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RAILROAD ELECTRIFICATION ACTIVITY IN NORTH AMERICA -- A STATUS REPORT: 1976-1978

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16. Abstract

In view of the increased activity and interest in railroad electrification in North America, it is appropriate to provide a continuing overview of activities of interest to the railroad industry and the U.S. Government. Major activities completed or underway are reported herein and include: Conrail feasibility electrification study; Tennessee Valley Authority electrification demonstration project; design of the New Haven CT to Boston MA sector of the Northeast Corridor Improvement Project; construction of the 25 kV and 50 kV catenary for the test track at the Transportation Test Center, Pueblo CO; Canadian Institute of Guided Ground Transport electrification study; Department of Energy assessment of prospects and impacts of railroad electrification.

Initially, the status of existing electrified railroads is summarized followed by a description of current planning activities. This is followed by a description of current research and development activities. Other topics covered include the activities of financial institutions and standards. The domestic supply industry equipment interests are discussed and architectural/engineering experience in the U.S. is reviewed. It is not the intent of this report to draw technical conclusions regarding the material presented.

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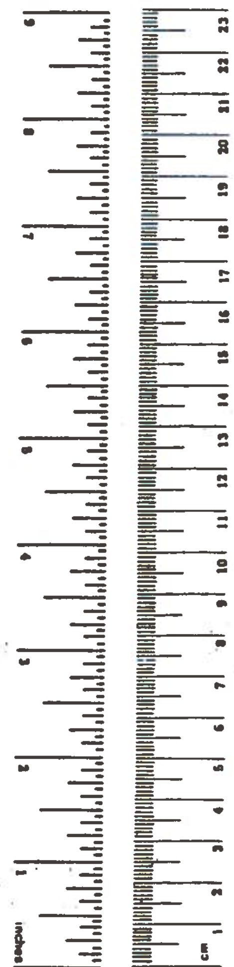
PREFACE

This report has been prepared by the Electrical Power and Propulsion Branch at the Transportation Systems Center (TSC) for the Office of Passenger Systems, Federal Railroad Administration. The purpose of this document is to review the current status of railroad electrification activities in North America. This report is part of the technical support provided by TSC to the Office of Passenger Systems in electrification research and development. The assistance of Mr. Richard A. Novotny, of the Office of Passenger Systems at FRA, and Dr. Curtis H. Spenny of the Electrical Power and Propulsion Branch, Vehicles and Engineering Division at TSC, in structuring this report is acknowledged. The efforts of Ms. Regina Clifton of the Technical Reference Center at TSC in performing a comprehensive literature search, and providing assistance in the organization of the bibliography, are acknowledged. The time period covered is from January 1976 through December 1978, although in some cases, it was necessary to reference earlier literature to obtain descriptive material for describing the project. Only activity described in publicly available literature has been included.

METRIC CONVERSION FACTORS

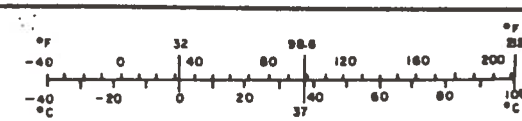
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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In view of the increased activity and interest in railroad electrification in North America, it is appropriate to provide a continuing overview of activity for rail industry and government personnel. This report was prepared under the sponsorship of the Office of Passenger Systems, Federal Railroad Adminstration.

Since the introduction of diesel locomotives during World War II, there has been a continual decline in electrification of U.S. mainline railroads, with less than 1 percent of the route miles currently electrified. However, attitudes toward electrification in the USA are being changed as the result of the continuing difficulties over oil supplies and cost. In anticipation of possible conversion to electrification, the FRA has undertaken to develop and maintain a data base for use in establishing Federal policy and for dissemination to the industry to aid in their reassessment. Accordingly, this overview is intended to provide a convenient reference source on current electrification activity.

Construction and maintenance activities on existing electrified railroads in North America, including the U.S., Canada, and Mexico, are identified together with the status of those electrification programs and feasibility studies currently in progress. The status of electrification planning by railroads, utilities, and Government agencies is then summarized, followed by a description of existing Government and private industry funded research and development programs. The activities of financial institutions are summarized in terms of electrification issues. Existing standards and the activities of various associations towards new standards are discussed. The domestic supply industry interests are discussed in the areas of power distribution equipment, catenary systems, electric locomotives, and signal and communications equipment. Finally, architectural/engineering experience in the U.S. is reviewed, and those companies are identified who have participated in recent electrification activities in the U.S. It is not the intent of this report to draw technical conclusions regarding the material presented.

Major activities completed or underway and reported herein are:

- o Study prepared by Gibbs & Hill entitled, "Conrail Feasibility Electrification Study," for the Conrail system between Newark NJ and Pittsburgh PA.
- o Start of Phase I of the Tennessee Valley Authority (TVA) Electrification Demonstration Project for electrification of the Cincinnati OH to Atlanta GA, routes of the Southern Railroad (SR) and the Louisville & Nashville (L&N) Railroad.
- o Design of the electrification of the New Haven CT to Boston MA railroad sector of the Northeast Corridor Improvement Project (NECIP).
- o Construction of the 25 kV and 50 kV catenary for the railroad test track at the U.S. Department of Transportation Test Center (TTC), Pueblo CO.
- o "Canadian Railway Electrification Study," prepared by the Canadian Institute of Guided Ground Transport. The study completed in 1976 concludes that electrification at the rate of 500 to 1,000 miles per year should start immediately to optimize the return on investment (ROI).
- o Department of Energy study conducted by Stanford Research Institute (SRI) International, "Railroad Electrification in America's Future: An Assessment of Prospects and Impacts."

1. INTRODUCTION

(Refs. 1, 2, 3, 4, 5, 6, 7)

One result of the Railroad Revitalization and Regulatory Reform Act of 1976 has been a major reassessment of electrification and its potential role in future railroad operations in the United States. Under Title VII, Amtrak's existing electrification facilities in the Northeast Corridor are being rehabilitated and extended from New Haven to Boston. Another provision of the Act allots $200 million in Federal guarantees to support Conrail, should it decide to extend its electrified freight routes following a feasibility study currently in progress. Federal assistance is also available to railroads for improvement projects, such as electrification, under Title V "Railroad Rehabilitation Improvement Financing." Finally, Title IX called for the Secretary of Transportation to conduct a comprehensive study of the American railway system, including the potential benefits of railroad electrification.

The study by the Secretary has been completed (Ref. 1). The data used in preparation of that report were taken primarily from an FRA staff study (Ref. 2) which provides a comprehensive assessment of electrification activity before 1976. This first annual activities report is intended to identify and summarize activity subsequent to preparation of references 1 and 2 and up to December 1978. The main obstacle in the past to large scale electrification in the U.S. has been financial. Electrification requires relatively large initial capital investments that comprise the following major costs: Catenary, Substations, Civil Reconstruction (to provide catenary clearance), Modifications to Signalling and Communications Systems, and Electric Locomotives.

The DOT/FRA study (Appendix C, Ref. 1) calculated the costs and rate of return on investment for electrification of three rail networks of varying size. The three networks of interest were: (1) a 10,000-mile network including only lines with traffic levels of 40 million gross ton-miles (MGTM) or more per year; (2) a 26,000-mile network that includes all the 40 MGTM lines and a significant portion of lines with more than 20 MGTM per year; and (3) a 40,000-mile network that includes essentially all lines with greater than 20 million gross tons per year.

The benefits of lower locomotive maintenance and energy costs appear to be sufficiently large to justify industry investment in electrification of most routes with traffic levels in excess of 20 million gross tons (MGT) per year. Although electrification of a large portion of the U.S. rail network would result in reductions in petroleum consumption figures, these reductions are relatively small in comparison with national petroleum consumption figures. Therefore, petroleum reductions alone would not appear to be sufficient justification for the Government to embark on a major electrification program.

A more critical concern to both the Government and the railroad industry is the cost and availability of petroleum. During the embargoes of '73 and '79, the inventory of diesel fuel on railroads dipped to critical levels with their reluctance to purchase from the spot market at higher than average prices. To withstand more severe embargoes, the railroads must be guaranteed a fuel allocation or find a motive power alternative (Ref. 3). As improvements are made in technology and traffic control, and as the cost of petroleum increases, electric railways become increasingly more attractive since the electric power could be generated from any fuel. Railroad electrification would be an easy option to support the U.S. energy policy to promote the use of coal in lieu of natural gas and petroleum (Ref. 4). It should be mentioned that cost data quoted in several sections of this report are based upon data obtained from reports published from 1976 through 1978. No attempt has been made to project costs into 1979 dollars.

1.1 BACKGROUND

1.1.1 <u>United States</u> (Refs. 1, 2, 5, 8, 9, 10, 11, 12, 58)

Although electric rail has existed in the U.S. since 1880, the nation has never adopted the sytem as extensively as have most other industrialized nations. The history of railroad electrification in the U.S. is described in References 8 and 58. Between roughly 1910 and 1940, the U.S. led the world in railroad electrification.

By 1931, the U.S. total of nearly 5000 electrified track miles constituted fully 20 percent of the world total. Following World War II, diesel fuel oil was cheap and abundant, and the diesel engine had developed during the war years into a reliable prime mover. The railroads found it more sensible to directly convert from steam to diesel electric locomotives. At present, the U.S., with approximately one-fourth of the world's total railroads, has less than 1200 route-miles of electrified line and has added only 100 miles of new electrification in the past 40 years (Ref. 5). Furthermore, some U.S. railroads have de-electrified certain sections of previously electrified track. Now, however, rapidly increasing fuel costs are making an alternative to diesel power look attractive.

In addition to alleviation of uncertainties in the cost and supply of diesel fuel, electrification offers other potential advantages. For example, the electric locomotive has a higher power density because part of the propulsion system is on the wayside. Thus, higher speeds and/or reduced size of the motive power fleet is possible. Further, the maintenance cost is expected to be less because the electric locomotive has fewer moving parts than the diesel-electric. Reduction in atmospheric pollutants is possible because the combustion process at the utility generator is stationary, thus making it amenable to more sophisticated emission control and because the load on the prime mover is more uniform. However, the amount of atmospheric pollutants will be dependent on the choice of fuel at the power plant.

When train frequency is high, the electric train's potential for lower maintenance, greater ease of automation, and more horsepower per locomotive begin to indicate advantages over the diesel-electric system. Diesel locomotive performance is also limited by engine size -- currently in the range of 3600 hp per unit, whereas electric locomotives are not constrained by an on-board power source and can provide 8000 to 10,000 hp per unit.

The 1970s began with the collapse of the nation's largest railroad, the Penn Central, into bankruptcy in 1970. The recession of the early 1970s further aggravated an already desperate situation for railroads in the northeast.

The Federal Government responded with legislation that created Amtrak (the National Railroad Passenger Corporation) in 1971, and the U.S. Railway Association (USRA) in 1973. The Consolidated Rail Corporation (Conrail) was formed in 1976 and the Railroad Revitalization and Regulatory Reform (4R) Act was passed also in 1976.

The former Highway Research Board became the Transportation Research Board (TRB) and in 1974, the TRB formed the Special Committee on Rail Transport Activities to evaluate the need for research activities in the area of rail transport, including electrification. In order to implement the recommendations of the Special Committee, qualified railroad personnel were invited to become members of selected existing TRB committees. A committee on Electrification Systems was one of five new committees formed and this committee is involved with economic, social, institutional, and technical research pertaining to railroad electrification (Ref. 9).

