on the Penn Central track.

The Silverliner IVs have four 175-hp motors per car; the earlier Silverliners, four 125-hp motors; and the older electric cars, two 250-hp motors. The electric cars pick up 11,000 V power at 25 Hz from an overhead wire.

Service

In 1975, suburban rail service was provided on six routes by the Penn Central system and on seven routes by the Reading system. Weekday services begin between 5 and 6 am and continue until about 1 am. Saturday service is from about 6 am to 1 am, and Sunday service is from about 7 am to 1 am on most routes. Weekday peak period headways are

Table 7-14

PHILADELPHIA SUBURBAN RAIL SYSTEM FLEET

Type	Quantity	Year Built	Weight (lb)	Seats	Cars with Air Conditioning
Penn Central					
Electric passenger cars	90	1911-26, 1950-51	140,000	72	0
Pioneer III	5	1958	93,000	126[a] 125-128	5
Silverliner	57	1963-4, 1967	104,000	120[a] 100-127	57
Silverliner IV	106	1974-75	127,000	127[a]	106
Total	258			124[a]	168
Reading Company					
Electric passenger cars	160	1931-3, 1949, 64, 65,75	127,000-140,000	95.8[a] 64-129	48
Electric combined cars	6	19[illegible]	140,000	63.3[a] 62-66	0
Rail diesel cars	16	1951,55, 57,62	120,000	94[a] 49-103	16
Coaches	6	1927,48, 49	140,000	58[a] 57-60	6
Total	188			109[a]	70
Total SEPTA fleet	446			117[a]	238

[a]Average

between 10 and 70 min (average 23 min) on the Penn Central routes and between 8 and 60 min (average 23 min) on the Reading routes. Base and evening headways are between 30 and 120 min (average 62 min) on the Penn Central and between 20 and 240 min (average 83 min) on the Reading routes. Penn Central routes had between 166 and 186 cars in service during peak periods (5 to 9 am and 4 to 6:30 pm) and 18 in off-peak periods. Reading had between 145 and 174 cars in service during peak periods. When total vehicle miles for 1975 were divided by total vehicle hours, the Penn Central average service speed was 28.69 mph and the Reading was 30 mph.

In 1975, the SEPTA suburban rail operation generated 13.08 million car-miles and carried 29.66 million passengers an average of 12.1 miles/passenger-trip. Total passenger-trip miles were 359.8 million and the average car load factor was 0.27. See Table 7-15 for a breakdown of the two systems. Both systems had almost identical load factors. Average daily passenger trips were:

	Weekday	Saturday	Sunday & Holiday
Penn Central	63,436	19,606	8,387
Reading	43,892	14,284	3,899
Total	107,328	33,890	12,286

Table 7-15

CY 1975 PHILADELPHIA SUBURBAN RAIL SERVICES[75,77]

	Penn Central	Reading	Total
Total car-miles			
SEPTA territory	6,337,926	6,744,800	13,082,726
Total service	6,337,926	7,402,000[a]	13,740,000
Total passenger trips			
SEPTA territory	17,568,272	12,088,119	29,656,391
Total service	17,568,272	12,478,535[a]	30,046,807
Average passenger trip length (miles)			
SEPTA territory	10.8	14.0	12.1
Total service	10.8	15.2	12.7
Total passenger-miles			
SEPTA territory	190,526,454	169,297,658	359,824,112
Total service	190,526,454	189,714,417[a]	380,240,871

[a]Includes non-SEPTA operations from Pottstown to Reading and Pottsville; from Quakertown to Bethlehem; and from West Trenton to Newark.

Most of the patronage (estimated by SEPTA at about 60%) occurs during the morning and evening rush hours on weekdays.

Beyond SEPTA, the Reading continues service on the outer portions of three routes for a total route mileage of 264.6 miles. Data reflecting the total Philadelphia commuter operation (including operation beyond the SEPTA territory) are detailed in Table 7-15. Therefore, the total Philadelphia commuter rail operations in 1975 generated 13.74 million car-miles and carried 30.05 million passengers an average trip length of 12.7 miles. These total figures are used later for energy intensity calculations.

The diesel-powered portion of the Reading suburban operation generated 60,416 locomotive unit-miles on road service and 85,464 locomotive unit-miles in yard switching, totaling 145,880 unit-miles. Passenger diesel locomotive train-miles were exactly one-half of the road service locomotive unit-miles, meaning that two of the three diesel locomotives were part of each train. A total of 160,000 passenger coach-miles were generated by the diesel locomotives. The self-propelled commuter cars on the Reading line moved 7,242,000 car-miles.

Energy Usage

In 1975, 117 million kWh of ac electric energy and 663,229 gal of diesel fuel were purchased for Philadelphia suburban rail vehicle operations. Of the 55,321,832 kWh purchased for Reading car operation, 2,665,581 kWh (4.8%) were used for yard switching. Of the 663,229 gal of diesel fuel purchased, 568,224 gal were used for rail diesel cars and 94,985 gal were used by push-pull trains on the Reading non-electrified routes.

Data on Penn Central were not reported separately but have been derived.

Based on national average heat rates, distribution losses, and equivalent fuel oil required, in 1975 the Philadelphia suburban rail operations used a total energy equivalent of 1,413 billion Btu or 9.73 million gal of fuel oil for vehicle operation. Table 7-16 contains more detail.

Energy Intensity

Because total energy data were not available, and because most of the energy used is for vehicle operation, energy intensities are based on vehicle energy consumption data:

- Service per gallon of fuel oil:
  1.34 car-miles
  3.09 passenger trips
  39.08 passenger-miles
- Energy per car-mile:
  103,000 Btu

- Energy per passenger trip:
  47,000 Btu
- Energy per passenger-mile:
  3,700 Btu

SEPTA's Commuter Rail Division has measured on-board car energy usage while simulating regular service. The newest car, the Silverliner IV, measured 14.3 kWh dc/car-mile while operating in normal local service with a 20,000 lb car load to simulate a full passenger load (but without heating or air conditioning operating). The Silverliners consumed 11.0 kWh dc/car-mile.

Table 7-16

ENERGY USAGE - PHILADELPHIA SUBURBAN RAIL FOR 1975

	Penn Central	Reading	Total Suburban Rail
Electric			
ac kWh purchased for car operation	61,861,609[a]	55,321,832	117,183,441
Equivalent Btu	697.68 billion	623.92 billion	1,321.6 billion
Equivalent gal of fuel oil	4.787 million	4.281 million	9.068 million
Diesel			
Gal of diesel fuel purchased		663,229	663,229
Total equivalent Btu		91 billion	91 billion
Total			
Total equivalent Btu	698 billion	715 billion	1,413 billion
Total equivalent gal of oil	4.787 million	4.944 million	9.731 million

[a]Derived

Economic Data[75]

Operating revenue and operating expenses for the SEPTA-operated portions of the Penn Central and Reading suburban rail operations for CY 1975 were:

Revenue			$22,645,300
Total expenses			51,027,700
Operating loss			28,382,400
Financial Operating Assistance (Subsidies)			
Federal	$ 2,892,000		
State	13,573,000		
Local	6,786,000		
Total		23,251,000	
Absorbed by railroads		-5,131,400	

The average cost per passenger-trip was $1.72 and the average fare was 73¢. Subsidies averaged 78¢ per passenger-trip. Fuel and power cost 42¢/car-mile and 15.4¢/passenger-mile.

VIII PITTSBURGH REGION

General

The Port Authority Transit (PAT) of Allegheny County was created by the 1956 state legislature to serve Pittsburgh and its surrounding suburbs by light-rail and motor bus. Under a 1959 amendment, PAT acquired the Pittsburgh Railways Company, 30 independent bus lines, and 2 cable-powered inclined rail shuttles. In 1964 PAT began operating the first unified transit system in the Pittsburgh area. Currently, the rail system serves only approximately one-third of the total population of 1.6 million.

In addition to the PAT light-rail system are two suburban rail-lines. The Pittsburgh and Lake Erie Railroad Company operates over a 31.2-mile line with one diesel locomotive and four coaches making one roundtrip train each weekday. The Baltimore and Ohio Railroad (now Chessie) receives PAT aid to operate over an 18-mile line with ten runs per weekday using four RDCs and five coaches. Because of the small size of these operations compared to other suburban rail systems, these suburban rail services were not analyzed.

Light-Rail Transit

Route

PAT operates over 24.1 miles of line, of which 0.6 mile is tunneled.[78] In the suburbs, the system has the right-of-way almost exclusively; in the city, the line is in mixed traffic, although in congested areas some signal prioritization is used. Average stop spacing is 0.15 mile.[79]

Equipment

The car fleet consists of 95 PCC cars: 26 cars with 54 seats/car (made in 1946) and 69 cars with 50 seats/car (made in 1948). The cars weigh 42,000 lb and have a top speed of 42 mph.[79] All cars are single-ended and have no MU connections. Six-hundred volt dc power is collected by overhead trolley.

