RAILROAD ELECTRIFICATION ACTIVITY

A SUMMARY REPORT: 1980-1981

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16. Abstract

This report reviews the status of railway electrification in North America and selected countries worldwide, for the period June, 1980 through June, 1981. Included in the report are updates on the extent of construction of electrification; research completed on feasibility studies and technical developments in engineering and design; a summary of cost-effectiveness studies which have explored the economics of railroad electrification during the period in question; a review of activities of U.S. engineering and architectural firms with experience in railway electrification; and, a synopsis of research on railway electrification which has been published during the period under review.

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Preface

This report has been prepared by Ebon Research Systems, Rockville, Maryland, for the Office of Passenger Systems, Federal Railroad Administration, U.S. Department of Transportation. The purpose of the document is to provide DOT planners, railroads, railroad suppliers, universities, consultants, and other interested groups with a single source reference concerning what has happened worldwide with regard to railroad electrification during the period June 1980-June 1981.

The author wishes to commend the able asistance and technical support furnished by the contract monitors, Mr. Richard A. Novotny, Chief, Passenger Systems and Facilities Division (retired); and Mr. Matt Guarino, Program Manager for Electrical Systems. The report would not have been as complete without the cooperation of many in FRA, most notably Mr. Gordon Mott, Mr. Curtis H. Spenny, and Mr. Richard Cogswell.

The help of the hundreds of industry and technical contacts who supplied documents and information is acknowledged by citations in the text, and listing in the project's Directory.

Finally, the professional staff support from Ebon Research Systems' Project Manager Guy Hudgins and Ed Ward (Consultant) enabled a successful product to emerge from early drafts. The groundwork of the study was carefully laid by a student research assistant at Syracuse University, Ron Shuman, whose enthusiasm for the topic and contribution to the research effort is hereby acknowledged.

The reports mentioned in this report are limited to those publicly available, or accessible by request from the source listed. Each synopsis of corporate activity has been reviewed with the appropriate agency for accuracy and completeness. A listing of contracts is supplied in a Directory.

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

This report reviews the status of railway electrification in North America and selected countries worldwide, with particular focus on the period 1980-1981. The report is a successor to earlier reviews of such activity:

> Task Force on Railroad Electrification, "A Review of Factors Influencing Railroad Electrification." Federal Railroad Administration, U.S.D.O.T., February 1974.
>
> Raposa, F.L., "Impact of Research and Development on Railroad Electrification," in Railroad Electrification: The Issues, Special Report 180, TRB, 1977.
>
> Clarke, John M., "Railroad Electrification Activity in North America -- A Status Report: 1976-1978," Federal Railroad Administration, U.S.D.O.T., November 1980, FRA/ORD-80/81.
>
> Koebel, Romin, "Foreign and Domestic Railroad Electrification Activity," Draft Report. Federal Railroad Administration, USDOT, January 1981.

Principal U.S. developments in the period included:

- Development of the Electromagnetic Compatibility Test Facility at the Transportation Test Center, Pueblo, Colorado.

- Initiation of construction on the Deseret/Bonanza Western Railroad, a 33-mile electric railroad in Colorado and Utah.

- Award of construction contracts for electrical conversion of the Erie-Lackawanna from 3kV, DC to 25 kV, 60 Hz AC system.

- Retirement of electric freight locomotives by Conrail.

- Award of a design contract for study of electrification of the Fort Worth-Houston line of the Missouri-Kansas-Texas.

- Completion of construction of an additional 6 miles of electrification on the N.J. DOT project (South Amboy to Mattawan).

- Realignment of catenary readjustment work to existing electrified portions of the Northeast Corridor.

- Progress in assessment of the economic costs and benefits of U.S. railroad electrification, a study in progress at the U.S. DOT Transportation Systems Center.

- Federal Railroad Administration review of various studies completed by contractors, such as the study of electrical traction power supply configurations on 10,000 miles of U.S. railroads.

Foreign activities in rail electrification included:

• Feasibility studies of rail electrification extensions in Australia, Canada, Colombia, India, Sri Lanka, Yugoslavia, Zaire, Zambia, and Zimbabwe, among others.