The Association of American Railroads (AAR) and the American Railway Engineering Association (AREA) have recommended 25 to 50 kV at 60 Hz for high-voltage electrification (Ref. 10). This is designated as high-voltage commercial frequency electrification. At the present time, three captive coal-hauling railroads in the U.S. have been electrified at high-voltage commercial frequency. One of these is the Muskingum Electric Railroad in southeastern Ohio which is 15 miles long and is electrified at 25 kV at 60 Hz. Another is the Black Mesa & Lake Powell Railroad located in Page, Arizona, which is 78 miles long and is electrified at 50 kV at 60 Hz. Texas Utilities Company has two lines electrified at 25 kV at 60 Hz, one being 6 miles long and the other 11 miles long.

The remaining railroads in the U.S. which have electrified operations use "special power" derived from the commercial frequency utility power grid requiring conversion equipment for operation at 11 kV at 25 Hz. Portions of the Conrail are electrified at 11 kV at 25 Hz, and the Washington to New Haven section of the existing Northeast Corridor utilizes 11 kV at 25 Hz. No electrification currently exists for the New Haven to Boston section (Refs. 10, 11).

1.1.2 Canada (Refs. 5, 6, 7, 13)

At the present time, Canada has about 70 miles of its 46,300-mile rail network electrified (Ref. 5). It was previously considered that Canada's population of about 24 million was too small, and that distances involved were too great, to justify electrification. Also, the economical operation of the oil-based diesels was considered in the argument against electrification.

A Canadian Railway electrification study was completed in April 1976 (Ref. 6). This study was commissioned by the Railway Advisory Committee (a joint committee of the Railway Association of Canada and the Transportation Development Agency) and has shown that electrification of Canadian (C.N. and C.P.) rail lines is technically feasible. The heavy initial capital expenditure and the relatively long payback period are identified as formidable obstacles in the corporate financial picture. Nevertheless, electrification of a substantial portion of the principal mainline trackage can be financially attractive under the conditions oulined in the study. On the basis of traffic projections and the economic analysis, a plan was developed to implement electrified operation of 15,300 km (9500 miles) over a 30-year period (Ref. 7).

As of 1976, the relative prices of electricity and diesel fuel were such that electrified operation would result in substantially lower energy costs for a well-designed and well-managed railway operation (Ref. 6). It should be noted that a substantial portion of Canada's electric energy is derived from hydroelectric sources, but further expansion of this capacity is limited and expensive. Coal-fired thermal plants are becoming more common, and in the short term, coal is likely to provide a substantial portion of the increased electric power capacity required. Because Canada is relatively immune to the embargoes which have occurred in the U.S., this assessment is probably still valid.

1.1.3 Mexico (Ref. 5)

At present, Mexico has only 80 miles or about 1% of its 12,300-mile rail network electrified.

No further information was available at the time this report was being prepared concerning the existing system or planning activities.

2. STATUS OF EXISTING ELECTRIFICATION

(Refs. 2, 5, 6, 7, 9, 10, 11, 13, 14, 15, 16)

A 1977 DOT/FRA study (Ref. 2) and several other recent technical publications have summarized the status of railroad electrification in the U.S. At the present time, only 1162 miles of the complete 206,000-mile rail network in the U.S. are electrified, as shown in Table 1.

This section summarizes the activities of railroads with existing electrification.

The only major electrification program currently in progress is the National Railroad Passenger Corporation (Amtrak) Northeast Corridor Improvement Project (NECIP). The NECIP is discussed in considerable detail below.

Conrail is currently examining the feasibility of extending electrification on several of its routes and this is also discussed in some detail.

The status is summarized for any of the other electrified railroads for which literature is available during the preparation of this report; the report also describes the status of the Transportation Test Center (TTC) at Pueblo CO.

2.1 AMTRAK/NORTHEAST CORRIDOR (NEC) IMPROVEMENT PROJECT (Refs. 15, 16, 17)

The National Railroad Passenger Corporation (Amtrak), established in 1971, is the only organization in North America committed to implementation at the present time. The NECIP includes the electrified line from Washington to New Haven (300 miles) and the planned extension of that line from New Haven to Boston (156 miles). It transits eight states having a population of 40 million people.

The present Northeast Corridor electrified section from Washington to New Haven utilizes power at 11 kV, 25 Hz. The power in the New York Metropolitan Transportation Authority and Connecticut Transportation Authority sectors from New York to New Haven are also 11 kV, 25 Hz, but are being converted to 12.5 kV, 60 Hz. The NECIP has selected 25 kV, 60 Hz for new electrification from New Haven to Boston. Conversion of the sector from Washington to New York City to 25 kV, 60 Hz is planned.

2.1.1 <u>System Selection and Specifications Being Prepared for Upgrading NEC</u> (Refs. 11, 14, 18, 19, 20, 21, 22)

The Task 5 Report on Electrification Installations in the NEC recommends that future electric operation should be with a nominal 25 kV, 60 Hz electrical system (Ref. 20). Use of 60 Hz utility power was recommended as being more cost-effective than rehabilitation of the existing frequency conversion equipment (Ref. 14).

The final report on Task 16 "Electrification Systems and Standards" of the NECIP comprises a study of the dynamic and electrical requirements of suitable catenary systems and associated concerns.

Task 16 consists of the following parts which are dealt with in appropriate sections of the report:

- o A review of the state-of-the-art of catenary design for speeds up to 150 mph.
- o A review of selected NEC reports relevant to Task 16. This included:

  Task 51: Electrification: New York Tunnels
  Task 5: Electrification: NEC
  Task 8: Local Coordination System Development
  Task 1: Demand Analysis.

- o Evaluation by computer simulation of the dynamic behavior of selected existing catenaries of the NEC route.

TABLE 1. U.S. RAILROAD ELECTRIFICATION

Railroad	Location	Route Miles	Propulsion Power
Illinois Central Gulf	Chicago IL	37	1,500 Volts DC
Chicago South Shore	Chicago IL	76	1,500 Volts DC
Erie-Lackawanna	Hoboken NJ	80	3,000 Volts DC
Penn Central	New Haven CT to Washington DC and Philadelphia PA to Harrisburg PA	762	11 kV, 25 Hz AC
Reading	Philadelphia PA	88	12 kV, 25 Hz AC
Muskingum Electric	Zanesville OH	15	25 kV, 60 Hz AC
Black Mesa & Lake Powell	Page AR	78	50 kV, 60 Hz AC
Texas Utilities	Monticello TX Martin Lake TX	11 15	25 kV, 60 Hz AC 25 kV, 60 Hz AC
Present Total U.S. Electrified Miles:		1,162	

- o Evaluation of preliminary specifications for new catenaries for parts of the route not yet electrified, and for replacement of existing inadequate catenaries that cannot be upgraded.
- o Prediction of the level of interference with telecommunications systems, and development of mitigation measures.
- o An evaluation of the power supply system proposed, and of the availability and means of power supply to prospective substation sites (Ref. 18).

Outline specifications are derived (Ref. 18, Section 10.0) for the proposed style of catenary for 150 mph operation (Style 5), also for substyles suitable for parts of the route where speeds are less than 150 mph (Style 5A, medium speeds).

A graphical representation was developed for the design of a catenary with a given operating speed. The conclusion reached was that if a catenary could be realized with tensions as high as 50-70% of the tensile strength, the principal critical speed would be shifted to about 170 mph with operation to 150 mph possible. Current collection would still be satisfactory with the present pantographs that were designed for 100 mph operation and large variations of contact wire height. The only change required would be a careful damping of the pantograph frame (Ref. 19).

An environmental impact analysis was performed and it was concluded that the replacement of diesel locomotives by electrical traction on the NEC may result in fewer total pollutant emissions at the system level, but may result in aggravating a localized point source pollutant problem. The total impact of the NECIP can only be ascertained by supplementing the systemwide assessment with detailed localized impact analysis in those areas where such impacts have been identified as potentially significant (Ref. 11).

2.1.1.1 Phase Breaks to Be Installed (Refs. 18, 21)-- To limit the effects of phase unbalance, a utility will generally place adjacent railroad substations on different phases. A phase break (Figure 1) is generally established midway between the supply substations.

It has yet to be proved that compact phase breaks such as the ceramic bead type can be designed for reliable operation at speeds of 150 mph. Initially, phase break arrangements of the multiple overlap span type would be required. These are physically very lengthy, and their design depends on the possible spacings between pantographs.

The availability of high speed compact phase breaks in a form suitable for 150 mph operation commencing in 1981 is uncertain.

It is mentioned in Ref. 18, Section 16.3.4, that the NECIP proposed operation at 120 mph should be based upon the use of compact phase breaks which will be available for the application in time.

2.1.1.2 Substation Sizing and Spacing Reviewed (Refs. 18, 22) - Single line diagrams for the various types of substations required are shown in Appendix J of the NECIP Task 16 Final Report (Ref. 18). The number and location of the substations covered in the detailed investigation with utilities is based on the original proposals outlined in Task 5, with the exception that Benning has been omitted. Also, Green Farm has been replaced by Ash Creek and Rowayton (Ref. 18).

Studies of the power demand for NEC loads have been made by Transmission and Distribution Associates (TAD) as a subcontractor to Bechtel and to Electrack. TAD also conducted a study for FRA under Task 17d, and prepared a report "Northeast Corridor (NEC) Rail System Power Demand Analysis," dated October 1975, in which an estimate was made of the power demand on each railroad substation using a set of train schedules based on 1990 high traffic demand (Ref. 22) and 150 mph operation.

2.1.2 <u>Conversion of Electric Multiple-Unit Car and Locomotive for Dual-Voltage, Dual-Frequency Operations</u> (Ref. 23)

One of the primary tasks of the Northeast Corridor Improvement Project (NECIP) is a conversion of the existing electrically isolated single-phase, 11 kV, 25 Hz network, to a system using single phase power at 25 kV, 60 Hz supplied from a three-phase commercial grid. Presently operating on the existing 11 kV, 25 Hz electric traction system are 647 electric multiple unit (MU) passenger cars (see Table 2) and 208