Service

PAT operates five light-rail routes over a total 35 route-miles. During weekdays, the number of rail vehicles scheduled to run varies from 82 during the morning rush to 17 at midday. The number climbs again to an average of 76 in the afternoon rush and drops again to 8 in the evening. The hours of service begin at approximately 4:30 am and terminate about 2:00 am. Normally, 19 cars are scheduled for Saturdays and 9 for Sundays. PAT operated 7,890 car-miles per weekday, 2,658 car-miles per Saturday, and 1,837 per Sunday. Average train headways vary from 5 min during peak periods to 15 min during off-peak periods.

In 1975[80] 7,302,962 passengers were carried. The system generated a total of 2,102,248 vehicle-miles at an average scheduled speed of 13.0 mph.[79] Data on average trip lengths were not found.

Energy Usage

In 1975, PAT reported electric power consumption of 15,151,618 kWh for light-rail vehicle operation. Nonvehicle operation energy data was not available and was assumed negligible. Based on national average heat rates and losses, this is equivalent to 171 billion Btu and 1.17 million gal of fuel oil.

Energy Intensity

Alternative statements of energy intensities for the PAT light-rail system are presented here:

- Service per gallon of fuel:
  1.80 car-miles
  6.24 passenger trips
- Energy per car-mile:
  7.2 kWh
  81,000 Btu
- Energy per passenger trip:
  2.07 kWh
  23,000 Btu

Economic Data

For 1975, PAT did not separate light-rail economic data from the total public transportation operation, which is largely a bus operation. Since the street-car operation is very small (5% in terms of vehicle miles for 1976) compared to the total public transportation service, no attempt was made to try to estimate PAT light-rail operating financial data.

IX SAN FRANCISCO REGION

The San Francisco region is served by three rail passenger systems: the Bay Area Rapid Transit (BART) heavy-rail system, the San Francisco Municipal Railway (Muni) light-rail system, and the Southern Pacific (SP) suburban railroad. Physical characteristics of the system are summarized in Table 9-1.

Table 9-1

SAN FRANCISCO REGION EQUIPMENT AND FACILITIES

	Line Miles	Stations	Cars	Locomotives
BART heavy-rail	71	34	450	-
Muni light-rail				
Old	19.4	1	115	-
New	19.9	9	100	-
SP suburban rail	47	26	83	23

BART Heavy-Rail Rapid Transit System

History

BART provides service in three counties on San Francisco Bay: Alameda, Contra Costa, and San Francisco. It crosses the bay in underwater tubes and links San Francisco with Oakland, Berkeley, and other East Bay communities.

San Francisco and the East Bay area have had rail passenger service for more than a century. The water crossing was made by ferry until the late 1930s, when the San Francisco-Oakland Bay Bridge was constructed with tracks for the Key System. The Key System originated in downtown San Francisco, crossed the bay on the lower deck of the bridge, and then branched into several radial lines extending through Oakland, Berkeley, and other East Bay communities. The Key System experienced severe financial difficulties after World War II and its operations were finally taken over by the Alameda-Contra Costa Transit District in 1960. Buses replaced rail service on the bridge and the rail lines were removed to increase the capacity for autos. In return, the bridge authority paid the cost of constructing BART's underwater rail crossing several years later.

In 1951, the California legislature created a special nine-county commission to study transportation problems in the Bay Area. In 1956, the commission recommended construction of a 385-mile regional transportation system, of which Phase I would have included 123 miles of line. In 1957, after the commission had recommended legislation to create the BART District, the legislature created the district, which initially comprised five counties.

In 1962, San Mateo county withdrew from the district, citing as reasons the prospect of high property taxes and the availability of the Southern Pacific suburban railroad. Marin county also withdrew, citing the high cost of an underwater crossing of the Golden Gate. These changes reduced the district to three counties and the Phase I program to 71 miles of line. In November of 1962, the voters of the three counties approved a $792 million General Obligation Bond for construction of the system.

Consultants were retained in 1959 but full-scale design engineering was delayed by litigation until mid-1963. Construction began in 1964 and was finished in July 1971. The first production cars were delivered in November 1971, and revenue service began on part of the line in 1972, more than 9 years after the bond election.[81]

The first increment of service began September 11, 1972 on 28 miles of the Fremont-Richmond route between Fremont and McArthur Station in Oakland. In January 1973, the second increment extended that route to Richmond over 11 miles of line. The third increment began in May 1973 on 17 miles of line between Concord and McArthur Station--the eastern end of the San Francisco-Concord route. The fourth increment started in November 1973 on a line located almost entirely within San Francisco between the downtown district and the Daly City Terminal at the western end of the system. The last increment of line placed in service was the transbay crossing between downtown San Francisco and the East Bay. Service started on that line in September 1974, 2 years after the start of revenue service. Since 1974, all of the BART line has been in regular use. However, at the end of the fifth year of revenue service, one of the four planned routes had not been initiated; the hours of service had not reached planned levels; and service was generally not provided on weekends.

BART has experienced a great number of difficulties, many of them imposed by outside forces. Inflation rates proved higher than planned and the effect of inflation was compounded by the delays. Numerous changes were made to overcome objections of cities and citizen's groups. In combination these factors increased costs to about $1.6 billion.

In the early years of operation, BART suffered low equipment reliability, long downtimes for maintenance, and high maintenance costs. These conditions often curtailed the availability of serviceable cars. In addition, safety regulations imposed by the California Public Utilities Commission limited system performance and capacity. The economic performance of the system was below early forecasts because of high operating costs and the delay in the development of patronage. Economic difficulties compounded the delays in the development of the system and the correction of deficiencies. BART's history has been marked by a series of financial crises and basic economic problems that remain to be solved.

Lines and Equipment

BART was conceived as a highly sophisticated and technically advanced system that would set new standards in performance and comfort. Many technical features of BART differ from other U.S. heavy-rail systems and some of these affect energy usage in important ways.

Some features tend to conserve energy. For example, BART's cars are the lightest high-speed, heavy-rail transit cars ever built. The use of choppers rather than resistors in the subsystem supplying power to traction motors avoids wasteful dissipation of energy during acceleration. The long intervals between stations--2.2 miles on the average--make starts and stops relatively infrequent and further reduce energy requirements for acceleration. BART cars are designed for regenerative braking except at very low speeds. (A hydraulic system is used at speeds below 4 mph.) Energy is generated by driving the traction motors during braking and can be returned to the third rail if it is receptive--that is, if there are other trains (or suitable loads) within the vicinity. Unfortunately, that condition does not usually prevail in BART and the energy is not recycled. Instead, it is dissipated as heat by means of resistor banks.

On the other hand, several features of BART tend to raise energy usage above the other systems. Four large motors (150 hp each) are required to accelerate to the top design speed of 80 mph and to maintain average speeds of 40 to 45 mph; these speeds are substantially higher than is common in other systems. All BART cars are air-conditioned. Cars are stored "hot" with lights on, heating and air-conditioning operating and other auxiliaries functioning.

BART designers sought a high degree of automation in the operation of trains and stations but were unable to eliminate station attendants and train operators. It is not clear that the degree of automation achieved by BART will have much effect on energy consumption. However, further advances in automation may be valuable for that purpose. Considerable difficulty has been experienced with controls for automatic train operations and the system has not yet achieved the 2-min headways for which it was designed.

BART owns 450 cars: 176 "A" cars and 274 "B" cars. The A cars have an operator's cab at one end; the B cars have no control cabs. All cars are powered and have multiple-unit controls for operation in trains. The cars operate under full automatic train control. Although there are few manual control functions, an operator is required on each train.

Cars were supplied by Rohr Industries, Inc., in three lots delivered between 1971 and 1975. The total price was $143 million, or an average of $318,000 per car. All cars are 10.5 ft high over the rail and 10.5 ft wide. The A cars are 75.0 ft long, the B cars 70.0 ft long. The car bodies are made of aluminum and the empty cars weigh 59,000 lb and 56,000 lb for the A and B cars, respectively. Both car types have the same passenger capacity (72 seats). The design standee capacity is 98 passengers at 2.7 sq ft per standee. The tare weight per passenger carried (empty weight divided by passenger load) is shown in Table 9-2.

Table 9-2

TARE WEIGHT PER PASSENGER

Passenger Load	A Car (lb)	B Car (lb)
72 seated passengers (load factor = 1.0)	820	780
Design capacity with 170 passengers (load factor = 2.4)	350	330
Crush capacity with 216 passengers (load factor = 3.0)	270	260

Clearly, increasing passenger loading reduces tare weight per passenger, and that, in turn, reduces energy intensity per passenger-mile.

A BART train must have two A cars and can have one to eight B cars. Thus, the minimum consist is three cars (216 seats) and the maximum is ten A and B cars (720 seats).

BART experienced very low car availability (about 60%) during the earlier years. Efforts to improve the reliability of components and to speed repair have increased car availability to 69% for B cars and 62% for A cars in September 1976 and further improvements were expected.

The BART network includes 71 miles of line: 19 miles underground, 25 miles elevated, and 27 miles at grade. BART's network diagram is similar to a hand-lettered "K": the upper left bar includes the Daly City Terminal and the line through San Francisco and across the Bay; the Fremont terminal is at the end of the lower left bar; downtown Oakland is on the crossbar; the Richmond terminal and Berkeley are on the upper right bar; and the Concord terminal is at the lower right bar.