• Construction of new rail lines has been completed in Australia, China, Finland, France, Federal Republic of Germany, India, Japan, Korea, Republic of South Africa, Taiwan, the United Kingdom, and Yugoslavia.

Research and development has focussed on assessing the economic costs and benefits of rail electrification (found to have a rate of return on investment of between 7% and 37.8%, depending upon assumptions), on finding lower cost technologies such as all-aluminum catenaries, or on assessing the physical prototypes of new locomotive designs with new solid state circuitry for improved energy utilization.

II. INTRODUCTION

The objective of this study is to provide Department of Transportation (DOT) planners, railroads, railroad suppliers, universities, consultants, and other interested groups with a single source reference about what has happened throughout the world to railroad electrification during the period June 1980-June 1981.

The scope of the report involves documentation of a variety of railroad electrification activities. Research activities undertaken in preparing this report included literature searches, review of periodic publications and reports, telephone calls to and correspondence with mid- and top-level management and engineering personnel in over 100 organizations concerning the planning, design, construction, and costs of railroad electrification.

This report is divided into several sections:

(1) Review of construction and completed railway electrification activities in the United States.

(2) Review of construction activities in railway electrification in selected foreign countries.

(3) Summary of planning and feasibility studies on railway electrification completed or in progress, 1980-1981.

(4) Synopsis of engineering studies completed, 1980-1981, with particular reference to new technological developments or findings.

(5) Economic analyses of railroad traction power alternatives: electrification versus diesel fuel alternatives.

As the impact of recent policy decisions creates a need for private sector management of decisionmaking regarding future rail electrification investment, this report may serve as a tool of reference for those managers who wish to review contemporary studies on the technical feasibility and economic cost of railroad electrification in the 1980's. The contribution of the public sector, through the possibility of loan guarantees or sponsored research at the Transportation Test Center (TTC) and the Transportation Systems Center (TSC) of the U.S. Department of Transportation, is noted as evidence of continuing public policy interest in the issues of railway electrification.

III. REVIEW OF CONSTRUCTION AND COMPLETED RAILWAY ELECTRIFICATION ACTIVITIES IN THE UNITED STATES, 1980-1981

Transportation Test Center (TTC), Pueblo, Colorado

In 1980 initial construction work was completed on the 13.5-mile (21.6 km) oval test track which will provide a flexible facility for research, development, and evaluation of electrification structures and equipment, including catenary, wayside equipment, rolling stock, permanent signal and communication facilities, and alternative power supplies. (1,2,3)

The electrification has a testing capability of 12.5 kV, 25 kV, or 50 kV at 60 Hz. The facility offers both single and double track at 56.5 inches (143.5 cm) gage. A 1-mile (1.6 km) test section is capable of changing catenary styles for testing purposes. Other design variations include poles, foundations, and other structures.

The facility has one substation and a 115-kV, 3-phase transmission line. The traction substation provides 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.

The Electromagnetic Compatibility Test Facility at TTC is almost 3 miles in length, extending 14,977 feet from the 50/25/12.5 kV traction substation. The track is divided by insulated rail joints which provide for six track circuits ranging from 210' to 5,330' in length. A signal housing is found at each insulated joint location, and a number of different kinds of track leads will be available so that different kinds of track circuits may be tested.

The Catenary Test Section of the TTC is equipped with three designs of compound (three conductor) catenary:

Style 1, compound catenary, (heavy)	336.MVM grooved contact wire; 4/0 grooved auxiliary wire, 5/8" copper weld messenger wire; and 2-0 ASCR return wire. This configuration is based on the existing catenary between Washington, D.C., and New York.
Style 3, compound catenary, (hanging beam)	4/0 grooved contact wire; 4/0 grooved auxiliary wire; 5/8" and 7/8" steel messenger wires; and 2/0 ACSR return wire. This conforms to the "hanging beam" catenary design between New York and New Haven.
Style 5,5X compound catenary,	4/0 grooved contact wire; 7/0.0833 auxiliary wire; 19/0.0833 messenger wire; and 2/0 ACSR return wire. This pattern was based on the lightweight catenary that had been proposed for the New Haven to Boston electrification.