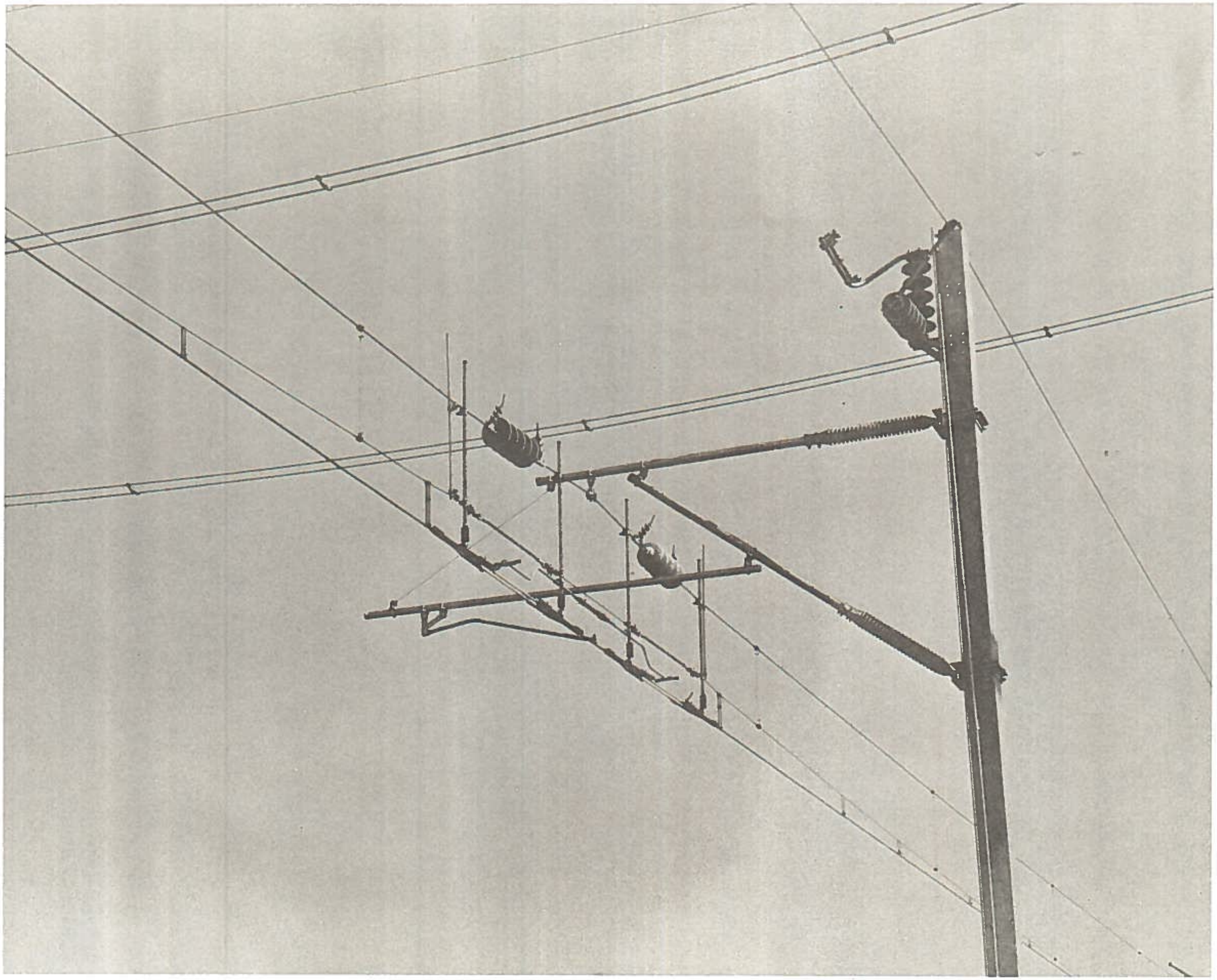

FIGURE 1. RAILROAD TEST TRACK (RTT) ELECTRIFICATION -- CONSTRUCTION PROGRESS, PHASE BREAK, NEAR SUBSTATION

TABLE 2. MULTIPLE-UNIT (MU) CARS IN SERVICE IN NEC

Popular Designation	Owner	Number Owned	Operator	Where in Service
E-6	NJDOT	18	Conrail	(1)
	SEPTA	28	Conrail	(2)
Silverliner I	SEPTA	5	Conrail	(2)
Silverliner II	City of Phila	37	Conrail	(2)
Silverliner III	City of Phila	12	Conrail	(2)
		8	Amtrak	
Silverliner IV	SEPTA	130	Conrail	(2)
Jersey Arrow I	NJDOT	34	Conrail	(1)
Jersey Arrow II	NJDOT	70	Conrail	(1)
M-2	MTA	122	Conrail	(3)
	CDOT	122	Conrail	
Metroliner	Amtrak	61	Amtrak	(4)

Total MU Cars = 647

(1) New York-Long Branch-Trenton Suburban Commuter Service.
(2) Philadelphia Suburban Commuter Service (Penn Central).
(3) New York-New Haven Suburban Commuter Service.
(4) Washington-New Haven High Speed Premium Service.

freight and passenger locomotives (see Table 3). The cars operate in commuter service throughout the suburban areas of Washington, Baltimore, Philadelphia, Trenton, New York, and New Haven, as well as in high-speed service through the entire Northeast Corridor (NEC). The locomotives are used for long haul passenger and commuter service, as well as for freight service through and connecting to the NEC. The MU cars and locomotives (except E60P) as they now exist could not operate without modifications after completion of the NECIP.

The cost of modifications to the 647 MU cars is estimated at 68.9 million. Fifty-one cars are considered candidates for replacement. If they are replaced, the cost of modifications for the other 596 cars will be $57.9 million, and the cost for 51 replacement cars will be $25.6 million.

The cost of modifications to the 208 electric locomotives is estimated at $126.3 million. One hundred and six locomotives are considered candidates for replacement. If they are replaced, the cost for converting the other 102 locomotives will be reduced to $27.9 million and the cost for 106 replacement units will approach $150 million. The desired conversion to commercial power entails a change in frequency and voltage. Because the entire Corridor will not be converted simultaneously, the rolling stock must retain its ability to function on the existing 11 kV, 25 Hz power supply. Consequently, the rolling stock must be modified for dual-voltage, dual-frequency operation before any segment of the Corridor on which it is to be operated can be converted to 25 kV, 60 Hz.

The 11 kV, 25 Hz electric traction system between Woodlawn and New Haven, which is presently being converted to 12.5 kV, 60 Hz, may initially remain an exception to the 25 kV, 60 Hz system.

The report (Ref. 23) covers engineering requirements of converting MU cars and locomotives operating on the NEC for dual-voltage, dual-frequency operation during and after rehabilitation of the electrification system for 25 kV, 60 Hz power.

2.1.3 NEC from New Rochelle to New Haven Converted (Refs. 12, 18)

The Connecticut DOT and NYMTA started a program to convert that part of the catenary used by commuter trains from Grand Central as far as New Haven from the existing 11 kV, 25 Hz to 12.5 kV, 60 Hz. During 1972 and 1973, studies were conducted by NUSCO (Northeast Utilities, including its subsidiaries) to predict the impact on the NUSCO system of converting to 12.5 kV, 60 Hz (Ref. 18).

Equipment for the conversion of the New Haven line between New York and New Haven is being installed. However, the change from 11 kV, 25 Hz electrification to the 12.5 kV, 60 Hz system has not yet taken place, and operation at the new conditions is not scheduled until 1981. The Connecticut DOT and the New York MTA are responsible for the conversion project (Ref. 12, Section 2.3).

2.1.4 Development of Failure Reporting-and-Analysis System to Correct Infant Failures on AEM-7 Locomotive

A contract has been awarded by TSC to Applications Research Corporation to develop a Failure Reporting and Analysis System (FRAS) to facilitate collection and analysis of failure data on the AEM-7 locomotive which will be tested at the Transportation Test Center. The FRAS will provide a mechanism for consistent documentation of the AEM-7 locomotive which will be tested at the Transportation Test Center. The FRAS will also provide a mechanism for consistent documentation of the AEM-7 locomotive reliability performance and failure history. The contractor visted GM/EMD in June 1979 to review industry procedures for failure reporting on diesel-electric locomotives.

2.2 CONRAIL (Refs. 24, 25, 26)

The Railroad Revitalization and Regulatory Reform Act of 1976 (4R Act) provided 200 million dollars in loan guarantees which could be used by the Consolidated Rail Corporation (Conrail) to help finance the electrification of its main line between Enola PA (across the Susquehanna River from Harrisburg) and Pittsburgh. This route is the old Pennsylvania Railroad's main artery across the state via Altoona and the Horseshoe Curve. A history of events leading to a current major electrification feasibility study is described (Ref. 25).

TABLE 3. FREIGHT AND PASSENGER LOCOMOTIVES IN SERVICE IN NEC

Popular Designation	Owner	Number	Operator	Where in Service
GG1	Conrail	9 Passenger	Conrail	Mainline and most branches of former PRR electrified territory.
	Conrail	44 Freight	Conrail	Mainline and most branches of former PRR electrified territory.
	Amtrak	40 Passenger	Amtrak	Washington, Harrisburg, and New York.
	NJDOT	13 Passenger	Conrail	New Jersey Suburban Service to New York.
E33	Conrail	10	Conrail	Freight lines of former PRR electrified territory.
E44	Conrail	66	Conrail	Freight lines of former PRR electrified territory.
E60CP	Amtrak	26	Amtrak	Washington to New Haven.

Total Locomotives = 208

Gibbs & Hill Completing Feasibility Study for Electrification of High-Density Lines (Refs. 26, 27)

The 4R Act provides loan guarantees for the electrification of high density lines if it can be shown economically beneficial. The 300-mile line between Harrisburg PA (Enola) and Pittsburgh PA (Conway) carries the highest freight tonnage of any U.S. route. This segment and certain other segments of presently electrified lines east of Harrisburg will be studied in projected traffic levels; projected costs of electric power and diesel fuel; effective methods of electrified operation; electric power supply and catenary system; effects of electrification on signals and communications and financial implications of electrification. Conrail selected Gibbs & Hill, Inc. (G&H) an independent consulting firm, to perform the feasibility study outlined above.

The study is scheduled for completion in 1979 and the results may be used by Conrail to assist in making a decision whether to apply under Section 606 of the 4R Act to obtain loan guarantees for electrification.

2.3 ERIE·LACKAWANNA RAILROAD

Rehabilitation and Conversion Initiated to Improve Service (Ref. 28)

The New Jersey DOT has undertaken major improvements and changes on the Erie-Lackawanna Electrification Project in northern New Jersey. The engineering and design is contracted to Gibbs & Hill, Inc., of New York City. In 1976, the railroad was merged into Conrail, which now operates the system.

The new electric multiple-unit, two-car sets and single-unit cars purchased will operate at 11 kV, 25 Hz which is the present Amtrak corridor and Conrail system voltage. Also, these cars will operate at 25 kV, 60 Hz, the proposed future Amtrak corridor catenary voltage. These cars will not operate on the existing Erie-Lackawanna catenary energized at 3 kV dc.

The original traction-power system is being replaced with ac substations which will have 25 kV, 60 Hz characteristics.

Current plans call for the complete system to be converted and operational by mid-1980.

2.4 SOUTHEAST PENNSYLVANIA TRANSPORTATION AUTHORITY (SEPTA) (Ref. 29)

SEPTA service includes six former Penn Central lines and seven former Reading lines. SEPTA Corridor operations are just to Trenton NJ and Wilmington DE. However, there is an UMTA-funded project to unify SEPTA's system by construction of a tunnel linking the Suburban Station with Reading Terminal in Philadelphia. When that occurs, the present 11 kV, 25 Hz system in operation could not be isolated on the Reading lines. A contract for underpinning Reading Terminal has been let, and completion of the tunnel is expected in 1981. SEPTA estimates the cost of converting their entire operation to 60 Hz to be $66 million of which NECIP would provide $17 million. Although it may be possible to continue to operate on 25 Hz power, it would still be necessary to convert cars to dual mode operation. The older cars could not operate at 60 Hz and still would have to be replaced.

2.5 BLACK MESA & LAKE POWELL RAILROAD (Refs. 30, 31)

The Black Mesa & Lake Powell Railroad (BM&LP) is a coal hauling railway in Arizona. It is the first line in the world to be electrified at 50 kV, 60 Hz. This voltage has been adopted so that the 78-mile line can be fed from a single substation at one end, with consequent savings in installation and maintenance costs.