The system has 34 stations, all of which have access to local transit lines. Passengers using both BART and local transit lines pay reduced fares on the local line. In the East Bay, the Alameda-Contra Costa Transit system connects with all BART stations. In San Francisco, Muni and BART have four collocated underground stations. Muni surface vehicles connect with all BART stations.

Parking is provided at most stations, except in downtown areas. BART has 18,570 parking stalls to serve about 66,000 daily patrons, or about one stall per 3.6 patrons. On the typical day, 83% of the parking stalls are used.[82] For persons commuting by bicycle, lockable bicycle racks are available, except at downtown stations in Oakland, Berkeley, and San Francisco.

Service

Initially, BART was scheduled to operate trains on four routes during peak hours:

Fremont - Richmond
San Francisco - Concord
San Francisco - Fremont
San Francisco - Richmond

However, only three routes were operating in 1977, since the San Francisco to Richmond route had not yet been initiated. Initially, only the San Francisco to Concord and Fremont to Richmond routes were to operate in slack periods and that practice has been followed. While BART trains were originally scheduled to operate every day, 20 hr each day, the system usually does not operate on weekends and operates somewhat less than 20 hr each weekday.

Each route was planned to be served every 6 min during peak hours, which would require 2-min headways on two parts of the system. At present, each of the three routes in operation is served every 12 min during peak hours; the shortest headways are 6 min. It was always planned that headways would be relatively long (e.g., 20 minutes) during midday and slack periods.

BART's inability to provide all of the planned service has somewhat discouraged patronage but has also tended to reduce costs. Existing services appear to satisfy most needs, and it is not clear that patronage would increase greatly, in the short run, if all planned services were provided. Eventually, all planned services may be needed to satisfy growing demands.

BART was the only rail passenger system treated in this research that had accurate data on the number of passengers served, their origins and destinations, and the number of passenger-miles of service rendered.

These data are produced by an advanced ticketing and fare collection system that uses magnetic tickets, automated turnstiles, and automated recording and data processing systems.

In the fiscal year ending June 30, 1976, BART generated 22,446,355 car-miles of revenue service, serviced 32,897,431 passenger trips and produced 443,145,000 passenger-miles.[83] Since the average system load factor for the year was 27.6%, BART has instituted a program to adjust train lengths to match changes in load and thereby to increase load factors.

Average trip length during the past fiscal year was 13.5 miles. This is 40% longer than forecasts made by BART and consultants in 1971. From the viewpoint of energy conservation, this difference warrants special consideration. One interpretation is that the speed and other attractive qualities of BART have encouraged travelers to choose homes further from their jobs and to make other personal choices that tend to lengthen trips. This suggests that energy intensity per passenger trip may be a better measure of energy cost vs effectiveness than energy intensity per passenger-mile. In other words, the energy used in transporting a person to and from work each day, by alternative modes, may be more relevant to transportation planners and energy conservation managers than the energy used per passenger mile.

Energy Usage

More is known about BART's usage of energy than is known about any other system treated in this research. Separate estimates are available (or can be derived) for electrical energy used for vehicle propulsion, vehicle auxiliaries, and operation of fixed installations. Information is also available on consumption of natural gas for heating. An estimate of the energy embodied in BART's capital assets is available and, by use of the same technique, an estimate has been prepared for the energy embodied in the various materials and services consumed in the operation of BART (other than electrical power and natural gas treated directly).

Consumption of electrical energy in FY 1975-76 was as follows:[84]

Vehicle propulsion and auxiliaries, kWh	165,144,000
Propulsion of vehicles, kWh	95,064,000*
Operation of auxiliary systems, kWh	70,080,000†
Fixed installations, kWh	63,598,000
Total kWh	228,742,000

*Derived.

†Based on 400 cars, 20 kW/hr, 24 hr/day and 365 days/year.

Based on national averages explained in Section I, BART's total electrical energy consumption is taken to be equivalent to 17.70 million gal of fuel oil or 2,580 billion Btu.

In addition, BART used natural gas containing 50 billion Btu for heating. Based on national averages discussed in Section I, this energy is equivalent to 343,000 gal of fuel oil or the purchase of 4.43 million kWh of electrical energy. Total energy consumed by the BART system is equivalent to:

18.04 million gal of fuel,
233.2 million kWh of electrical energy, or
2,630 billion Btu.

Energy Intensity

System average energy intensities are stated here:

- Service per gallon of fuel:
  1.24 car-miles
  1.82 passenger trips
  24.56 passenger-miles
- Energy per car-mile:
  10.39 kWh
  117,000 Btu
- Energy per passenger trip:
  7.09 kWh
  80,000 Btu
- Energy per passenger-mile:
  0.53 kWh
  5,900 Btu

Energy intensities for propulsion alone, excluding auxiliaries and fixed installations, are 4.24 kWh per car-mile. Ultimately, the propulsion energy may be recoverable and reused by regenerative braking and immediate transmission of the energy to another load. However, little or no recycling is done at present.

Capital and Indirect Energy Usage

BART has sufficient data to estimate both capital and indirect energy usage. In the discussion that follows, a number of terms commonly used in accounting practice are adapted to energy usage. Each term is underscored and explained or defined when first used.

Capital Energy

Healy and Dick[85] estimated the amount of capital energy (the energy consumed to create BART's capital assets) using two techniques: both produced similar results. One technique used an input-output energy model and detailed information on the energy content of the different classes of resources. The data on energy content of resources were used in conjunction with an analysis of BART construction and hardware contracts. The second method used the total cost of the project and an energy-per-dollar factor based on annual domestic energy consumption in the United States and the gross national product.

Healy and Dick estimated energy in BART's capital assets to be about 110,000 billion Btu. This can be placed in perspective by comparison with the annual consumption of direct energy (electrical power and natural gas) for the most recent fiscal year--1,930 billion Btu. Thus, capital energy exceeded direct energy for that year by a ratio of 41.8:1.

Indirect Energy

Operation of BART also requires consumption of indirect energy for the production and delivery of all of the materials and services other than electricity and natural gas required for current operations. The energy content of these resources could be estimated by the input-output technique mentioned above if sufficient data were available, but that type of analysis has not been possible in this research. However, the technique, based on energy-per-dollar of cost, also used by Healy and Dick, is readily usable for estimating indirect energy.

The energy-per-dollar factor is developed here. In 1975, U.S. domestic consumption of energy was 70.85 quadrillion (million billion) Btu; the gross national product was $1,498 billion. In that year, the average energy consumption was 47,300 Btu/dollar of GNP. In applying this method, it is assumed that the indirect energy consumed in the operation of BART during 1975-76 was 47,300 Btu/dollar of operating expense, excluding the cost of direct energy and the amortization of debt.

During 1975-76, BART's expenses totaled $58.9 million: energy cost $3.8 million and materials and services other than direct energy cost $55.1 million. Thus, indirect energy for that year was estimated to be 2,606 billion Btu, compared to an annual direct energy consumption of 2,630 billion Btu--a ratio of 0.99:1.0.

The system average energy intensity (5,900 Btu/passenger mile) included only direct energy, as with all other systems. If indirect energy were added, the new energy intensity would be 11,700 Btu/passenger mile. Readers are cautioned that this figure would only be useful in decision-making if discontinuation of operations were under study. However, indirect energy consumption, as estimated, is directly proportional to BART's budget (excluding costs of direct energy). Thus, savings of money made by cutting costs, increasing productivity of labor, curtailing service and similar measures would also save indirect energy. It is likely that much of the indirect energy usage by BART is fixed. That is, costs and the amount of indirect energy consumed are not easily changed. Detailed studies will always be required to determine the effects of specific decisions upon indirect energy usage.

Long-Term Average Energy Usage

A comprehensive measure of the long-term average energy usage is useful in making decisions about the construction of new rail passenger systems. Developing this figure requires a knowledge of the combined direct, indirect, and capital energy usage. Since direct and indirect energy usage are estimated annually, there is a need to annualize capital energy as well.

Reasoning used in accounting practice can be applied to this problem. That is, the capital energy can be depreciated or averaged over the expected service life of the system. The weighted average service life of BART's assets is 57 years. The capital energy estimate cited above was 111,000 billion Btu. Thus, the long-term average cost of BART's capital energy is 1930 billion Btu/year.

The three classes of energy usage can now be combined as follows:

Direct energy	2630 billion Btu/yr
Indirect energy	2606 billion Btu/yr
Capital energy	1947 billion Btu/yr
Total	7183 billion Btu/yr

Note that since the direct and indirect energy figures are based on a single, recent year's experience, those elements are subject to change. However, for the year in question, BART provided 443.1 million passenger miles of service and the long-term average energy intensity was 16,200 Btu/passenger-mile.

Again, the comprehensive energy figure is not relevant to any decisions yet to be made regarding BART. For example, almost all of the capital energy in BART has been expended in ways that preclude recovery, even by selling the assets of the system. On the other hand, if a decision to build an entirely new system were under consideration, estimates of long-term average energy usage would be highly relevant. The BART example only aids in gaining perspective for future decisions. Each new rail passenger project will require a specific analysis of its long-term average energy costs.

Economic Data

In 1975-76, BART received operating revenue of $21.7 million from passengers and incurred expenses of $58.9 million. Prorated to passenger trips, expenses were $1.79 and fares were 66¢. Operating subsidies were about $1.13/passenger trip. By this accounting, passengers paid about 37% of current expenses and subsidies covered about 63%. In addition, BART reported $26.1 million of unfunded depreciation and amortization on all assets. This brings the total costs to about $85.0 million. BART's capital costs are paid by subsidies. With capital costs included, fares account for only 26% of total costs.