After all testing of the installed catenary was complete, the catenary was placed at a height of 22'6". Maximum speed reached during the checkout procedures was 125 mi/h (200 km/h). The new design (Style 5) showed considerably less loss of contact at 129 mi/h as compared to Styles 1 and 3. (4) Additionally, the dynamic performance of both phase breaks was considered acceptable. The close tolerances required for catenary construction were attained, an evidence of the need for a qualified construction crew particularly experienced in catenary construction.

Deseret/Bonanza Western Railroad

In August 1981, Western Fuels-Utah Inc., started construction of a large underground coal mine near Rangely, Colorado, to supply two 400 MW units of the Bonanza Power Plant being built by the Deseret Generation and Transportation Cooperative at Bonanza, Utah. Construction of a 33-mile (53 km) single track, electrified railroad to deliver the coal is scheduled to begin in mid-1982. The first powerplant unit will require delivery of 1,350,000 tons annually beginning in 1984. The second unit is projected to be on line in 1988, and 2,700,000 tons will then be required.

The electrification specifications call for a 50-kV, 60-Hz voltage, simple catenary and one end-feed substation. Four 6,000 hp electric locomotives will pull a train of 62 100-ton-capacity rapid discharge-type coal hopper cars when both powerplants are on line. The project is designed to withstand severe temperature extremes and rugged terrain, including 2% grades in places. The construction engineering is under the direction of Stone and Webster Engineering Corporation for Western Fuels-Utah, Inc. (5)

Northeast Corridor Improvement Project (NECIP)

In February 1981, the new Administration decided not to initiate construction of a previously planned section of railroad electrification which would have extended the electrification of the Northeast Corridor (NEC) rail system from New Haven to Boston. The earlier period had seen near completion of all blueprints and design work for track alignments, structural work, and catenary systems.

However, some work continues on the previously electrified portions of NECIP to improve track alignments, and thus permit trains of higher speed in the Washington-New Haven portion. DeLeuw, Cather and Electrack shared work on design during 1980.

Because of the new policy, the proposed conversion from 11-kV, 25-Hz to 25-kV, 60-Hz has halted. A section of track currently within the electrified portion from Grand Central to New Haven will be upgraded to 12.5-kV, under the joint efforts of the Connecticut DOT and the New York MTA. This project will soon be completed.

Erie-Lackawanna Railroad -- Part of Conrail

A project is currently underway to convert an existing electrified line (previously 3-kV, DC) to a 25-kV, AC system with 60-Hz characteristics. The improvement project comprises 66 route miles of 1, 2, 3 and 4 track territory, located in northern New Jersey. The route is divided into five sections separated by phase breaks. The project includes:

- Conversion from 3-kV to 25-kV, and from direct current to alternating current.

- Rehabilitation of the overhead catenary.

- Construction of 14 electrical supply substations, 11 auto transformer stations, 1 tie station, and 7 signal stations.

- Signal and communicating systems alterations.

- New signal control tower and new supervisory control room at Hoboken.

Once completed, it is estimated that the system will consume 119.2 million KWH of electrical energy per year. (6)

A total of 180 new, multiple unit railroad cars have been purchased for passenger service. The cars are able to exceed 100 mph and can run on voltage of 11-kV, 25-Hz (the present voltage on the NEC) or on 12.5/25-dV, 60-Hz (as previously proposed for the NEC). (7)

By late 1981, all the major electrical and signalling contracts had been awarded and construction was underway. The 66-mile (106 km) system is expected to be completed by 1983.

Muskingum Electric Railroad, Beverly, Ohio

Built in the mid-1960's, the Muskingum Electric Railroad was the first railroad in the U.S. to use a 25-kV, 60-Hz power supply. The electric railroad hauls coal along a 15-mile (24-km) line from mine to preparation plant. From there, a 4.5-mile overland conveyor system transports the coal to a generating station. The system exhibits significant cost savings, as compared to highway truck coal haul cost. (8).