The railway links the Black Mesa mines near Kayenta AZ with the Navajo generating station on the shores of Lake Powell. Its annual requirement of 8 million tons of coal is supplied entirely by the BM&LP, a single train that is powered by three G.E. 180-ton E60-C locomotives, each with a continuous rating of 5100 hp. The train makes three round trips of 156 miles daily, to satisfy the fuel requirements of the power station (Ref. 30). The railroad currently has a traffic level of 18.2 x 10^6 gross trailing tons (GTT) per year and this is not expected to change unless a fourth generating unit is added at the Navajo power station (Ref. 31, Vol. 2).

Capacitors Installed to Reduce Reactive Power (Ref. 30)

The 50 kV BM&LP electrified railroad has been uprated to double its handling capacity without additional substations or transmission line. The line originally had only one train which used three locomotives for 73 to 83 cars. Traction power was supplied by two 10-MVA transformers at the substation. When the demand for coal increased, GE altered the electrical design by adding a third 10-MVA transformer and line capacitors to reduce the catenary inductive reactance. These changes permitted addition of a second coal-hauling train.

2.6 TRANSPORTATION TEST CENTER (Ref. 32)

The Transportation Test Center (TTC) of the U.S. Department of Transportation is located northeast of Pueblo CO. At TTC, the latest developments in railroad and transit technology are tested under varied operational conditions. TTC is managed by the Federal Railroad Administration (FRA), and the center has available 130 km^2 (50 $miles^2$) of land leased from the state of Colorado.

Construction of Catenary and Substation for 14.5-Mile (23.3-km) Railroad Test Track (RTT) Oval (Refs. 18, 33)

Construction of an electrified 14.5-mile RTT (23.3 km) which will provide a flexible facility for research, development and evaluation of electrification equipment is underway at TTC (Figure 2). International Engineering, Inc., San Francisco, under contract from DOT/FRA, is responsible for the design of the high-voltage electrification system at the test center. The electrical contractor is Fischback and Moore, Inc. The initial purpose of the electrified RTT is to provide a test facility for the NECIP to evaluate rolling stock and wayside equipment for eventual use in electrification of the corridor from New Haven to Boston. The electrification system will have a testing capability of 12.5 kV, and 50 kV at 60 Hz providing the industry with a facility to make full-scale evaluation of equipment, components, and systems for electrification.

Work involved in making the power supply available to the overhead contact system (OCS) includes extension of an existing 115-kV transmission line to a new traction substation at a location convenient to the catenary feed points. The traction substation in the baseline system will provide a continuous load demand of 10,000 hp at a lagging power factor of 0.75 at the two higher voltages, and about half the above load at 12.5 kV (Ref. 33, Vol. 1, Section 3.2).

The OCS for the RTT (Figure 3) consists of 13.5 miles of style 5 catenary plus a test section 1 mile in length. The test section consists of a 0.5-mile length of style 1 catenary and a 0.5-mile length of style 3 catenary.

The purpose of the 1-mile test section is to study various styles of OCS catenaries at speeds up to 150 mph.

The DOT/FRA have specified the installation of the following catenary styles in the OCS 1-mile test section:

- Style 5X - New compound, stretched (Style 5 extended to 250-foot spans)
- Style 3 - Hanging beam (used on NEC between New York and New Haven)
- Style 1 - Heavy compound (used on NEC between Washington and New York).

These styles are defined in Task 16, Electrification Systems and Standards (Ref. 18), which was prepared as a study of the NEC OCS.

In order to test other catenary styles, it will be necessary to remove one of those listed above and this will be replaced by the catenary to be studied (Ref. 33, Addendum 1).

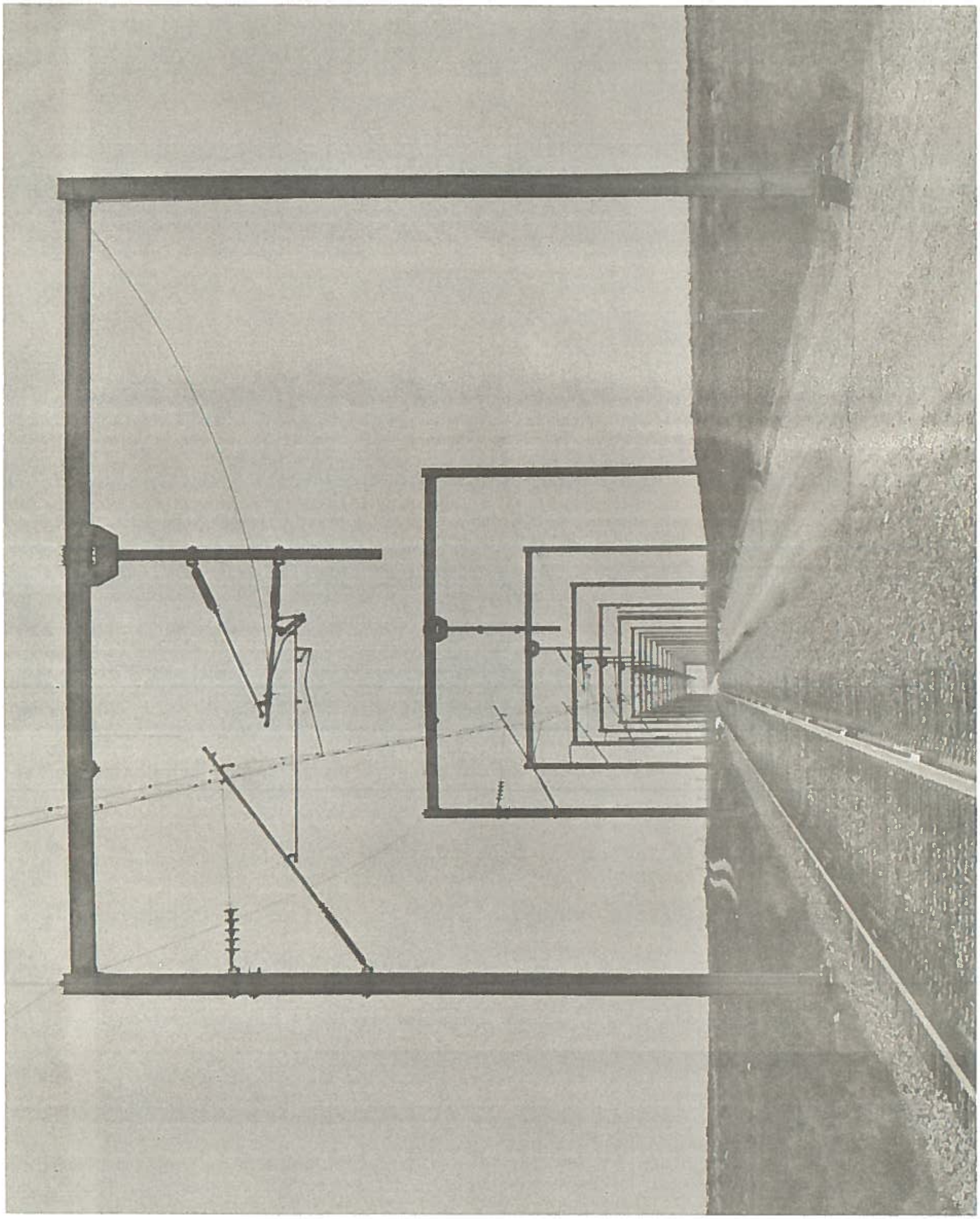

FIGURE 2. RTT CATENARY -- TYPICAL PORTAL STRUCTURE
WITH STYLE 3 CATENARY TRANSFER ASSEMBLY

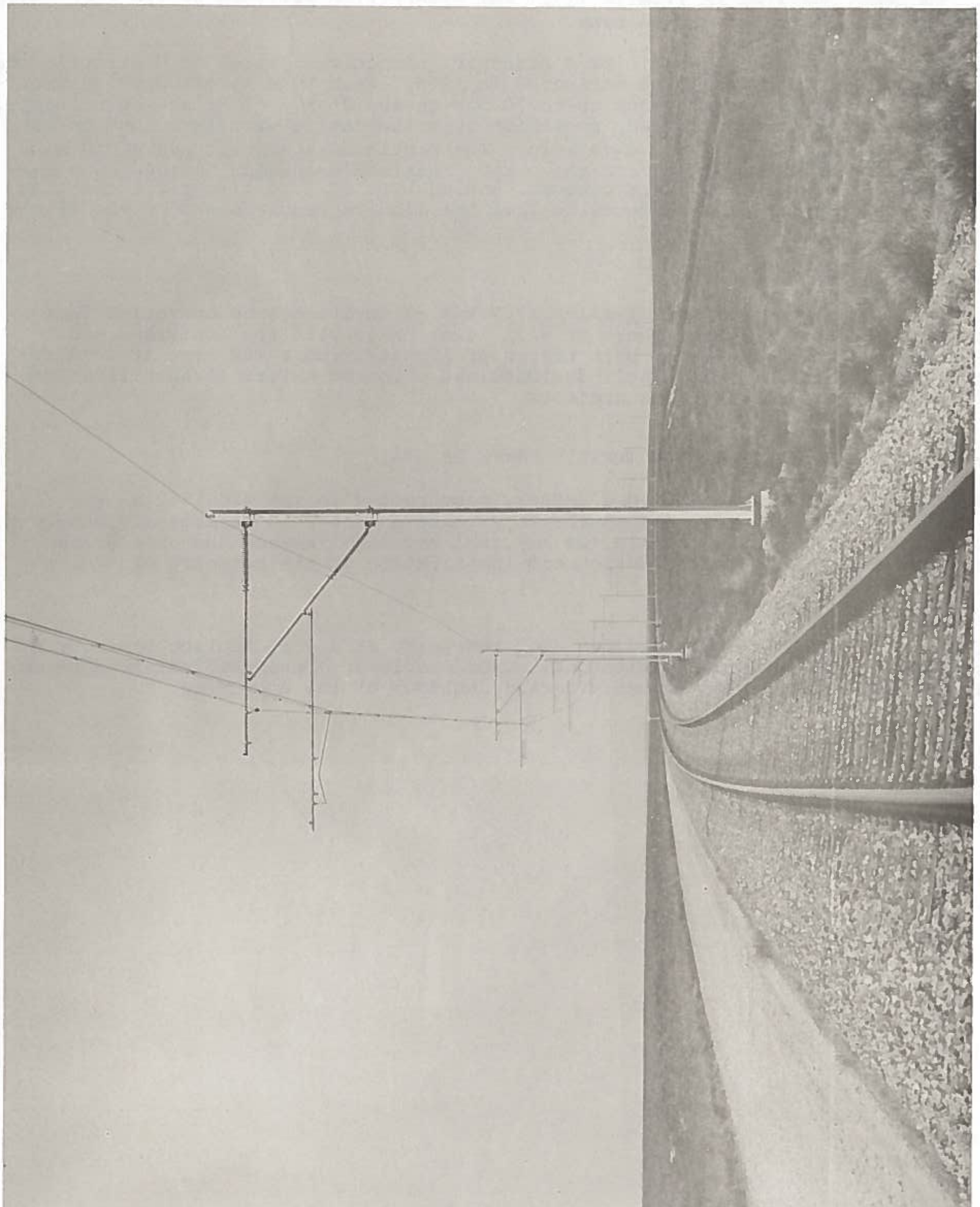

FIGURE 3. RTT ELECTRIFICATION -- CABLES ATTACHED TO CROSS ARMS

2.7 TEXAS UTILITIES COMPANY (TUC) (Ref. 34)

The fourth and newest of the nation's electrified coal railroads is a six-mile (9.7 km), single-track, 25 kV, 60 Hz line with two passing sidings carrying unit trains between Texas Utilities Company's (TUC) Martin Lake generating station and the mines. TUC also operates an 11-mile (17.7 km) electrified railroad at the Monticello station, 90 miles north of Martin Lake.