BART's capital assets total $1,475 million, valued at cost. At $26.1 million/year depreciation, charges will accumulate to that amount in 57 years. The $26.1 million charge is only a rough measure of the long-term average cost of capital assets. About one-half of the cost of BART has been paid by public agencies. The remaining costs were paid from the sale of bonds early in the project, but the bonds will have to be ammortized by future tax revenues. The current cost of debt service is not known.

In the calculation of indirect and capital energy usage presented above, care was used to avoid double counting. Capital energy usage was computed for original construction only, and was not recognized again in depreciation or debt service. Indirect energy usage was computed using current expenses for all resources ($58.9 million) less costs of electrical power and natural gas ($3.8 million) or a net of $55.1 million. Indirect usage did not include the depreciation charges.

Muni Light-Rail Transit

Introduction

The San Francisco Municipal Railway (Muni) provides transit service in buses, trolley coaches, cable cars,* and street cars throughout the City and County of San Francisco. The area served is 46.5 square miles.[88] San Francisco has a resident population of 688,500 and the 1970 census indicated that 178,000 commuters enter the city from other communities each weekday.[89]

Privately owned transit systems existed in San Francisco at least as early as 1873, when cable car service began. In 1909, a bond issue

*Muni operates the last remaining grip cable cars in the world. The three remaining cable car lines enjoy a unique status as tourist attractions. This would seem to preclude their being subjected to the same degree of analysis and scrutiny for possible improvements in energy efficiency as other transportation facilities.

was adopted to construct the first Muni streetcar line, and in 1912 service was initiated. In 1944, the Muni acquired the principal private transit property, the Market Street Railway, and thereby tripled the size of the municipal system. In 1952, the last remaining private property (a cable car line) was incorporated into the system.

Many streetcar lines have been removed and replaced by buses. The rail system that remains is now undergoing an extensive renovation. On Market Street, surface tracks are being replaced by a subway, now nearing completion. The existing fleet of aging street cars will be replaced by new light-rail vehicles (LRV), now being built. Tracks are being rebuilt, a new electrical power system is being installed, and a new yard and shops are being constructed.

Equipment

Muni now owns 115 streetcars of the President's Committee Conference (PCC) type, built between 1946 and 1952. The cars vary from 46 ft to 50 ft 5 in. in length, and from 100 in. to 108 in. in width. The typical car weighs 36,000 lb. Seating capacities average 55 passengers/car and there is standing room for about 53 people at 2 sq ft/standee or about 91 people at crush load. The maximum total load for a typical car seldom exceeds 110 passengers. Acceleration is 3.7 mph/sec, with an effective top speed of 35 mph, but there is no internal speed limiting control and no speedometer.

The entire fleet is "single ended," meaning that a change of direction requires that the car be physically turned around by using a loop or a "Y." Unlike some other PCC systems, Muni's cars are not equipped for multiple-unit (MU) operation.

The existing fleet will be replaced by 100 new light-rail vehicles (LRV*), to be supplied by Boeing Vertol Company. The date of conversion is uncertain as both the production of cars and construction of facilities have been delayed. The Muni LRV is an articulated or "hinged" car 71 ft long and 8 ft 10.25 in. wide. Each unit seats 68 passengers (compared to 55 for the PCC car) and accommodates 29 standees at normal design load, allowing 6 sq ft/standee and excluding four of the six door passageways and the articulated floor. Alternative capacities are 66 standees at crush design load (3.6 sq ft/standee, including all space not occupied by seated passengers) and 151 standees at design capacity (1.2 sq ft/standee). Total capacity is taken as 219 persons--about double that of PCC cars.

Service acceleration is 2.8 mph/sec (maximum 3.1 mph/sec) with a top operating speed of 50 mph and service deceleration rate of 3.5 mph/sec. LRV cars are double-ended and have multiple-unit capabilities.

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*The term light-rail vehicle is used to denote streetcars today, especially the new ones.

Trains of one to four units can be operated. Propulsion is provided by two motors rated at 210 hp with dc chopper control. Service power (600 Vdc) is collected by an overhead pantograph. The cars have dynamic braking with an option for recovery of energy through regeneration.

Muni's LRV cars are loaded in two ways: by steps while operating in the street mode, and by a level walking surface at underground stations where floor-level platforms have been provided. Two doors on each side have adjustable floor surfaces. In the "down" position, the surfaces form steps; in the "up" position, the surfaces form a level floor. Two doors (one at the front right end of the vehicle in each direction of travel) have fixed steps and are only used for street loadings.

While underground, LRVs operate with cab signals and automatic speed protection, but at street level, they are operated by visual observation, as with the present PCC cars.

Energy requirements of the new LRV system differ from the old PCC cars in many ways and it appears likely that the overall result may increase energy intensity, measured as Btu per passenger mile. Three factors appear important:

- LRV vehicles weigh 67,000 lb empty and seat 68 persons, giving a total of 985 lb of vehicle weight per seated passenger.[88] The same measure for a typical PCC car is 656 lb of vehicle per seated passenger.
- LRV vehicles travel at higher speeds than PCC cars on some new underground routes. The energy required for higher speeds partly offsets the reductions in the number of stops in the subway.
- During slack periods, LRVs operate at lower load factors and higher energy intensities than PCC cars (unless LRV headways are lengthened or demands are increased).

Muni's 100 LRVs have greater capacity than the 115 PCC cars being replaced, for two reasons: the new cars have a slightly higher total seating capacity (6800 vs. 6300); and the higher speed of LRVs is exploited in the subway and tunnels, thereby allowing each vehicle to make more trips per day.

Routes

Muni tracks are located partly on streets in mixed traffic, partly on semiexclusive rights-of-way located in the medians of streets but with grade crossings, and partly in two tunnels through hills. The largest element in the Muni renovation program is the moving of streetcar tracks on Market Street to a new subway called Muni Metro. The downtown terminal, now at the Transbay Terminal on Mission Street, will be moved to Embarcadero station near the east end of Market Street and the waterfront. At the outer ends of the system, two lines may be extended short distances to connect with a BART station and the Muni shops. Other minor route changes will also be made. The renovated system will include 19.9 miles of double-track route, compared to 19.4 miles at present (see Table 9-3).

Table 9-3

LENGTHS OF LINE BY TYPE
Miles

	Old	New
Tunnels	2.9	2.9
Subway	0.0	3.3
Streets and at-grade	16.5	13.7
Total	19.4	19.9

Muni's new 3.2-mile-long subway, which is being constructed by BART, contains seven stations, four of which are located above BART stations. The seven stations--spaced at an average of 0.5 miles apart--will replace about 20 street car stops at average spacings of about 0.15 mile. While some travelers will enjoy reductions in riding time because of the subway, others will experience longer walks to gain access to the system.

The subway will connect directly with the Twin Peaks Tunnel. This 60-year old facility is about 2.1 miles long and includes one underground station. At the end of the tunnel will be a new surface station called West Portal. The combined subway and tunnel will provide 5.3 miles of exclusive right-of-way and nine stations. The average interval between stations will be 0.65 mile.

The Muni light-rail system includes five routes: J, K, L, M, and N. All share tracks on Market Street to Duboce, where the J and N tracks branch. Thereafter, most of the J tracks are on the street in mixed traffic. Most of the N line will also be on the street in mixed traffic, but the route will continue to use the 0.8-mile-long Sunset tunnel and will also use a new, experimental semiexclusive right-of-way about 0.6 mile long which has been constructed in a street median. The K, L, and M lines will continue west in the new subway and through the Twin Peaks Tunnel to West Portal Station, where all three lines surface. The L line remains on streets in mixed traffic west of West Portal. The K and M lines continue to share track for a short distance beyond West Portal and then diverge on separate tracks. Parts of the K and M lines are on semiexclusive streets in mixed traffic. The K line will be extended a short distance (0.6 mile) to connect with BART and a new car barn. The M line will also be extended 0.7 mile to the car barn. The J line is also being considered for extension to the car barn. The characteristics of all lines, including the M line extension (but not the J line extension), are summarized in Table 9-4.

Table 9-4

LENGTH OF LRV ROUTES
(Miles)

Route Designation	J	K	L	M	N
At-grade (street & semi-exclusive right of way)	2.2	2.0	2.7	3.6	3.9
Tunnel	0.0	2.1	2.1	2.1	0.8
Subway	2.4	3.2	3.2	3.2	2.4
Total (new)	4.6	7.3	8.0	8.9	7.1
Total (old)	(4.4)	(7.6)	(8.4)	(8.6)	(7.1)

Services

Streetcar operation is a relatively small part of the entire Muni system. For example, streetcars account for 14% of Muni's passenger revenue, 15% of total patronage, and 13% of both vehicle hours and vehicle miles in revenue service. Patronage by route, on a typical weekday, is about as follows:

N	26,100 passengers
K	21,500 passengers
L	19,100 passengers
J	17,400 passengers
M	13,600 passengers

Streetcar routes are not the most heavily patronized in the Muni system. Four bus routes carry more passengers than the N route and one bus route carries 49,100 passengers. Seventeen bus routes each carry more passengers than the M route. However, on the trunk line where several of the streetcar routes share the track, traffic is substantially higher than that carried by buses on streets.