It has been reported that the cost of the electric railroad including track maintenance, was less than one-third the cost of the truck haul, including haul road maintenance costs.

Factors influencing these cost savings included: relative costs of diesel fuel and electric power (the latter at 2.92¢ per kW hour as of 1979); increased replacement cost of coal haul trucks as compared to diesel electric locomotives; and inflationary costs for drivers.

No significant design problems or maintenance difficulties have been experienced with this highly automated system. Motive power for the electric railroad is provided by two GE EU-50 locomotives rated at 5,000 hp at the rail with a continuous tractive effort of 82,300 lbs. These locomotives were the first U.S. application of thyristor controls for locomotive power supplies.

Conrail

In April 1981, Conrail stored its remaining fleet of electric freight locomotives. Factors entering into this decision were: (1) the cost of supporting two separate types of maintenance facilities (for both diesel and electric locomotives); and (2) debate concerning allocations of electrical distribution and catenary maintenance costs on the Amtrak-owned Northeast Corridor.

The relatively older fleet of electric locomotives were expensive to maintain, and when traffic volumes declined to the point where Conrail had a surplus of locomotive power, the above factors made it more cost-effective to store the electrics rather than the diesels.

The Railroad Revitalization and Regulatory Reform Act of 1976 (4R Act) allows up to $200 million in loan guarantees which could be used by Conrail to electrify portions of its system. In April 1980, Conrail forwarded to the DOT a copy of the completed Gibbs and Hill (G&H) Electrification Study between Pittsburgh and Harrisburg and Newark and Harrisburg. The G&H study showed that electrification "would provide economic advantages to Conrail," yielding a return on investment (ROI) of 18.1% over 29 years. (14) Electrification of Harrisburg-West was estimated by G&H to yield an ROI of 17.7% over a 29-year period; on Harrisburg-East, the ROI was estimated at 23% over a 29-year period.

No action has been taken by Conrail since a policy decision was made by the current Administration to leave the financing of railroad electrification to the private sector. Conrail does not have sufficient internal funds to underwrite the project.

Chicago, South Shore and South Bend

In February 1981, the South Shore Railroad abandoned the use of electric locomotives as a source of traction in its freight operation.

Texas Utilities' Electrification

Texas Utilities Generating Company operates two electrified railroads at the Martins Lake and Monticello powerplants. Both operate with 25-kV, 60-Hz power supplies, single phase, with one 5 Mw(e) substation. The traffic density operates 8 million to 9 million net tons per year. One system is 20 route-miles of electrified trackage; the other one 14 miles in length. Together, these lines bring 17 million to 18 million tons of coal to two lignite-fired powerplants in northeast Texas. It is estimated that these two railroads are responsible for a savings of from 0.8 million to 1.0 million gallons of diesel fuel per year. The railroad has not experienced any notable maintenance problems with either the catenary or the locomotives, with the exception of some steel shoe overheating on the latter, noticed during hot weather. Insulating joints on the signaling catenary need periodic replacement. The most important operating problem has been the sinking of the roadbed in areas where soil cementation occurs during periods of dry weather. The black clay soils of the region are most susceptible to this problem.

Estimated capital amortization costs for catenary, locomotive, car and track are listed at 4 cents per net ton mile (based upon 20% per annum interest charges and an equipment life of 30 years). Operating costs including maintenance have been shown to be 2 cents per net ton mile.

Black Mesa and Lake Powell Railroad

Operating satisfactorily since its opening, this line has exhibited the feasibility of the 50-kV, 60-Hz system, which is fed from a single substation. This coal-hauling railroad brings raw material from the Black Mesa mines near Kayenta, Arizona, to the Navajo generating station, a distance of approximately 78 miles (125 km).

The system also has made use of three thyristor controlled locomotives. To be able to operate these units over the 78-mile (125 km) system fed from one end, it was necessary to use a return wire close to the catenary, specifically, directly above it. Constant tension is maintained by using one counterweight through a three-part line and two yoke plates in tandem. In addition, a series capacity is used to reduce the voltage drop. An ACSR messenger wire reduces cost and improves system performance. Solar energy is used to power signals and alarms for crossings at grade.