TUC has five General Electric E25B electric locomotives, three at Monticello and two at Martin Lake with two to be delivered in 1979. Each E25B weighs 280,000 lbs. (70,000 lbs. per axle) and they run up to 70 mph on the 25 kV, 60 Hz ac-power supply. The E25B is a thyristor controlled, rectifier type locomotive with four 1000 hp GE 752-Vdc traction motors, one for each axle. The Martin Lake station has a 750 MW generator, first of four planned for the site. Consists averaging 19 100-ton Ortner bottom-discharge hopper cars and a caboose, hauled by a GE E25B electric locomotive, make eight to ten trips each 24 hours to fill the lignite requirements of the single generator.

Electrification at TUC

TUC will soon have another 11-mile (17.7 km) electrified line operating from Monticello to Leesburg, Texas, where it will interchange with the Louisiana and Arkansas Railroad hauling 80-car unit trains of lignite from a TUC mine at Sulphur Springs, Texas. Gibbs & Hill, Inc., designed and prepared materials specifications for all three TUC electrification projects.

2.8 MUSKINGUM ELECTRIC RAILROAD (MERR) (Refs. 35, 36)

The Muskingum Electric Railroad (MERR), constructed in the mid-1960's, was the first railroad in the Western Hemisphere to utilize a 25 kV, 60 Hz catenary supply for its locomotives. MERR is a 15-mile (24 km) coal hauling line and the Ohio Brass Company was responsible for the design and installation of the catenary system.

MERR Maintenance Schedule

The 15-mile MERR has operated for over ten years at a coal hauling capacity of 52.5 million-ton miles annually with only minor problems. Scheduled maintenance on the fixed plant is conducted annually during shutdown of the coal mine.

3. STATUS OF ELECTRIFICATION PLANNING BY RAILROADS, UTILITIES, AND GOVERNMENT AGENCIES

(Refs. 1, 2, 16, 37)

An earlier 1975 paper (Ref. 37) identifies the following railroads having electrification studies in progress at that time: Southern Pacific, Union Pacific, Burlington Northern, Canadian Pacific, Santa Fe, Illinois Central Gulf, Southern, and Penn Central. This report section discusses planning that has occurred 1976 to 1978 by railroads and by Utilities and Government agencies.

3.1 TENNESSEE VALLEY AUTHORITY (TVA)/SOUTHERN RAILWAY (SR)/LOUISVILLE & NASHVILLE (L&N) RAILROADS (Ref. 38)

A railway electrification demonstration project was initiated by the Tennessee Valley Authority (TVA). TVA has the responsibility of managing the natural resources of the Tennessee Valley region. A railroad electrification project is being considered to demonstrate petroleum conservation. Transportation nationwide uses 8×10^6 BBL/day of petroleum. If the TVA project established the economics so that other railroads would follow suit, it was considered that the total scope of the effort might entice 15 percent rail usage employing diesel power locomotives to be electrified. Furthermore, it was estimated that a potential exists to save 2 million barrels per day of diesel fuel.

Electrified operation of two Cincinnati-Atlanta rail routes is targeted for 1984 by the TVA. Studies have been completed for the 480-mile routes of the L&N and SR. TVA was to propose formation of a management corporation to provide capital funds for the $100 million needed for electrification of each railroad from Cincinnati to Atlanta. The two railroads would provide their own electric locomotives.

3.2 CONRAIL

See Section 2.2.

3.3 BURLINGTON NORTHERN RAILROAD (Ref. 39)

BN is taking a long view and making major investments to provide an expanded efficient transportation system to haul western coal. This is essential to the electric utility companies because assurance of a continuing fuel supply at relatively stable prices is a critical factor in the planning of new generation stations.

BN operates 1,800 km (1,118 miles) of railroad between its coal mining areas in Montana and its terminal at Lincoln NE. Because of the heavy coal traffic and the favorable terrain conditions, electrification appears to be an effective means of reducing operating costs. The BN railroad's initial candidate for electrification is the line from Lincoln NE to Alliance NE (363 miles). In this area, about 34 Tg* (38 million tons) are currently being moved annually and this could increase to more than 90 Tg (100 million tons) by 1980. Studies have indicated that an annual movement of 27 Tg (30 million tons) would be adequate to economically justify electrification. The number of trains could increase from 15 to 50 per 24-hour period. This potential increase in such a short period of time is related entirely to the movement of coal out of Wyoming and Montana.

Clearance restrictions are minimal, making 50 kV practical. Operating at the higher voltage reduces the current by half compared with a 25 kV system. In addition, substations can be spaced further apart -- 65 km (40 miles) -- and therefore fewer substations are required at 50 kV resulting in significant savings. BN is looking for a locomotive for their coal hauling operations with power in the range 6 MW (8,000 hp). The diesels are limited to 2.7 MW (3,600 hp). BN would be able to operate through a given territory with half the present number of locomotives requiring less locomotive maintenance and fewer operating personnel.

The problem of inductive interference to signaling and communications has been considered and preliminary studies indicate that this is not insurmountable, but must be investigated further.

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*1 Tg (Teragram) = 1.11 million tons

The cost of an electrified installation, depending on the geographical location, can vary from $55,000 to $80,000/km ($90,000 to $125,000/mile). This involves catenary, substations, and signal and communications modifications. The recommended solution to the inductive interference problem mentioned previously is to bury signal power cables and employ microwave communications. Electric locomotives cost from $700,000 to $1 million each.

3.4 UNION PACIFIC RAILROAD (Ref. 37)

A 1972 study by Union Pacific Railroad (UP) dealt with the technical and economic feasibility of mainline freight electrification of the North Platte to Green River section. The expanded study included extension of electrification west of Green River UT to Salt Lake City UT and Pocatello ID. No further planning activity occurred, 1976-1978.

3.5 ATCHISON, TOPEKA, & SANTA FE RAILROAD (Ref. 37)

During the period 1972-1973, International Engineering Company Inc. (IECO) conducted a feasibility study to determine costs for electrifying a mainline of over 1,700 route miles (2,737 km) between Missouri and California. This included more than 2,500 track miles (4,025 km) of main tracks, sidings, and yards. No further planning activity occurred, 1976-1978.

3.6 ILLINOIS CENTRAL GULF (ICG) RAILROAD (Ref. 37)

At present, ICG has 37 miles of track electrified as indicated in Section 2, Table 1. A study was completed in 1972 to determine if portions of the mainline from Chicago to New Orleans could be more economically operated using electric locomotives instead of diesel locomotives. No further planning activity occurred, 1976-1978.

3.7 BESSEMER & LAKE ERIE RAILROAD (Ref. 40)

A 1975 electrification study was performed for the Bessemer & Lake Erie railroad mainline, a 140-mile route from Conneaut OH to North Bessemer PA. The study recommended a 50 kV catenary installation over 190 track miles that carry 27 million gross tons annually. A hybrid locomotive consisting of an electric/diesel-electric combination would be used. Costs of the various subsystems are given, along with projected maintenance and operating costs of the proposed electric and current diesel-electric operation. Although the return of investment (ROI) was found to be low, impending ecological and fuel-supply problems led to a recommendation for pilot electrification. No further planning activity occurred, 1976-1978.

3.8 SOUTHERN PACIFIC RAILROAD (Ref. 41)

A study was performed in 1970 to determine the feasibility of railroad electrification using commercial frequency supply for heavy long-haul freight operation through areas with low electric utility power density. Railroad operating philosophy, locomotive parameters, method of supply and catenary voltage levels are discussed, as well as some of the technical problems associated with supplying large single-phase loads from a three-phase utility system. At least five routes were considered candidates for electrification studies. The 760-mile Colton to El Paso route was considered to lend itself best to a study of applied electrification technology. This was based on a number of considerations, including sufficient traffic density and potential for continued traffic growth on this route, high operating speeds necessary to maintain competitive schedules, substantial mileage and duration of runs, absence of tunnels, and a small number of bridges and overpasses with restrictive clearances. Heavy grades of almost 2% challenge electrification to increase speed. The relative absence of close, parallel, open-wire communications circuits over most of the route means the potential inductive interference problem from high voltage lines will be insignificant.

Southern Pacific developed a train schedule optimized for electrified operation in the form of a train graph typical for a 24-hour period projected to 1980. From these data, electrical demand requirements indicated that 7,000-ton trains would have a 20 MW demand between Colton and Indio and 10 MW between Indio and Yuma at design speed for the section.

It was concluded that electrification, using commercial frequency supply from a three-phase utility system, appeared technically feasible for heavy long-haul freight operations through low electric utility power density areas. Also, a catenary voltage of 50 kV was recommended based on a comparison of current demands at both 25 kV and 50 kV, and the cost to provide clearance at overpasses, bridges, and utility line crossing for both voltages. No further planning activity occurred, 1976-1978.

3.9 CANADIAN PACIFIC RAILROAD (Refs. 5, 6, 7, 13)

At present, Canada has about 70 miles of its 46,300-mile rail network electrified (Ref. 5). The status of railroad electrification in Canada was discussed in Section 1.1.2. A study commissioned by the Railway Advisory Committee (a joint committee of the Railway Association of Canada and the Transportation Development Agency) has shown that electrification of Canadian railroads is considered technically feasible, although the heavy initial capital expenditure and the relatively long payback period are considered formidable obstacles in terms of financing. Nevertheless, electrification of a substantial portion of the principal mainline trackage was shown to be financially attractive under the conditions outlined in the study (Ref. 6).

Some useful comparisons are made between Canada and other countries, including Sweden, USSR, and South Africa, having most of their existing railroad routes electrified. These comparisons were made on the basis of similarities in population, geographic area, and route lengths (Ref. 13).

On the basis of the future traffic projections and the economic analysis conducted, a plan was developed to implement electrified operation on 15,300 km (9,500 miles) over a 30-year period. The plan has not been implemented to date (Ref. 7).

3.10 UTILITIES

3.10.1 American Electric Power Research Corporation (AEPRC)

In 1969, the American Electric Power Research Corporation (AEPRC) placed the automated Muskingum Electric Railroad in operation. This is a 15-mile coal hauling line, which is operated at 25 kV, 60 cycle, single-phase, and is the first commercial-frequency electrified railroad to operate in the United States. Refer to Section 2.8 for a description of the current status of this railroad.

3.10.2 Tennessee Valley Authority (TVA)

Electrified operation of two Cincinnati-Atlanta rail routes is targeted for 1984 by the TVA. Studies have been completed for the 480-mile routes of the Louisville and Nashville Railroad and the Southern Railroad. TVA was to propose formation of a management corporation to provide capital funds needed for this electrification project.

Refer to Section 3.1 for a description of this TVA electrification project.

3.10.3 Edison Electric Institute (EEI) (Ref. 42)

Early in 1965, the Board of Directors of the Edison Electric Institute (EEI) appointed a committee to investigate the technical and economic feasibility and problems associated with electrification of railroads. A Task Force was organized to help carry out the assignment. The study was to include a review of the ability of power systems to supply single-phase energy for railroad propulsion directly from commercial-frequency electric power systems.