All five routes have service on a 24-hr basis. However, to facilitate construction in recent years, buses have been substituted for streetcars from midnight to 5 am. In addition, supplementary bus service has been provided during the morning rush hours, when streetcars are in short supply because of maintenance problems.

Schedules for operation of the Metro have not yet been finalized. However, Muni has estimated that travel times in the subway and tunnel will be 15 min between Embarcadero and West Portal (a savings of 18 min), and 8 min in the subway between Embarcadero and the Duboce Portal (a savings of 15 min). One-way running time on routes K, L, and M will be reduced 18 min from current schedules of 39 to 45 min. The J and N lines, which enter the subway at Duboce Portal, are expected to shorten schedules by 15 min--from 30 min at present to 15 min on the J line and from 37 min to 22 min on the N line.

Operating statistics for a typical weekday reported by Muni are tabulated here, together with some derived data:

Total fleet, cars	115
Maximum scheduled for service, cars	104
Roundtrips scheduled	693
Vehicle miles scheduled:	
Revenue trips	9,941*
Deadhead travel	1,367*
Total	11,308
Vehicle hours scheduled:	
Revenue trips	885*
Deadhead and waiting	317*
Total	1,202
Average speed, revenue trips	11.2 mph
Total passengers	96,000
Per car	826
Per trip	137
Per revenue vehicle-mile	9.56
Per revenue vehicle-hour	107.34

Deadhead movements of empty equipment from and to storage yards, before and after regularly scheduled service, account for 12.4% of vehicle-miles. Deadhead movements and other idle time account for 26% of vehicle-hours. Considerable money and energy is expended on deadhead travel and the renovated system may experience even more deadhead mileage (especially on the J and N routes). A consultant to Muni is presently examining this issue to devise alternative means of reducing deadhead mileage and cost.

The car barn and shops are located at the end of the K route. Cars entering service must go downtown to the east end of the K route at Embarcadero Station and then go west to the end of each of the

*Derived.

appropriate lines before inbound service can begin. The reverse procedure must be followed when cars are taken out of service. The routes have the following "deadhead" distances:

J	11.9 miles
K	0 miles
L	15.3 miles
M	15.5 miles
N	14.4 miles

Within limits, headways are adjusted to accommodate varying loads and thereby limit variations in load factors. Headways differ among routes and change with time of day. Data for a typical weekday are as follows:

	Headways (min)
Base	5.5 to 8.5
Peak	
am	3.5 to 7.5
pm	2.5 to 6.0
Night	12

Surveys made in Spring 1975 indicate that total patronage on the five streetcar lines is 96,000 passengers during a 24-hr weekday period. The total Muni system (i.e., streetcars, cable cars, trolley coaches, and motor coaches) carries 696,750 passengers on all vehicles. These figures count patrons a second time when they transfer between routes (transfers are free). Revenue patronage on a typical weekday is estimated to be about 490,000 passengers.

The number of revenue passengers or total passengers cannot be determined directly from farebox records for these reasons:

- School children and senior citizens pay 5¢ fares while regular passengers pay 25¢ (30¢ for express service).
- Some travelers use monthly flat rate passes ("Fastpass" and "Seniorpass").
- Some travelers use flat-rate passes on Sundays and holidays.
- Some fare boxes are nonregistering.
- Employees use passes.
- The number of passengers using free transfers from other lines are not recorded.

Patronage estimates have not been made for the Muni-Metro system currently under construction. Muni estimates the capacity of the new subway line will be 21,000 passengers for the peak hour in the peak direction. This would be achieved by carrying 200 passengers per car, by operating a mix of three- and four-car trains, and by maintaining 2-min headways in the Market Street subway. Trains will be assembled at West Portal by coupling cars from the K, L, and M routes.

Muni reported 818,000 actual car-miles in passenger service for the period January to March 1975. Extrapolated for the entire year, the system is estimated to generate 3.27 million revenue car-miles. An analysis of schedules shows that deadhead travel is about 12.4% of revenue travel. Using that factor gives an estimated deadhead travel of 0.41 million car-miles, and a total travel figure of 3.68 million car-miles.

The number of passengers transported each year is not reported by Muni. After consultation with Muni staff members, patronage was estimated to be 28.8 million passenger trips, 300 times the reported weekday patronage. Average trip length is reported to be 2.47 miles for the entire Muni system, but it is not reported separately for streetcars. After consultations with staff members it was estimated that the average streetcar ride is 3 miles in length, about one-fourth higher than the system average. Based on these estimates, Muni streetcars provide about 86 million passenger-miles of service during the year.

The Muni-Metro will supply more service capacity than the old system, depending on the route and time of day. Capacity is measured as the number of seats past a point in an hour's time. The capacity will increase 60 to 65% on the L and M lines and 20 to 30% on the J, K, and N lines. It is not certain that patronage will increase in proportion to capacity; however, some increase should occur because of the improvement in service.

<u>Energy Usage</u>

Power for the Muni is supplied by a second municipal agency, Hetch Hetchy Water and Power and is produced in three hydroelectric powerhouses. In calendar year 1975, Muni used 55.4 million kWh for streetcar and trolley coach traction power as measured from substations. Power consumption by the two systems is not measured separately, but the power consumption by Muni streetcars has been estimated at an average of 5.525 kWh/car-mile. This estimate, made by a Muni employee in a thesis prepared as part of a graduate study program, provides other information of interest. The following paragraphs are quoted from the thesis.

> "The electric power costs for trolley coaches are reported in the <u>San Francisco Municipal Railway's Annual</u> Reports since 1950 as being approximately equal to streetcar power costs on a per mile basis. This is a highly improbable situation as streetcar cars weigh twice as much as trolley coaches and should thus require considerably more power in a stop-and-go transit operation, such as with the San Francisco Municipal Railway. Since power lines for streetcars and

trolley coaches are inter-connected in many parts of the system, it is impossible to allocate power costs to the two types of vehicles from direct power meter readings, which may partially explain the Municipal Railway's failure to rationally differentiate power costs between the two vehicles.

"To determine the probable allocation of power to the two vehicle types, a multiple regression analysis was performed using total system electric power consumption as the dependent variables, X_1, and streetcar vehicle mileage, X_2, and trolley coach vehicle mileage, X_3, as the independent variables. The most readily available data was for the fiscal years 1945-46 through 1951-52. The following equation was obtained:

$$X_1 = 5{,}525\ X_2 + 3{,}689\ X_3 + 11{,}163{,}733$$

$$R = .9989$$

This equation indicates that the trolley coach in San Francisco consumes 3.689 kw.hrs. per mile and the streetcar 5.525 kw.hrs. per mile. The constant indicates that there is a dead loss of 11,163,723 kw.hrs. per year in the system. This loss, which amounted approximately to between 9% and 15% of the total, appears to be due to losses in the ac-dc rotary converters and losses through the insulators on the trolley lines. Conversion losses with modern silicon rectifier should be only about 1%.

"The Municipal Railway paid $0.00904 per kw hr. for ac current in 1972-73. If $.002 per kw hr. is added for power plant employees to operate a silicon rectifier system, the cost per mile for power for the trolley coach would be $.04073. This amount is substituted in this analysis for the Municipal Railway account figures. Source of ac power costs: Bob Collins, Hetch Hetchy Bureau of Light and Power. Source of power consumption data: San Francisco Municipal Railway, Annual Report (San Francisco, 1945-46 to 1951-52)." [90]

The magnitude of the dead loss raises a question that should be addressed in a conservation program. About 40% of the dead loss (4,336,000 kWh) can be allocated to streetcars, based on total consumption by each class of vehicle.

Another estimate of energy intensity per car mile was made by a consultant[91] to compare existing and possible future cars on the improved Muni-Metro route, including the subway. The estimate suggested that energy consumption of PCC cars on the N line (and in the Market Street subway) would average 5.4 kWh per car-mile and would vary greatly with conditions. The estimate for uphill and street travel with frequent stops was 8.2 kWh per car-mile. Downhill and subway travel was 2.2 kWh per car-mile. In consideration of the two estimates, the figure of 5.5 kWh per car-mile appears reasonable as the average running load of Muni PCC cars.

Total energy consumption is estimated at 24.85 million kWh. This includes the loss of 4,336,000 kWh and 5.5 kWh per car-mile for 3,730,000 miles of travel in revenue and nonrevenue service. Although this power comes from hydroelectric power plants, any power saved is assumed to be useable elsewhere to save in the quantity of fuel oil consumed. The electrical energy used is equivalent to 1.92 million gal of fuel oil, or 280 billion Btu.