New Jersey Department of Transportation Project

Installations have been completed on the extension of electrification from South Amboy to Matawan, a distance of approximately 6 miles (10 km). Testing of the line will be accomplished by Spring 1982.

Additional work to extend the line from Matawan to Long Branch will be completed if the planning process warrants this action. The N.J. DOT and N.J. Transit are in the process of updating these plans. N.J. Transit is planning to submit a Grant Amendment Application to Urban Mass Transit Authority to obtain grant funding for the design, fabrication and installation of signal improvements from (1) Rahway to Perth Amboy (6.8 miles) and (2) Matawan to Long Branch (15.7 miles).

Electrification in Selected Passenger-oriented, Light Rail Applications

Since the focus of the current report is on applications of railroad electrification to freight traffic, only passing reference will be made to two current construction projects involving electrification of commuter lines.

- Buffalo Light Rail Rapid Transit System

  In 1980, Day and Zimmermann completed preliminary work on the development of an electrification system which will generate 650 V DC for traction power, to propel light rail vehicles along a 6.4-mile line (10 km) from downtown Buffalo to the State University at Buffalo campus at the city line. Five substations will be located along the line. Niagara Frontier Transportation Authority in 1981 asked for bids for a contract in construction management.

- San Diego Metropolitan Transit Development Board

  Bechtel headed a design team to provide an electrified, 16-mile corridor for commuter rail service in San Diego. The system was installed in one year, and went into service July 26, 1981. It is expected to carry 20,000 passengers per day. The signal system is integrated with the street traffic signals so that the presence of a train in the station will trigger the appropriate street traffic signals. The system used 650 V, 5.5 MWe for single-track operation. Plans are underway to build a double track system.

IV. STATUS OF ELECTRIFICATION PLANNING BY NORTH AMERICAN RAILROADS, UTILITIES, AND GOVERNMENT AGENCIES

Two earlier reports (12) reviewed the activities of a number of railroads and utilities which were individually studying the feasibility of rail electrification. These included the Southern Pacific, Union Pacific, Burlington Northern, Canadian Pacific, Santa Fe, Illinois Central Gulf, Southern, and Conrail. This report updates earlier studies, focusing on developments in the period 1980-1981.

Missouri, Kansas & Texas Railroad (MKT)

Late in 1981 the Missouri, Kansas and Texas Railroad (MKT) hired Electrack to do a preliminary engineering study of electrification of 323.4 miles of mainline track from Fort Worth to Houston. Currently under consideration is the construction of a 25-kV, 60-Hz single-phase system. The railroad is contemplating the purchase of 23 locomotives rated from 4200 to 4500 hp. Power for the system will be supplied by 11 substations: one from Texas Electric, four from Texas Power and Light, four or five from the Lower Colorado River Authority and one or two from Houston Power and Light.

The next step in the process, assuming appropriate financing is arranged, will be the awarding of contracts for detailed engineering. Contracts for project management and construction are not expected in 1982.

Louisville and Nashville Railroad (L&N)

In 1980, the International Engineering Company, Inc., (IECO), was awarded a contract by the Louisville and Nashville Railroad (L&N) to study and estimate the costs of electrifying an existing 500-mile mainline between Cincinnati and Atlanta. The engineering questions involved preliminary estimates of costs of electrification of 610 miles (970 km) of track length, which carries 31 million gross tons per year. The voltage will be either 25-kV or 50-kV; 60-Hz. Catenary desgin will be simple. Twenty-six substations are under consideration for the 25-kV system; 11 for the 50-kV system.

The reports are under study by the L&N and the Tennessee Valley Authority (TVA).

Richmond, Fredericksburg & Potomac Railroad Company (RF&P)

In 1981, Kaiser Engineers was under contract to the Richmond, Fredericksburg & Potomac (RFP) to provide the preliminary design to relocate 5 miles of track in Crystal Park, Arlington, Virginia. It has been recommended that the constant tension overhead contact system replace the previous fixed tension system, because of the costsaving involved in lighter structures. The new system will eliminate current shortages (caused by variable sagging under varying ambient temperatures) and will minimize the amount of maintenance required.