From experience abroad and, to a limited extent in the United States, it appeared that economic advantages could accrue to both railroads and utilities by electrification. For the railroads, savings in investment costs and in operation and maintenance expenses may be available to railroad operators where traffic density is high and in other circumstances. For electric utilities, increased sales of power and energy provide incentive for investigation.

The 1965 Task Force on railroad electrification included the following representatives of the electric utility industry:

E.B. Shew, Chairman, Philadelphia Electric Company

P.A. Duker, The Detroit Edison Company

R.P. O'Brien, Southern California Edison Company

B.A. Ross, American Electric Power Service Corporation

F.S. Walters, Potomac Electric Power Company

R.W. Wyman, The Cleveland Electric Illuminating Company.

The 1965 study concluded that electrified railroad load is desirable from the utility viewpoint, also, large modern electric power systems can successfully supply single-phase energy at commercial frequency for railroad propulsion. It was further concluded that the railroad electrification market could be looked upon not only as a stable source of sales and revenue for the electric utility industry, but also as a market with very good growth potential. In total, railroad electrification offers a number of specific benefits to the utility industry.

The 1965 Task Force had felt that a complete study which would produce meaningful results could be made only if an operating high-traffic-density railroad were to be used as a model. The New York Central Railroad from Harmon NY, to Cleveland OH, was selected for this purpose. The route has a common terminal with the already electrified 600 route miles of the Pennsylvania Railroad and would add another 600 miles of electrified mainline railroad. (Ref. 42, Volume 1).

A New York Central Railroad Electrification Engineering Study Group was organized in August 1966, with representation from the railroad and from each utility system involved. The engineering report of the Study Group was completed in January of 1969 (Ref. 42, Volume 2).

In parallel with this work, Gibbs & Hill, Inc., was engaged by EEI to prepare designs and estimates for overhead wire systems using the latest technology available both in the United States and elsewhere (Ref. 42, Volume 3).

3.11 U.S. GOVERNMENT AGENCIES (Refs. 1, 2, 43, 44, 45, 46)

3.11.1 U.S. Department of Transportation/Federal Railroad Administration (DOT/FRA)

The Railroad Revitalization and Regulatory Reform Act of 1976 (4-R Act) has resulted in a major reassessment of electrification and its potential role in future railroad operations in the U.S. Under Title VII, Amtrak's existing facilities in the Northeast Corridor are scheduled for rehabilitation and extension from New Haven to Boston (refer to Section 2.1). Conrail has undertaken a major feasibility study concerning electrification of some of its routes in response to a provision of the Act which allots $200 million in Federal guarantees to Conrail if the decision is made to proceed with an electrification program (refer to Section 2.2). Federal assistance is also available to railroads for improvement projects under Title V, "Railroad Rehabilitation Improvement Financing." Finally, Title IX called for the Secretary of Transportation to conduct a comprehensive study of the American railway system, including the potential benefits of railroad electrification. The study has been completed and is documented (Refs. 1, 2).

The main obstacle to electrification in the U.S. to date has been financial. Electrification requires relatively large capital investment that comprises the following major costs: Catenary, Substations, Civil Reconstruction (to provide catenary clearance), Modifications to Signalling and Communications Systems, and Electric Locomotives. A DOT/FRA study calculated the costs and rate of return on investment (ROI) for electrification of three rail networks of varying size as follows (Ref. 1, Appendix C):

1) 10,000-mile network, including only lines with traffic levels of 40 MGTM/year.
ROI greater than 12 percent

2) 26,000-mile network, including all lines carrying 40 MGTM/year and a significant portion of lines with more than 20 MGTM/year.
ROI 9 to 10 percent.

3) 40,000-mile network, including all lines carrying more than 20 MGTM/year. ROI 9 to 10 percent.

The investment in electrifying individual route segments of 300 to 1,000 miles of very high density (between 70 and 100 MTGM) rail lines would yield ROI values between 18 and 21 percent. It should be noted that the basic assumptions regarding traffic growth and inflation are different from those for the three network scenarios above.

It was concluded that the operational and economic benefits would be sufficiently large to justify industry investment in electrification of routes with traffic levels in excess of 20 MGTM/year.

Reduction in petroleum consumption alone would not be sufficient justification to embark in a major electrification program, as the reduction in petroleum consumption would be small in comparison to national petroleum consumption figures. Benefits which would be realized by railroad companies through lower operating, maintenance, and energy costs appear to be sufficiently large to justify industry investment in electrification of routes with traffic levels in excess of 20 MGTM/year (Ref. 1).

3.11.2 Tennessee Valley Authority (TVA)

See Section 3.1.

3.11.3 Department of Energy (DOE)

The Division of Transportation Energy Conservation of the DOE contracted the Stanford Research Institute tc assess the broad consequences of electrifying selected mainline U.S. railroads. First, a scenario was developed for the electrification of major mainline freight routes, extending from 1985 through 2000. The consequences of the scenario were then examined with the help of a new, national financial model of the railroad industry. The model was used to study the ramifications for the participating railroads, the financial community, equipment suppliers, governmental regulatory agencies, electric utilities, labor, customers, and the public at large. The central feature of SRI's model is a detailed, year-by-year accounting of the financial condition of the railroad industry. Results of the study will be published as a DOE-contractor report.

4. RESEARCH AND DEVELOPMENT (R&D) ACTIVITIES

4.1 DOT FUNDED R&D (Ref. 43)

It is the FRA posture that the successful completion of selected R&D can result in reductions in costs, both capital and operating, and that the savings are sufficient to justify the R&D. However, no technological break-throughs are forecast which would render an electrification system that used present technology obsolete.

A TSC study (Ref. 43) investigated the cost-effectiveness of R&D related to railroad electrification in the U.S. The source of R&D topics was a series of industry/government workshops conducted early in the study. In order to provide a quantitative measure of the impact of individual R&D topics, a scenario was established for implementing an electrified network in the U.S. Costs were estimated with and without implementation of the proposed R&D topics to determine their cost-effectiveness.

Those topics found to have major impact include substation and railroad/utility interface improvements to reduce energy costs, improvements in locomotive power density and adhesion, and reduction in electromagnetic interference. The magnitude of the benefits depends on the cost and size of the network and the installation rate, as well as the degree of success in completing the individual R&D efforts.

The state-of-the-art in electrification is continually changing and advancing in those countries where railroad electrification is a national commitment. As electrification is experiencing a resurgence in the U.S., the changes can be expected to be even more rapid. It is therefore planned by the FRA to review and update the R&D program on a continual basis.

A number of feasibility studies and R&D programs either recently completed or currently in progress are summarized below.

4.1.1 Poly Chlorinated Bi-Phenyl (PCB) Coolant Replacement Tests

The feasibility of PCB coolant replacement in locomotive and wayside transformers is currently being investigated under two DOT/TSC funded contracts as follows:

a) Flammability Tests

The primary objective of this contract is to determine the flammability characteristics of a silicone fluid in the presence of PCB contamination.

The flammability characteristics of silicone fluid are being tested. Also, a hydrocarbon transformer oil is being tested with PCB contamination ranging from 0 to 7%. The completion date for these tests was the end of September 1979. Tests are proceeding on schedule.

b) Laboratory and Field Tests

The primary objective of this contract is to evaluate a potential replacement material of the PCB coolant presently used in transformers by the railroad industry. The replacement fluid shall function as a coolant for new railroad transformers, as well as a replacement for the PCB's in the transformers already in railroad service.

Another objective is to retrofit a PCB-filled transformer with silicone, conduct temperature tests, install on a SEPTA vehicle, and follow by tests in service for one year.

Original transformer failed temperature test, and the operation was repeated with a second transformer previously tested and known to operate satisfactorily. Temperature test data were due by mid-July 1979. Decision for further activity on this contract will be made following analysis of temperature data.

4.1.2 Development of Solid-State Inverter for Auxiliary Power

A solid state inverter has been built for laboratory testing at TSC. The objective is to establish a more efficient and reliable source of auxiliary power than the motor-generator.

4.1.3 Synchronous Motor Development

The contract calls for the design, development, and manufacturer of a cycloconverter synchronous motor system for electric locomotives to be operated from a 480 V single-phase, 60 Hz supply and to meet specific drive criteria set forth in Appendix A of the contract amended March 24, 1978. The statement of work includes:

a) Phase I

Task 1 Prepare program plan

Task 2 Design, develop and manufacture a synchronous motor drive system

Task 3 Prepare performance test plan

Task 4 Prepare operator's instruction manual.

b) Phase II

A) Conduct performance test program at EMD

B) Prepare test program final report

C) Deliver system to TSC by 24, September 1979 (18 months following commencement).

The monthly progress report dated 9 July 1979, for the period ending 30 June 1979, indicates the degree of completeness of the planned activities which are proceeding on schedule. This report also stated that system control had been improved to the point that operation in all modes was stable. Also, an 8 Hz inductor current oscillation which was previously apparent above base speed had been eliminated and the transition between the speed range below base speed to the speed range above base speed was smooth.

A major resonance peak in the measured torque appears between 125 and 175 rpm. A second resonance occurs between 280 and 320 rpm. These resonance torques are not excited in the dynamic braking mode where the motor currents are sinusoidal. It appeared that the resonances could be eliminated by replacing the flexible torque transducer shaft with a much stiffer shaft. However, the accuracy of measuring torque output would be greatly impaired.

System performance testing is proceeding using average torque measurements at the resonance speeds.

4.1.4 High-Voltage DC Electrification (Ref. 47)

High-voltage (10-50 kV), direct-current (HVDC) power distribution may prove to be an economically and technically attractive option for future railroad electrification. There may be potential economic advantages in both wayside installation and operation and in the propulsion equipment aboard the rolling stock. However, before the economic comparison with AC can be completed, the technical feasibility must be determined. This determination is the purpose of this report.

This study is directed toward the wayside equipment only. The problem of HVDC rolling stock is not considered.

This preliminary analysis shows no technical obstacle to the use of HVDC power distribution systems for application to the wayside portion of railroad electrification. Circuit breakers, which can be applied to these systems, are in various stages of development, and with reasonable directed research can meet the duty requirements. Likewise, rectifiers which can satisfy both current and voltage requirements are within the state-of-the art.

An alternate to using the DC breaker, namely sectionalizing on the AC side of the system, is a viable option. This option can sacrifice some operational flexibility, as well as performance.

A five-step program for future research efforts leading to the demonstration of a HVDC power distribution system is outlined.

4.1.5 Flywheel Energy Storage Along Wayside on Major Grades (Ref. 31)

An in-depth application study was conducted to determine the practicality and viability of using large wayside flywheels to recuperate braking energy from freight trains on long downgrades.

The study examined the route structures of nine U.S. railroads and identified various wayside energy storage system (WESS) configurations. The optimum means of transferring energy from the train to the wayside was by means of a high-voltage ac catenary from either regenerative electric locomotives or modified dual-mode (diesel-electric/electric) locomotives.

The application of WESS was then analyzed for four specific routes of typical U.S. railroads. These routes and the annual returns on investment (ROI's) resulting from WESS deployment on existing railroads were as follows: Atchison, Topeka, & Santa Fe (Los Angeles to Belen), 27.1 percent; Black Mesa & Lake Powell, 17.3 percent; Conrail (Pittsburgh to Harrisburg), 22.0 percent; and Union Pacific (Los Angeles to Salt Lake City), 20.2 percent.