Energy Intensities

To make possible the comparison with other systems, energy intensities are stated in terms of the equivalent quantities of fuel oil and Btu that would be required to supply Muni's electrical power from steam plants. The national average heat rates and losses explained in Section I are used here:

- Service per gallon of oil:
  1.92 car-miles
  15.00 passenger trips
  44.79 passenger-miles
- Energy per car-mile:
  6.75 kWh
  76,000 Btu
- Energy per passenger-trip:
  0.86 kWh
  10,000 Btu
- Energy per passenger-mile:
  0.29 kWh
  3,200 Btu

The full impact on energy intensity of the change to LRV cars has not been assessed. However, the new cars are heavier than the old, and have higher performance. It seems certain that energy intensity per car-mile will be higher. Energy intensity per passenger-mile would rise if service frequencies and patronage remain unchanged. However, with service frequencies unchanged, the LRVs have more passenger capacity than PCC cars. Any increase in patronage will tend to offset the rise in energy intensities per passenger-mile. Similarly, decreases in service frequency could help to offset the rise in energy usage per car-mile. It is doubtful that any realistic combination of increased patronage and reduced frequency of service would prevent some net rise in energy intensity per passenger-mile. Thus, the transit service improvement afforded by LRV cars is likely to require penalties in energy intensity.

Costs

Muni's budget and accounting reports do not segregate light-rail transportation from other modes. In 1974-75, the total budget was

$75.6 million, of which $71.8 million was for operating expenses and $3.8 million was for equipment and replacement. Actual operating expenses were somewhat lower, in large part because hiring was curtailed and service was reduced. According to Muni's accounting system, the deficit from operations was $41.6 million for the same year. In their Income Statement for Fiscal Year 1974-75, which shows details of income and expense, the depreciation expenses accounted for $2.4 million of operation expenses. In the light of increase in replacement costs for equipment and facilities, this figure appears to understate greatly the long-term capital costs of the system. If the operation expenditures for 1974-75 are taken as $67.1 million, the loss from operation would be $41.6 million, or 163% of revenue. This loss was covered by subsidies of various types. For example, Muni obtains power from Hetch Hetchy at bargain rates. This form of subsidy has not usually been recognized. It has been estimated that power costs Muni 16.7¢/vehicle-mile for the PCC cars and will cost about 21¢/vehicle-mile for the LRVs.[92]

Muni also receives important capital subsidies. In 1969, Muni embarked on a massive and comprehensive program to rebuild and replace over-aged rolling stock and deteriorated fixed plant equipment, and to make important improvements in service. The total cost of the program was estimated at $290 million, with $76 million coming from local funds and the balance being provided mainly by the Urban Mass Transportation Administration (UMTA) in the form of capital grant funds. The program has four segments:

- Transit Equipment Program (TEP) $97 million
- Transit Improvement Program (TIP) $67 million
- Power Improvement Program (PIP) $58 million
- System Improvement Program (SIP) $68 million

These programs apply to all the modes--streetcar, trolley coach, bus, and cable car.

Muni will expend at least $75 million to renovate the LRV system. See Table 9-5. The listing of capital outlays in this table may not be complete. In addition, BART will pay a large amount to construct Muni's 3.1-mile subway, eight underground stations, and other facilities. The total cost of BART's work for Muni may be in the order of $100 million.

Table 9-5

SUMMARY OF MUNI CAPITAL OUTLAYS

	$ Millions
Cars, 100	34 (estimated)
Rerail repair	15.4
Repair tunnel	3
Controls and communications	3.6
Electrical power	15 (estimated)
Fare collection and signs	4.6
Total	75.6

Southern Pacific Suburban Rail

History

Suburban rail service has existed between San Francisco and San Jose, California, for more than 100 years, and was a dominant factor in shaping the development of Peninsula communities before World War II. During the past 20 years, the relative importance of the service has declined, and its patronage has dropped 50%. The decline was caused by growth of population, employment, and other activities on the Peninsula, and construction of two major freeways on routes parallel to the railroad. More recently, construction of BART to Daly City on the south border of San Francisco has further diminished commuter rail patronage.

Line and Equipment

The Southern Pacific (SP) commuter line has one terminal about 0.6 mile south of the San Francisco CBD* and the other near the CBD in San Jose. The line serves parts of San Francisco, San Mateo, and Santa Clara Counties, and contains 26 stations, including San Mateo, Redwood City, Palo Alto, and Sunnyvale. The line is 46.9 miles long. It is not electrified. It is double-track throughout its length and is equipped with block signals. The line carries both commuter and freight trains. Passenger equipment includes 23 locomotives and 83 cars. (See Table 9-6).

Service

The number of trains and schedules have remained constant for several years, but the lengths of trains have been shortened as patronage

*Central Business District.

Table 9-6

EQUIPMENT

Locomotives

Model	Power (hp)	Built	No.
GP 9	1800	1954-55	10
GPP 40	3000	1974	3
SDP 45	3600	1967	10
		Total	23

Cars

Model	Seats	Built	Weight* (lb)	No.
Suburban	96	1924-25	125,660	37
Gallery (Pullman)	145	1955	151,500	10
Gallery (ACF)	145	1957	145,950	21
Gallery (Pullman)	164	1968	148,560	25
Gallery, Average	151.2		148,600	46
		Total		93

*Weight of cars includes empty weight plus passengers at 150 lb each and in numbers sufficient to fill 40% of the seats.

has declined. In a normal week without holidays there are 262 trains: 44 on weekdays, 24 on Saturdays, and 18 on Sundays. (Holiday train schedules are the same as Sundays.) Trains vary in length from one to eight cars and range from 151 to 1210 seats.

Schedules and station stops have been tailored mainly to serve the needs of travelers who have white-collar, daytime jobs in downtown San Francisco. Patrons use the SP for other trips, but the service is not well-suited for travel among many station pairs and for off-peak travel.

Aggregate service statistics for 1975 are as follows:

13,500 trains
631,727 train miles (46.9 miles each trip)
2,471,381 car-miles
328,026,934 seat-miles
4,719,679 passengers (estimated)
116,498,579 passenger-miles

Passengers and passenger-miles are computed from revenue statistics and neglect two desirable adjustments. First, travelers who purchase multiple-ride commuter tickets are assumed to use every trip for which the fare is paid (e.g., up to 62 trips per month on a monthly ticket). This obviously overstates patronage. Also, some SP employees ride on free passes. The reported statistics are likely to be slightly higher than actual, but there is no evident way to estimate the amount.

The following averages computed from these data are interesting, but should not be used directly in evaluating possible innovations:

- The average load factor is 0.355 passenger-mile per seat-mile
- The average passenger trip is 24.68 miles.

Energy Usage

In 1975, 2,338,064 gal of diesel fuel were used. At 137,300 Btu/gal, this is equivalent to 321 billion Btu.

Energy Intensity

System average energy intensities were:

• Service per gallon of fuel:	
Car-mile	1.06
Passenger trip	2.02
Passenger-mile	49.83
• Energy per car-mile	130,000 Btu
• Energy per seat-mile	979 Btu
• Energy per passenger trip	68,000 Btu
• Energy per passenger-mile	2,800 Btu

Variation in Energy Intensities

Energy intensities would be relevant if the issue were discontinuation of the entire service, but are not suitable for the evaluation of smaller and more realistic changes. Fuel consumption does not rise in direct proportion to the number of seats, and energy intensity per seat-mile is lower for long trains than for short trains for the following reasons: (1) long trains are heavily loaded express runs that make fewer stops, (2) they have lower train weight per passenger, (3) they have more appropriately sized locomotives. It is worthwhile to examine the distribution of fuel consumption and energy intensity by trains of different sizes making various numbers of enroute stops. The following paragraphs supply such data for selected trains, including those having relatively favorable and unfavorable energy intensities.

The amount of fuel consumed by each SP commuter train has been estimated in terms of the weight of the train, the number of times the train is accelerated, and other factors. The following tabulation summarizes data for some of the most significant trains.

	Gal/Train	Btu/Seat-Mile
8 gallery cars, 3600 hp, 8 stops, 1210 seats	187	450
5 mixed cars, 3600 hp, 10 stops, 701 seats	146	610
2 gallery cars, 1800 hp, 21 stops, 302 seats	89	860
1 gallery car, 1800 hp, 21 stops, 151 seats	67	1300

One 8-car train operating in the morning peak period carries 943 passengers in 1210 seats and has an average passenger-trip length of about 35 miles. Its average load factor is estimated to be 58%, and its energy intensity is 780 Btu/passenger-mile. However, there are only two 8-car trains each workday.

A typical 5-car train has a load factor estimated at 40% and an energy intensity of about 1,500 Btu/passenger-mile. Many 1- and 2-car trains have low load factors and high energy intensities. For example, a survey made in 1975 disclosed that 27% of all trains (72 of 262 trains each week) carry very small loads. Six weekday trains each have average loads of 60 passengers; 24 Saturday trains have average loads of 103 passengers; and 18 Sunday trains have average loads of 60 passengers. Most of the 72 trains contain two cars, burn 89 gal of fuel, and have an average energy intensity of 6660 Btu/passenger-mile. The "worst case" train operated early Sunday morning, used 89 gal of diesel fuel to carry 12 passengers an average distance of 24.68 miles, and had an energy intensity of 41,260 Btu/passenger-mile.

Economic Data

The cost of commuter service is now receiving special attention. The SP is seeking authority for fare increases of about 100% above 1976 levels in proceedings before the California Public Utilities Commission. The company has reported that the commuter service generated costs of $10,916,500 and revenue of $5,214,400 in 1974, a loss of $5,702,100. The average fare was $1.10/passenger and costs were $2.31/passenger. The loss was about $1.21/passenger.