Southern Railway (SR)

After completing various internal studies of railway electrification (in cooperation with the TVA and the L&N, Southern Railway (SR) has concluded that the uncertainty of future fuel prices (and consequently the relative price of electric power and diesel fuel) restrains any current decision to electrify unilaterally. However, the president of SR, Harold Hall, offered to "go halves."

> "Let DOT install the catenary and we'll buy the necessary electric locomotives." (Harold Hall, the DOT Railroad Electromagnetic Compatibility Symposium, Pueblo, Colorado, May 14, 1980.)

Factors cited as influencing the uncertainty of relative fuel prices include: (1) uncertainty about the availability of substitute fuels; (2) possibility of politically influenced decisions about construction of nuclear-powered generators; (3) tendency for electricity charges to customers to escalate apace with increases in fossil fuel prices; and (4) uncertain demands for fuel from other sectors of the economy.

The SR has variously estimated the rate of return for electrification to vary from 15% upward, but "because of the large capital outlay ... and the uncertainty surrounding ... fuel prices," it has not made a firm commitment to electrification. (3)

UTILITIES

Western Fuels, a consortium of publicly owned utility companies, is building a coal haul railroad between Colorado and Utah.

The Edison Electric Institute, responding to an inquiry noted that as of November 1981, "no other public utilities are currently considering new rail electrification application."

The Electric Power Research Insititute in 1981 issued a request for proposals to investigate the impacts of railroad electrification loads on supplying utilities. This study will not be completed until 1982.

FEDERAL AGENCIES

Transportation Systems Center

Development of a model to estimate the costs and benefits of total system linkup of electrification is proceeding under an industry-Government working group. Individual railroads (CSX, SR, L&N, Burlington Northern, Union Pacific, Atchison/Topeka & Santa Fe, Illinois Central Gulf, Southern Pacific, and Chicago and North Western) have been invited to submit data concerning freight volumes along specified segments of their systems, to permit simulation of the effect of electrification on fuel costs, maintenance costs, and other factors influencing the alternative traction power analysis.

This work is in progress; no results are available yet. (16)

Other studies by the Transportation Systems Center are discussed below.

Federal Railroad Administration (FRA)

In the period 1980-1981 the Federal Railroad Administration (FRA) has supervised several research contracts designed to weigh the advantages and disadvantages of aspects of electrifying three rail networks of varying size, as follows:

(1) 10,000-mile network, including only lines with traffic levels in excess of 40 MGTM/year.

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

(3) 40,000-mile network, including all lines carrying more than 20 MGTM/year.

This work was completed and included such documents as:

- "Electrical Traction Power Supply Configurations on 10,000 Miles of U.S. Railroads," prepared by Electrack for TSC, April 1981.
- "Project Memorandum: An Update of the Costs and benefits of Railroad Electrification," by C.H. Spenny, TSC, April 1980.
- "Parametric Analysis of Railroad Electrification Economics, Final Report," Booz, Allen & Hamilton, for the DOT/FRA, November 1980.

Department of Energy (DOE)

Working under a contract with the Department of Energy (DOE), the SRI International in January 1980, issued a report entitled, "Railroad Electrification in America's Future: An Assessment of Prospects and Impacts." The SRI model of industry operations and finances produced income statements and balance sheets at yearly intervals calculating alternative railroad energy costs, railroad freight levels, maintenance costs, purchases and leases of rolling stock, electrification facility investments, future inflation, rate setting practices and financial data. The report concludes: "If all the links in the scenario were electrified, the U.S. could reduce oil consumption by about 1% of the mid-1978 import rate."

Investment to achieve this objective would be about one-third to one-half of that required for new rolling stock. Few, if any, railroads are likely to embark on electrification under the present regulatory climate of rate-setting.

Other work on railroad electrification subsequently conducted by the DOE is included in Report 117, 1980.