4.1.6 Applicability of Dual-Mode Locomotive for Phasing-in Electrification (Ref. 31)

A preliminary design study was conducted to confirm the technical viability and economic attractiveness of the dual-mode locomotive concept based on the most common U.S. road locomotive, the SD40-2. The study examined the existing characteristics of the base locomotive and ensured that operation in the diesel mode would not be compromised by a locomotive which has a pantograph, transformer, converter, and choke added to permit operation from a 50 kV catenary. The study concluded that the concept is technically viable (although some equipment is only available overseas) and is economically attractive, the modification cost being $217,500.

The results of this study are contained in Volume IV of the WESS described in Section 4.1.5.

4.1.7 Electromagnetic Compatibility (EMC) (Refs. 48, 49, 50)

Signal and communication systems in alternating current electrified territory must withstand substantial interference effects produced by current flowing in the catenary and the use of rails to return the propulsion current. These interference effects may be conveniently divided into four categories (Ref. 48):

1) Electromagnetic induction - the effect on a conductor produced by varying current flowing in a parallel conductor.

2) Electrostatic induction - the effect on a conductor produced when another conductor has a higher potential than the ground.

3) Rise in ground potential - the effect produced by the use of the ground as a conductor.

4) Metallic cross-conduction - the effect produced by the accidental connection of one conductor to another.

Signal and communications systems must function reliably under a wide range of environmental conditions and must also withstand the interference effects produced by commercial power systems along the right-of-way, and in the case of electrification, the additional interference effects produced by the propulsion power supply and the locomotives.

Currently, the Bell system is engaged in a program to assess the magnitude of the potential problem. Measurements are being made in cooperation with the Muskingum Electric Railroad, which operates thyristor controlled E-50 locomotives in 25 kV, 60 Hz power. The results of these studies will be reported through the TRB Committee on Electrification Systems (Ref. 48).

A railroad EMC research program was performed for DOT/FRA by the DOD Electromagnetic Compatibility Analysis Center (ECAC) (Refs. 49, 50). Volume I of the Final Report, dated March 1978, contains an Electrification Bibliography. The objective was to provide a single source of referable material concerning electromagnetic interference/electromagnetic compatibility (EMI/EMC) associated with railroad electrification. The material is categorized into the following subject topics: Catenary

System, Electrification, Power Transmission Line, Signaling and Telecommunication, Substation, Track Circuit, Track Control System, and Miscellaneous (Ref. 49).

Volume II of the Final Report, dated September 1978, contains an EMC assessment for Classification Yards and Electrification. The electromagnetic radiation of the environment and selected railroad yard devices such as doppler radars and switch machines were measured at three classification yards. The susceptibilities of selected yard devices were measured to determine operational sensitivity to the yard electromagnetic radiations (Ref. 50).

4.1.8 Energy Saving by Regeneration (Ref. 51)

Electrification of the railroads in the United States is a viable strategy for conserving oil. One of the prime candidate routes for electrification is the mainline for Conrail between Harrisburg and Pittsburgh. Because of the large tonnage and steep grades which occur on this route, it is also a prime candidate for further energy savings by use of regeneration of electrical power.

This study investigates the feasibility of using regeneration on the proposed electrification of the mainline of Conrail between Harrisburg and Pittsburgh. Locomotives equipped for regeneration convert the braking energy, when operating with trains on downgrades, to electrical energy for use by other locomotives hauling trains on the upgrade.

Energy consumption and energy costs are estimated with and without regeneration.

Several distribution system configurations are investigated and the sensitivity of regeneration savings to substation spacing, type of distribution system, and power contract is investigated.

Based upon hauling 56.8 million gross trailing tons per year in each direction, Harrisburg to Pittsburgh and Pittsburgh to Harrisburg, the annual estimates of energy requirements and cost of energy, with and without regeneration, are:

	Without Regeneration	With Regeneration	Regeneration Savings
Million KWH Reduction	647	589	58 9%
Energy Cost (Million $) Savings	26.1	24.3	1.8 7%

It is estimated that the cost of a locomotive equipped for regeneration may be about 10% higher than a non-regenerative locomotive, or based on a fleet size of one hundred 6000 HP locomotives required for service at $1.1 million each, an additional capital expenditure of $11 million would be required.

Recommendations and suggestions for development, test, and further study are provided.

5. FINANCIAL-INSTITUTIONAL AND ECONOMIC ISSUES

(Refs. 1, 2, 44, 45, 46, 52, 53, 54, 55, 56, 57)

5.1 FINANCIAL CONSIDERATIONS

A number of U.S. railroads and the U.S. Government, as well as joint Government/Industry study groups, have studied the technical and economic feasibility of railroad electrification in considerable detail. FRA previously organized a task force to study railroad electrification in the U.S. The task force was composed of representatives of railroads, equipment manufacturers, electric utilities, trade associations, and Government officials. The report of the task force, (Ref. 59) issued in 1974 concluded that, notwithstanding the technical feasibility and operational benefits of electrification, the principal obstacles to electrification in the U.S. were financial considerations. In particular, the following issues were named as having influenced decisions not to electrify (Ref. 52):

1) Investment in electrification creates a long-term obligation for a railroad and, thus, affects its credit standing and ability to obtain capital for other necessary improvements.

2) The long-term earnings prospects for the railroad industry, in general, have not appeared to be strong in recent years. This has limited the interest in long-term railroad capital investments and precluded the opportunity to take full advantage of tax incentives when making large capital investments.

3) The economic benefits of electrification occur gradually over a long period of time, but the large investments necessary to initiate the flow of benefits must occur first and over a short period of time.

4) The investment of fixed electrification facilities may become subordinate to previous railroad mortgage commitments.

For a railroad, the issue of electrification is ultimately an investment decision that must compete with other investment opportunities for available funds. The amount of the investment is formidable. Current estimates by Arthur D. Little, Inc. (Refs. 44, 45, 46), indicate that the cost of a typical electrification system, including catenary, substations, and communications and signaling, would approximate $95,000/km ($150,000/track-mile). Double track would cost about $155,000/km ($250,000/mile). Assuming an average cost of $125,000/km ($200,000/route-mile), the total cost of electrifying the approximately 16,000 km (10,000 route-miles) in the United States that have traffic densities of at least 36 Tg/year (40 million tons/year), which is considered necessary by some experts under current economic and technological assumptions to realize a satisfactory return from electrification, would approximate $2 billion.

In addition to the electrification system, there would be the cost of the electric locomotives, although in some cases this would not require substantial additional investment, but rather would substitute in large part for diesel locomotives the railroad would otherwise have to purchase. There would, however, be the added cost of structural changes in track conditions, such as bridge and tunnel clearances, and new investment in electric power facilities. These costs could be very large in some instances.

In sum, the total cost of a national program of electrification would be at least several billion dollars initially, with potentially greater sums required if electrification becomes economical for route segments that have traffic densities of fewer than 36 Tg/year (40 million tons/year).

During the last 10 years, capital expenditures by class 1 railroads averaged approximately $1.5 billion annually, most of which was expended on rolling stock. Only about $400 million/year was expended on roadway and structures. Electrifying the railroads would be the largest investment in roadway and structures the railroads would make since the laying of the original track in the nineteenth century.

A recent study by First National City Bank (Citibank) projected that from 1976 to 1985, class 1 railroads, outside the Conrail system, would incur cash outlays for capital expenditures, deferred maintenance, debt service, dividends, and taxes of

$21.1 billion in excess of internal cash generation (net income before depreciation and other noncash charges but after dividends) and proceeds from rate increases, which will have to be met either from new capital or additional profits. Of this amount, Citibank estimated that $11.8 billion could be raised through traditional means of equipment financing, leaving a $10 billion financing problem. Citibank being a major lender to the railroad industry and creditor of the Penn Central Transportation Company, it can be assumed that the railroads will have difficulty meeting their capital requirements in the years ahead. This makes it unrealistic to expect them to finance, from their own resources, the substantial sums required for a national program of electrification. It is more typical for railroads to consider electrification of route segments of 800 to 2400 km (500 to 1,500 miles) rather than shorter segments. This is because the longer segments will tend to yield a higher return on investment (ROI).

Using an average cost of $125,000/km, an 800 to 2,400 km system would cost $100 million to $300 million plus the cost of electric locomotives, structural modifications of right-of-way, and additional power facilities. There are railroads that are in a position to finance such sums, but the decision will depend principally on the projected ROI. These railroads can consider four principal financing options. First, a railroad can consider the sale of mortgage bonds. In recent years, the amount of railroad mortgage bonds sold has been limited. However, there is a market of mortgage bonds of particular railroads. A second option involves new common stock equity, although there have been no railroad common stock offerings in recent years. It should be mentioned that electrification is a long-term capital investment with an attractive projected return that lends itself to permanent equity financing.

A third option is leasing which has the advantage of permitting the electrification to be financed by itself, unencumbered by existing railroad mortgages.

Fourth, there is the possibility of financing a railroad electrification system through project financing in which the system would be jointly owned or financed by the railroad, the utilities that provide the power, and institutional investors and would be leased to the railroad and possibly, in part, to the utilities as well. Railroad electrification lends itself to project financing because of the limited financial resources of certain railroads and their inability to fully use the tax advantages of ownership.

For each of the above means of financing, there are various factors to be considered, including the financial condition of the railroad, its projected internal cash flow, future capital requirements, the marketability of its debt and equity securities, its tax position, relevant IRS regulations, accounting considerations, and indenture restrictions. Circumstances vary, and each railroad must select the financing package that best meets its particular needs.

Financing a national program of electrification in the U.S. at a cost of at least several billion dollars is, as stated previously, simply beyond the means of the railroad industry. If it is to be done, it will require Government assistance. From the Federal Government's point of view, a program of federally guaranteed loans or leases would have the advantage of not requiring the direct advancement of funds. Moreover, it may prove not to be expensive. The Federal Government's experience with such guaranteed loan programs has been favorable (Ref. 45).

Railroad Investment Analysis from Public Sector Perspective (Ref. 53)

Enactment of the railroad Revitalization and Regulatory Reform Act of 1976 -- the 4R Act -- established a new and active role for the Federal Government in helping railroads, nationwide, to meet the costs of renewing facilities and replacing equipment -- and in the longer term, to restore the industry to economic self-sufficiency. As such, the Government's role clearly recognizes the economic necessity of a viable national railroad network and the urgent need to address the critical issues of deteriorating facilities and system rationalization.

Mechanisms for two Federal funding programs to assist railroads in meeting their rehabilitation needs are provided under Title V of the Act: one through the purchase of redeemable preference shares issues by railroads, or in the case of bankrupt railroad -- trustee certificates (Section 505); the other through the guarantee of obligations (Section 511). The aim of these programs is to enhance the provision of essential freight services over those facilities that are most important to the national rail system. Individual features of each program are discussed in greater length in the body of this statement.

Basically, Title V financing is project-oriented. The types of rehabilitation and improvement projects that are involved usually are increments of long-term programs. Section 505 authorizes Government purchase of up to $600 million of redeemable shareholder interest in private railroad companies.

The aggregate unpaid principal amounts of obligations which may be guaranteed under Section 511 may not exceed $1 billion at any one time. Railroads and other eligible persons, including public agencies, can be recipients of a guarantee. The Secretary determines the reasonableness of the interest rate but does not establish the rate.