Rising costs and declining patronage have increased the loss. According to the company, by March 31, 1976 revenues had decreased to $4,666,400 and costs had increased to $13,269,400. The net loss was $8,603,000 or 184% greater than revenues. Labor is the largest element of operating cost--58% in 1974. Fuel accounted for 5% of total costs in 1974.

X WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY (WMATA)

Data for WMATA were collected near the end of 1976. Consequently, important developments in 1977 are not treated here. Among these are the extension of operation on the first line opened, and the start of service on a second line from National Airport to a station east of the Capitol Building.

Background[93]

Studying and planning of a Washington Metropolitan Area Transit System was initiated with the passing of the National Capital Planning Act of 1952. In 1966, WMATA was created under agreements signed by Maryland, Virginia, and the District of Columbia. On December 9, 1969 the first construction contract for $33.7 million was awarded and groundbreaking took place on the same day. The WMATA opened the first 4.87 miles of double-track line of its proposed 98-mile heavy-rail transit system on March 27, 1976. The system has not gained enough operating experience to provide data for fruitful analysis.

Routes

The system will include five lines with a total length of 98 miles and 86 stations. It is being constructed and opened in stages.

Equipment

WMATA will purchase 300 cars. The cars are 75 ft long, 10 ft 1-3/4 in. wide, and 10 ft 10 in. high, and seat 80. Empty weight is 72,000 lb. Each car picks up 700 Vdc from the third rail and has four 175-hp motors, allowing 75-mph service speeds. The cars are married pairs and are airconditioned. Cam-controlled propulsion is used.

Service

Initially, WMATA operated from 6 am to 8 pm, Monday through Friday. Headways are 5 min from 7 am to 9 am and 4 pm to 6 pm, 6 min from 11:30 am to 1:45 pm, and 10 min at all other hours. Peak patronage occurs between 8 to 9 am, 12 noon to 2 pm, and 4 to 6 pm, which corresponds with suburban and intercity train schedule variations. The system operated about 240 one-way trips/day. Most are four-car trains, although occasionally a two-car train is run. Average service speed is 35 mph. For the first 8 months of service (April to November 1976) an average 22,317 passengers rode WMATA each day and an average 3,752 car-miles were operated for revenue service each day.

Energy Usage

Although WMATA reports that records of energy for operation of the cars and energy consumed by stations, shops, offices, etc., are being kept, the data were not yet available at the end of 1976.

Energy Intensity

WMATA cars were designed to operate on 11.7 kWh dc per car-mile. WMATA has made engineering calculations based on such things as pickup voltage, motor performance, acceleration curves, track layout, and station spacing, and has estimated that cars actually consume 11.8 kWh dc per car-mile with all the auxiliary equipment operating. WMATA indicated that this figure should vary little with passenger load.

Appendix A

RECAPITULATION

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Appendix A

RECAPITULATION

The principal quantitative findings of this task are recapitulated in five tables in this appendix. Readers are cautioned that the findings are, in many cases, rough approximations rather than definitive estimates. Comments regarding the limitation and quality of input data, and explanations of assumptions made and methods employed will be found in the text describing individual systems.

Table A-1 recapitulates findings for all major elements of the national rail passenger network. Tables A-2, A-3, and A-4 recapitulate results for suburban railroad systems, heavy-rail and light-rail transit systems. Table A-5 recapitulates data for two systems in which heavy-rail and light-rail data could not be separated.

The systems omitted account for only a very small part of total rail passenger service and are therefore not highly significant from the energy viewpoint. The Rock Island and Georgia Railroads are parts of the national rail passenger network but were omitted here because of the small scale of their operations. Other railroads that offer very small amounts of intercity service were also omitted. Several suburban railroad passenger systems were omitted because of their small size or because of the difficulty of separating the operation of a railroad among two or more regions. The most significant omissions of this kind are Chessie services in Washington and Baltimore; ConRail services in Boston, Chicago, and Cleveland; Pittsburgh-Lake Erie services in Pittsburgh; and Chicago, South Shore, and South Bend service in Chicago. The Washington Metro heavy-rail system was discussed, but energy intensities were not computed because of the limited scale of operations during the startup period. The New Orleans light-rail system was omitted because of reports that operations have ended or are about to end.

Some of the systems studied in detail are quite small in size. These systems are not highly significant, from the viewpoint of energy conservation, and might also be omitted from future studies. On the other hand, a few very large systems are highly significant and should be studied in greater detail. Among these are Amtrak and Auto-Train; the suburban railroad services in Boston, Chicago, New York and Philadelphia regions; all of the heavy-rail systems; and the light-rail systems in Boston, Philadelphia, and San Francisco.

Readers are cautioned that the data and estimates presented in this report are the products of a preliminary study, and are tentative rather than definitive. Published data were used, but this resource is neither complete nor entirely reliable. Field visits were made to all major systems to obtain information from primary sources. Only one system, BART, had data of good quality on all relevant subjects. Data obtained for all other systems were deficient in small or great degree. Considerable difficulty was experienced in obtaining some needed data and interpreting some of the data that were obtained. Consequently, it was often necessary to use approximations. An intensive program of field work and detailed analysis will be needed to make substantial improvements in the quality of the estimates presented here. In the long run, the quality of the data on rail passenger energy intensities can be improved by standardizing the reporting procedures of system operators, and by enforcing compliance with the standard procedures.

Table A-1

NATIONAL RAIL PASSENGER NETWORK

	Amtrak National Railroad Passenger Corp.	Auto-Train Corporation	Southern Railway Company	Denver & Rio Grande Western Railroad Company
Physical data				
Line miles	25,499	1,850	1,200	600
Cars	<2,000	74	94	40
Stations	480	3	32	12
Service data				
Passenger trips (10^6)	17.40	0.31	0.23	0.24
Average passenger trip length, mi	226	867[a]	361	79
Passenger-miles (10^6)	3,939	267.5	84.6	18.8
Revenue car-miles (10^6)	252.94	12.71	5.50	1.30
Total energy used				
kWh per year (10^6)	274.32[b]	n.a.	n.a.	n.a.
Equivalent gallons of fuel (10^6)	101.12	6.27	5.29	0.53
Btu (10^9)	14,063	861	727	73
Energy Intensity				
Service per gallon of fuel				
Car-miles	2.50	n.a.	1.04	2.44
Passenger-miles	38.95	42.68 (+ 14.23 car miles)	15.98	35.26
Energy per car-mile				
Btu (10^3)	66	n.a.	132	56
Energy per passenger mile				
Btu (10^3)	4.2	3.2[c]	8.6	3.9
Economic data				
Cost (10^6)	$605.23	$23.91	$10.64[a]	
Revenue (10^6)	$252.70	$28.97	$5.14	
Deficit (profit) (10^6)	$352.53	($1.75) (Operating Income)	$5.50	
Average fare per passenger-mile	$0.06	$0.11	$0.06	
Average loss (profit) per passenger-mile	$0.09	($0.01)	n.a.	

[a]Derived.

[b]Includes electrical energy only, not diesel fuel purchased.

[c]Energy per passenger-mile and per 0.333 car-mile.

n.a. = Not available.

Table A-2

SUBURBAN RAIL SYSTEMS

	BOSTON		CHICAGO						NEW YORK			PHILADELPHIA		SAN FRANCISCO
	Boston & Maine Corporation	ConRail	Burlington Northern	Chicago & Northwestern	Illinois Central Gulf	The Milwaukee Road	Norfolk & Western	Rock Island Lines	Long Island	Hudson, Harlem and New Haven	New Jersey	Penn Central	Reading	Southern Pacific
Physical data														
Line miles	151	98.6	38.0	171	62.6	106.1	23.2	46.7	319.0	263.7	480.0	149.7	264.6	46.9
Cars	84	119	124	280	165	103	8	93	1,047	1,436	755	258	188	83
Stations	50	n.a.	26	65	59	45	10	30	150	100	n.a.	101	116	26
Service data														
Passenger trips (10^6)	4.77	2.90	12.29	25.08	14.47	7.87	0.31	5.83	67.17	39.30	34.70	17.57	12.48[a]	4.72
Average passenger trip length, mi	16.3	n.a.	18.7	21.2	19.0	23.2	13.8	18.6	27.6	27.2	n.a.	10.8	15.2	24.7
Passenger-miles (10^6)	77.8	n.a.	230.0	531.3	277.8	182.1	4.3	108.8	1,851.0	1,069	n,a.	190.5	189.7[a]	116.5[b]
Revenue car-miles (10^6)	3.04	n.a.	3.92	11.11	4.66	3.64	0.21	2.97	55.82	25.78	43.42[b]	6.34	7.40[a]	2.47
Total energy used		n.a.												
kWh per year (10^6)	n.a.		n.a.	n.a.	52.44	n.a.	n.a.	n.a.		633.07[c]		61.86[b]	55.32	n.a.
Equivalent gallons of fuel (10^6)	2.18		3.19	7.38	4.17[c]	3.78	0.04	1.63		95.76		4.79	4.94[c]	2.34
Btu (10^9)	299		438	1,013	606	519	5	224		13,148		698	715	321
Energy intensity[b]		n.a.												
Service per gallon of fuel														
Car-miles	1.40		1.23	1.51	1.12	0.96	5.62	1.82		1.33		1.34		1.06
Passenger trips	2.19		3.86	3.40	3.47	2.08	8.41	3.58		1.38		3.09		2.02
Passenger-miles	35.76		72.17	72.03	66.62	48.15	116.41	66.74		32.23		39.08		49.83
Energy per car-mile														
kWh	--		--	--	--	--	--	--		--		--		==
Btu (10^3)	98		112	91	130	143	24	75		103.5		103		130
Energy per passenger trip														
kWh	--		--	--	--	--	--	--		--		--		--
Btu (10^3)	62		36	40	42	66	16	38		99		47		68
Energy per passenger-mile														
kWh	--		--	--	--	--	--	--		--		--		--
Btu (10^3)	3.8		1.9	1.9	2.2	2.8	1.2	2.1		4.26		3.7		2.8
Economic data			*d*	*d*	*d*	*d*					n.a.			
Cost (10^6)	$21.90		$9.25	$20.36	$16.05	$7.96	$0.35	$8.91	$361.10			$51.03		$10.92
Revenue (10^6)	$4.80	$2.20	$7.76	$24.28	$10.95	$6.36	$0.21	$4.73	$179.30			$22.65		$5.21
Deficit (10^6)	$14.90		$1.49	$3.92	$5.11	$1.61	$0.14	$4.18	$181.80			$23.25		$5.70
Average fare per passenger trip	$0.53		n.a.	n.a.	n.a.	n.a.	$0.66	$0.81	n.a.			$.73		$1.10
Average loss per passenger trip	$2.01		n.a.	n.a.	n.a.	n.a.	$0.45	$0.72	n.a.			$.78		$1.21