V. SELECTED DEVELOPMENTS IN WORLDWIDE RAIL ELECTRIFICATION, 1980-1981

Space does not permit enumeration of all developments in worldwide rail electrification. A review of international journals yields the following information on selected countries.

Australia

SofreRail has completed a feasibility study of electrification of the 600-mile mainline between Sydney and Melbourne. The Government has taken no action with respect to the study.

In June 1980, construction began on the overhead wiring for the Gosford-Newcastle electrification. It was reported that electric trains will be running between Syndey and Newcastle by late 1982.

The New South Wales State Railway Authority plans to extend its 1.5-kV DC electrification from Waterfall (near Sydney) to Port Kembla, a distance of 50 miles (80 km). Transmark has received the contract for design and construction management.

A feasibility study is underway for the Yandicoogina Railroad. CSR, Ltd., an Australian mining company, is proposing to build a new, 200-mile (320 km) iron ore railroad from Yandicoogina to Port Hedland in northwestern Australia. CSR plans to evaluate electric traction as an alternative.

The International Engineering Company (IECO) has participated in a feasibility study of electrification of an existing 241-mile (386 km), diesel-operated line hauling iron ore from the Pilbara area of northwstern Australia to two port locations near Dampier. No firm commitment to construct the line was made by Hamersley Iron Railway by July 1981. The electrification proposed was 50-kV, 50-Hz, single track.

Brazil

Carajas Railroad electrification is under study. A new, 550-mile railroad is being constructed in northeast Brazil as part of the Carajas iron ore mine development. Basic design of an electrification system for the railroad has been prepared, although as of July 1981, no firm decision had been made to electrify.

Sao Paulo State Railway (Fepasa) is re-equipping substations and installing nine new ones. It has ordered 23 meter-gauge electric locomotives. Plans are underway to electrify 352 miles (563 km) between Uberaba and Mayrink, west of Sao Paulo. This project would encompass 438 route-miles (700 route-km), 17 substations, and 37 additional locomotives.

In 1982 work will start on 185 route-miles (296 route-km) of electrification from Jeceaba to Saudade, including conversion of portions from 3-kV to 25-kV.

Canada

Transport Canada reports that several planning studies are completed or in progress with respect to railway electrification. The Canadian Institute of Guided Ground Transportation reported in 1980 that after reassessing the

TABLE 1

Railroad Electrification in Selected Countries

Country	Total Railroad Route-Miles	Route-Miles Electrified	Percent Electrified
North & South America			
Canada	46,300	10	0
Chile	4,900	590	12
Costa Rice	470	80	17
United States	234,500	1,170	1
Asia			
China	32,000	650	2
Indonesia	4,300	50	1
Japan	15,000	6,560	44
N. Korea	2,000	310	15
S. Korea	2,000	270	14
Taiwan	621	310	50
Australasia			
Australia	25,700	580	2
New Zealand	3,000	60	2
Europe			
France	22,900	5,800	25
Italy	12,600	5,850	46
Spain	10,800	4,080	38
Sweden	7,400	4,640	62
Switzerland	3,200	3,190	99
United Kindgom	13,900	2,390	17
USSR	86,900	26,720	31
W. Germany	20,500	6,890	34

Source: Willard D. Weiss, "Railroad Electrification in the Pacific Area," Paper presented at the American Society of Civil Engineers, MG-C Conference, "Broadening Horizons -- Transportation and Development Around the Pacific," July 21-23, 1980, Honolulu, Hawaii.

conclusions of the 1976 study, the decision to electrify a national system was still sound. A 50-kV system is suggested, although portions may have to be 25-kV because of clearances. Standardization of equipment nationwide is necessary. Finally, a substantial number of studies should be undertaken.

Canadian Pacific Consulting Services, Ltd., in March 1981, completed the Quebec Cartier Mining Co. Engineering Definition Study for an Electrification Demonstration (Field Survey Report). Subsequent feasibility studies are being performed to assess the applicability of electrification of an iron ore hauling operation between Fire Lake and Lac Jeannine.