Obligation guarantees (Section 511) are less attractive than preference share financing to the borrower who already has difficulty in meeting fixed charges from revenues and is not, therefore, able to increase its debt burden. Approval of Section 511 financing is primarily a function of the economic worth of the project and of the borrower's ability to repay, as well as the adequacy of the security which is pledged to the Government. If an electrification project is to be financed with a Federal loan under the 4R Act, the FRA is responsible for assessing the feasibility study submitted in support of the loan application.

Upper and lower limits on ROI must be established following procedures specified under the 4R Act and the net present worth as specified by OMB Circular A-94.

5.2 ELECTRIFICATION ECONOMICS (Refs. 54, 55)

The prime objective of an electrification economic study is to determine if electric operation of a particular railroad is more advantageous than operation with another form of power which may or may not be in actual use. The method of making electrification economic studies from the commercial viewpoint of a privately operated railroad is described (Ref. 54).

Under our present economic system, the amount of traffic over a line will generally determine if electrification is an economical alternative to diesel operation.

Total gross tons moved over a line can be used initially to determine if that route is a likely candidate for electrification. As a general "rule of thumb," if the terrain is flat, track straight, few obstructions, and a dense commercial power grid exists, electric operation may be more economical than diesel at a level of 15 to 20 million gross tons per year. If the terrain is mountainous, track curvy, many obstructions, and no commercial power grid exists, electric operation may not become economical until the 30- to 35-million ton mark is reached. The minimum tonnage required will be influenced also by the required rate of return. Under identical conditions, a low-speed drag operation tends to increase the tonnage required. Electrification financial options and benefits are many and varied. Four of these options were discussed in Section 5.1.

Twenty-four major areas that must be investigated in making an economic study of railway electrification are discussed (Ref. 55).

In summary, it can be stated that as the diesel becomes more and more expensive to operate, the economics of electrification may force a power change on some high-density mainlines.

Electrification System Component Costs (Refs. 1, 2, 56, 57)

Cost estimates were given previously in Section 5.1 for a typical electrification system, including catenary, substations, and communications and signalling. Table 4 summarizes all component costs used in recent electrification studies, including locomotives in 1977 dollars (Ref. 1, Appendix C).

TABLE 4. ELECTRIFICATION COST FACTORS

Category	Cost Single track (thousand $/route-mile) Low	High	Arithmetic Average	
Capital Costs:				
Catenary	64.0	143.0	103.5	
Substations and breaker stations	20.3	47.7	34.0	
Signal and communications modifications	40.0	65.0	52.5	
Civil reconstruction	5.0	50.0	27.5	
TOTAL	129.3	305.7	217.5	
	Double track (thousand $/route-mile)			
Capital Costs:				
Catenary	106.0	275.0	190.5	
Substations and breaker stations	39.2	84.8	62.0	
Signal and communications modifications	60.0	95.0	77.5	
Civil reconstruction	7.5	75.0	41.25	
TOTAL	212.7	529.8	371.25	
Utility Connect Costs:	$10,000/route-mile			
	Per gallon (cents)	Per kWh (cents)	Per mile (cents)	Per route-mile (thousand $)
Operating Costs:				
Diesel energy	42.0			
Electric energy		2.7		
Diesel locomotive maintenance			68.0	
Electric locomotive maintenance			29.0	
Catenary maintenance				2
	hp	Cost (thousand $)	$/hp	Lifetime (years)
Locomotive Costs:				
Diesel electric	2,550	500	196	20
Electric	5,000	1,000	200	30

6. STANDARDS ACTIVITY

Electrical Manual of Standards and Recommended Practices of the Association of American Railroads contains pertinent information up to 1959. Recent activity in standards and practices is as follows:

1) Catenary

   a) AREA Manual for Railway Engineering.

      Chapter 33, part 2: Proposed specifications for overhead electrification clearances (adopted 1978).

   b) NESC (ANSI Standard C2) Standard C2.2-1976 Section 23 on clearances. Changes to Section 23 are expected in the 1980 edition of the NESC.

   c) AREA Manual for Railway Engineering.

      Changes 33, part 3: Recommended voltage for new construction of electrified railroads (adopted 1978).

   d) AREA Manual for Railway Engineering.

      Chapter 33, part 7.1: Recommended methods for contact rail bonding (adopted 1978).

2) Power Supply and Distribution

   a) "IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters," Static Power Converter Committee of the Industry Applications Society of IEEE (January 1979).

   b) AREA Manual for Railway Engineering.

      Chapter 33, part 6.2: Recommended practices for crossing of electric supply lines and facilities of the railroad (adopted 1978).

3) Signal and Communication Interface

   a) IEEE Standards project P-679: Safe headway distances (IEEE Land Transportation Committee).

7. DOMESTIC SUPPLY INDUSTRY

Table 5 provides a summary of the major equipment suppliers for six current electrification projects in the U.S. The equipments are listed by major categories as shown.

For the Northeast Corridor Improvement Project the electrification conversion of the Conrail New Haven Line (to New Haven CT) the current electrification is at 11 kV, 25 Hz. Since the increase in catenary voltage (from 11 kV to 12.5 kV) is less than 14 percent, no change of the current catenary insulation is required. The 3-wire autotransformer method of feed will be retained for the re-electrified line.

The Muskingum Electric Railroad uses automatic speed code for regulating train speed along the route -- wayside radio transmitters send the command speeds to the coal-hauling trains. Up until two years ago, these trains operated without benefit of an onboard trip rider.

The Black Mesa & Lake Powell (BM&LP) Railroad has a current coal-hauling capacity of 60,000 tons/day (refer also to Section 2.5 for additional data on BM&LP), if each of the two 83-car trains makes 3 daily round trips. The high line voltage (50 kV) was selected to reduce line voltage drop (lower currents) so that one substation providing power at the Lake Powell Generating Station could handle the entire 78-mile system.

The Railroad Test Track (RTT) of the Transportation Test Center (TTC) is a test bed for evaluating performance of various electric locomotives and self-powered electric cars, provided they derive their power from overhead catenaries. (Third rail-powered vehicles will use the Urban Test Track at TTC.)

The Texas Utilities Company uses short trains of 15 to 19 cars, pulled by one locomotive. The coal-hauling runs are done under manual control. For the return runs, the empty trains are pushed (backwards) since there is no turn-around loop at the generating station. When the caboose leads the train, radio remote control from the caboose is used.

The re-electrification of the Erie-Lackawanna Railroad will change over the current 3,000 Vdc overhead electrification to 25 kV, 60 Hz ac. The 3-wire autotransformer method of feed will be used for the re-electrified line. The Gladstone Branch will be re-electrified first for low traffic density usage. A short section of run-in track (a third track along the mainline) will be used to evaluate the new hardware before it is generally deployed.

TABLE 5. SUMMARY OF EQUIPMENT SUPPLIERS FOR CURRENT U.S. ELECTRIFICATION PROJECTS

Project Equipment	Northeast Corridor Improvement Project NYC to New Haven Only	Muskingum Electric RR (MERR)	Black Mesa & Lake Powell RR (BM&LP)
Catenary	-----------	Ohio Brass Co. (Mansfield OH)	Salt River Project IECO G.E.
Substation Transformers	N/A	G.E.	N/A
Substation Relays and Protection	N/A	G.E.	N/A
Electric Locomotives	G.E. E60 CP Cosmopolitan Car (MU)	G.E. E60 C	G.E. E60 C
AC Signal System and Grade Crossings	N/A	N/A	N/A
Characteristics:			
Route km	120	24	27
Track km			
AC Voltage kV	12.5	25	50
Frequency Hz	60	60	60
Remarks	For Conn DOT/MTA UMTA-Funded 3-Wire Autotransformer Feed System	Coal-Haul RR	Coal-Haul RR

NOTE: N/A = Not Applicable

TABLE 5. SUMMARY OF EQUIPMENT SUPPLIERS FOR CURRENT U.S. ELECTRIFICATION PROJECTS (Continued)

Project Equipment	Railroad Test Track Transporation Test Ctr (RTT/TTC)	Texas Utilities Company	Erie-Lackawanna RR
Catenary	Fittings - Ohio Brass	N/A	Bids requested by G&H
Substation Transformers	Primary XFMR - ASEA Rectifier" - H.K. Porter	G.E.	Ferrante Packard* (Montreal)
Substation Relays and Protection	Main Breaker - West Rectifier" - Allis-Chalmers D.C. " - ITE	N/A	Bids requested for Long-Lead Items by G&H
Electric Locomotives	Various Tests	G.E. E25 B	M.U. Cars Planned: Jersey Arrow-3 by G.E.
AC Signal System and Grade Crossings		N/A	Trans Control**
Characteristics:			
Route km	23	45	113
Track km			282
AC Voltage kV	50/25/12.5	25	25
Frequency Hz	60	60	60
Remarks	Used for Evaluation 500 VDC to 1500 VDC, also	Coal-Haul RR 3 Sections: Martin Lake Sta. -96km Monticello Sta. -17.7km Monticello Sta. to Leesburg -17.7km	3-Wire Autotransformer Feed *For Gladstone Line Only, Bids Requested for Rest. **For Run-In Track Only Bids Requested for East of Run-In Track West of Run-In Track

NOTE: N/A = Not Applicable.

8. ARCHITECTURAL AND ENGINEERING (A&E) EXPERIENCE IN UNITED STATES

Table 6 provides a summary of the firms that have performed feasibility studies, detailed design, or construction supervision for various railroad electrification projects or studies.

- o Feasibility studies can include route selection, preliminary cost studies and preliminary selections for wayside and rolling stock equipment.
- o Detailed design studies can include engineering design, generation of engineering drawings and specification, and the procurement of hardware.
- o Construction supervision can include project management, cost and manpower scheduling, on-site inspections, direction of subcontractors, and approval of completed work.

TABLE 6. SUMMARY OF ARCHITECTURAL AND ENGINEERING (A&E) EFFORTS FOR CURRENT U.S. ELECTRIFICATION PROJECTS AND STUDIES

Project or Study	Type of A&E Services Supplied		
	Feasibility Studies	Detailed Design	Construction Supervisor
1. Northeast Corridor Improvement Project--NYC to New Haven Only (NECIP)	Northeast Utilities Electrack, Commonwealth Association, Inc. DeLeuw, Cather/Parsons (DCP) L.T. Klauder & Assoc.	Day & Zimmerman Electrack	Electrack
2. Muskingum Electric Railroad (MERR)	American Electric Power Service Corp. Ohio Power Co. Ohio Brass Co.	Amer. Elect. Power Service Corp.	
3. Black Mesa & Lake Powell Railroad (BM&LP)	IECO, Salt River Project G.E. Co.	IECO	IECO
4. Railroad Test Track, Transportation Test Center (RTT/TTC)	IECO	IECO	IECO
5. Texas Utilities Co.	Gibbs & Hill, Inc.	Gibbs & Hill, Inc.	Texas Utilities Co.
6. Erie-Lackawanna Railroad	Gibbs & Hill, Inc.	Gibbs & Hill, Inc.	
7. Conrail (Harrisburg PA to Pittsburgh PA)	Gibbs & Hill, Inc., A.D. Little		
8. Burlington Northern Railroad	IECO, G.E. Co., Electrack L.T. Klauder & Assoc., A.D. Little	Electrack (Test Section Only)	
9. Union Pacific Railroad Co.	A.D. Little Co., G.E. Co. Union Pacific RR Co. Pacific Power and Light Co. Utah Power and Light Co.		
10. Southern Pacific	L.T. Klauder & Assoc. Electrack		

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