[a] Includes non-SEPTA operations.

[b] Derived.

[c] Includes electrical energy and diesel fuel purchased.

[d] 1973 data; 1975 data not available.

n.a. = Not available.

Table A-3

HEAVY-RAIL SYSTEMS

	CHICAGO	CLEVELAND	NEW YORK			PHILADELPHIA	SAN FRANCISCO
	Chicago Transit Authority	Regional Transit Authority, Cleveland Division	New York City Transit Authority	Staten Island Rapid Transit Operating Authority	Port Authority Trans-Hudson Corporation	Port Authority Transit Corporation of Pennsylvania & New Jersey	Bay Area Rapid Transit
Physical data							
Line miles	90.2	19	230.6	14.6	13.9	14.2	71.0
Cars	1,093	116	6,681	52	298	75	450
Stations	142	18	461	22	13	13	34
Service data							
Passenger trips (10^6)	148.00	10.88	1,077.60	4.59	38.34	11.12	32.90
Average passenger trip length, mi	6.9	7.8	7.0	9.0	4.8	8.5	13.5
Passenger-miles (10^6)	1,078.0	84.9	7,543.0	41.31	184.0	94.5	443.1
Revenue car-miles (10^6)	49.50	3.56	302.80	n.a.	10.66	4.19	22.45
Total energy used							
kWh per year (10^6)	260.15	30.9	2,048.80	14.11	64.87	40.53[a]	233.20
Equivalent gallons of fuel (10^6)	20.13	2.39	192.34	1.09	5.02	3.14	18.04
Btu (10^9)	2,934	349	28,030	159	32	457	2,630
Energy intensity[b]							
Service per gallon of fuel							
Car-miles	2.47	1.49	1.57	n.a.	2.12	1.34	1.24
Passenger trips	7.35	4.55	5.60	4.20	7.64	3.54	1.82
Passenger-miles	53.55	35.52	39.22	37.83	36.65	30.14	24.56
Energy per car-mile							
kWh	5.2	8.69	6.8	n.a.	6.1	9.7	10.4
Btu (10^3)	59[b]	98[b]	93	n.a.	69	109	117
Energy per passenger trip							
kWh	1.76	2.84	1.90	3.07	1.69	3.64	7.09
Btu (10^3)	20	32	26	35	19	41	80
Energy per passenger-mile							
kWh	0.24	0.36	0.27	0.34	0.35	0.43	0.53
Btu (10^3)	2.7	4.1	3.7	3.9	4.0	4.8	5.9
Economic data							
Cost (10^6)	$90.48	$4.77	$713.00	$5.90	$44.51	$13.40	$85.00[d]
Revenue (10^6)	$47.24	$3.56	$380.60	$1.71	$12.19	$6.60	$21.70
Deficit (10^6)	$43.24	$1.21	$332.40	$4.19	$32.32	$6.80	$63.30
Average fare per passenger trip	$0.32	$0.32	$0.35	$0.35	$0.30	$0.57	$0.66
Average loss per passenger trip	$0.29	$0.12[a]	$0.31	$0.94	$0.86	$0.63	$1.92

[a]Estimate.

[b]Derived.

[c]Economic data for heavy- and light-rail systems are combined.

[d]BART costs include $26.1 million of unfunded depreciation.

n.a. = Not available.

Table A-4

LIGHT-RAIL SYSTEMS

	CLEVELAND	NEW YORK	PHILADELPHIA	PITTSBURGH	SAN FRANCISCO
	Regional Transit Authority, Shaker Division	Newark	SEPTA Red Arrow Division	Port Authority Transit of Allegheny County	San Francisco Municipal Railway
Physical data					
Line miles	13	4.2	24.8	24.1	19.4
Cars	57	30	61	95	115
Stations	29	11	73	n.a.	1[a]
Service data					
Passenger trips (10^6)	3.73	2.45	5.71	7.30	28.80[b]
Average passenger trip length, mi	7.4	2.2[b]	4.8[c]	8.0[b]	3.0[b]
Passenger-miles (10^6)	27.5	5.4[c]	27.6	58.4[b]	86.0
Revenue car-miles (10^6)	1.02	0.58	1.55	2.10	3.27
Total energy used					
kWh per year (10^6)	5.27	2.80[b]	17.58	15.15	24.85
Equivalent gallons of fuel (10^6)	0.41	0.22	1.36	1.17	1.92
Btu (10^9)	59	32	198	171	280
Energy intensity[d]					
Service per gallon of fuel					
Car-miles	2.54	2.66	1.14	1.80	1.92
Passenger trips	9.13	11.31	4.20	6.24	15.00
Passenger-miles	67.40	24.87	20.30	n.a.	44.79
Energy per car-mile					
kWh	5.1	4.6	11.3	7.2	6.75
Btu (10^3)	57[c]	52[c]	128	81	76
Energy per passenger trip					
kWh	1.41	1.14	3.08	2.07	0.86
Btu (10^3)	16	13	35	23	10
Energy per passenger-mile					
kWh	0.19	0.52	0.64	n.a.	0.29
Btu (10^3)	2.1	5.9	7.2	n.a.	3.2
Economic data[e]				n.a.	(See text.)
Cost (10^6)	$2.22	$1.09	$4.32		
Revenue (10^6)	$2.02	$0.92	$2.13		
Deficit	$0.20	$0.17	$1.98		
Average fare per passenger trip	$0.53	$0.38	$0.31		
Average loss per passenger trip	$0.05	$0.08	$0.35		

[a] Plus street stops.

[b] Estimate.

[c] Derived.

[d] Heavy- and light-rail data are merged and cannot be separated.

[e] Economic data for heavy- and light-rail systems and trolley coaches are combined and cannot be separated.

n.a. = Not available.

Table A-5

COMBINED SYSTEMS--HEAVY-RAIL AND LIGHT-RAIL

	BOSTON		PHILADELPHIA	
	MBTA		SEPTA	CTD[a]
	Heavy-Rail	Light-Rail	Heavy-Rail	Light-Rail
Physical data				
Line miles	32.6	28.9	24.5	74.2
Cars	338	290	490	290
Stations	44	14[b]	54	8[b]
Service data				
Passenger trips (10^6)	120[c]		84.64	39.66
Average passenger trip length, mi	3.4		5.0	2.8
Passenger-miles (10^6)	408[d]		417.2	111.0
Revenue car-miles (10^6)	15.91		14.56	6.26
Total energy used	[e]			
kWh per year (10^6)	203.92		111.86	47.96
Equivalent gallons of fuel (10^6)	27.64		8.66	3.71
Btu (10^9)	3,990		1,262	541
Energy intensity[d]				
Service per gallon of fuel				
Car-miles	0.60		1.68	1.69
Passenger trips	4.52		9.78	10.68
Passenger-miles	15.38		48.40	29.91
Energy per car-mile				
kWh	12.3		7.7	7.6
Btu (10^3)	241		87	86
Energy per passenger trip				
kWh	1.63		1.32	1.21
Btu (10^3)	32		15	14
Energy per passenger-mile				
kWh	0.48		0.27	0.43
Btu (10^3)	9.4		3.0	4.9
Economic data			[e]	
Cost (10^6)	$116.58		$53.73	
Revenue (10^6)	$27.29		$31.66	
Deficit (10^6)	$89.29		$19.85	
Average fare per passenger trip	$0.23		$0.23	
Average loss per passenger trip	$0.74		$0.14	

[a] City Transit Division.

[b] Plus street stops.

[c] Estimate

[d] Derived.

[e] Heavy and light rail data are merged and cannot be separated.

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