The Transportation Development Centre (Transport Canada) is evaluating the technical implications and costs of a number of alternative electrical distribution schemes for railway electrification, pursuant to a 1976 study. An offshoot of the study is a program of concept definition of energy storage systems applicable to the railway electrification demonstration on the CRC.

No construction work in railway electrification is reported by Transport Canada.

China

By 1977, China had electrified two lines totaling more than 625 miles (1000 km), the Baoji-Chengdu railroad through the Qinling Mountains, and the Yangpingguan-Ankang line. (18) Four more lines are being electrified at 25-kV, 50 Hz: Shijiashuang-Taiyuan (146 miles or 235 km); Xiangfan-Daxian (401 miles or 646 km); Baoji-Lanzhou (317 miles or 510 km); and Chengdu-Chongqing (314 miles or 505 km). A fifth is planned for a length of 236 miles (379 km) from Beijing to Datong. Upon completion, these projects will give China a total of over 2,000 miles (3,300 km) of electrified rail systems.

China has adopted composite aluminum/steel conductors in an effort to cut the cost of construction. All products used in electrification are produced in China.

Colombia

As of 1981, the International Colombia Resources Corporation had extended a contract to IECO to conduct a feasibility study of electrification of an 100-mile (160 km) single track coal-haul railroad known as the Cerrejon Coal Project. Electrification was suggested at 50-kV, 60-Hz, with single catenary, and two end-feed substations.

Finland

As of 1981, Finland had 576 miles (922 km) of electrified railway in operation. By December 1980, Finland had completed 119 miles (191 km) from Kouvola to Piersamaki (part of a larger line) at 25-kV, 50-Hz.

France

Approximately one-third of the route miles of French railroads are electrified, and more construction work continues. The French National Railroad (SNCF) has begun construction of the 25-kV, 50-Hz electrification of the 76-mile (121 km) Amiens-Rouen line and the freight-only line to Motteville. Work on the 25-mile (40 km) suburban electrification from Pontoise to Gisors is nearing completion and studies underway will evaluate the electrification of the 67-mile (42 km) Persan- Beaumont-Beauvais line. Narbonne-Cerbere (Spanish frontier) connections by electrification should be completed by April 1982.

Catenary power at 25-kV, 50-Hz is supplied to the rail network from the utility network at 63-kV, 90-kV, and 22-kV. Substations are spaced between 41 and 67 km apart. The substations are interconnected through the catenary where additional power is required. Reactive compensation is employed at some substations to increase the power factor presented by the substation to the utility. The new, high-speed line uses auto-transformers spaced every 15 km to allow greater substation spacing and to reduce interference with communicating circuits.

Catenaries consist of simple, automatically tensioned stitched equipment with a bronze messenger and 107 mm^2 round copper wire. A common weight anchoring creates a tension in the messenger and trolley wire of 1000 kg. Improved catenary equipment is used for operation at 156 to 188 mi/h (250 to 300 km/h).

All new purchases of locomotives have been for application with electric traction. Application of thyristor converters in the BB 15000 AC type locomotive and chopper circuits in the BB 7200 DC type locomotives makes it possible to adjust the tractive effort for maximum adhesion. Eighty-seven TGV tilting train sets from Alsthom and Francorail-MTE for high-speed passenger service from Paris to Sudest are in service.

Germany, Federal Republic of

As of December 31, 1981, the electrified network of GermanRail totaled 6,950 miles (11,190 km), or approximately 40 percent of the total network of 17,671 miles (28,450 km).

In 1980, the following lines and sections were added to the electrified network.

Line	Miles	Km
Salzbergen-Emden-Norddeich	105	168
Siegen-Betzdorf-Troisdorf	50	80
Muhlheim(R)-Duisburg-Ruhrort Hafen	9	14
Bremen-Hude-Hordenham/Oldenburg	53	85
amplification S-Bahn Munich	4	6
Neuoffingen-Donauworth	28	44
Ludwigsburg-Marbach	7	11
Short supplements and joint sections in the Ruhr area	14	23
Total	270	431

West Germany uses 15-kV, 16.67-Hz power for its standard AC railroad electrification system. A high-voltage, 110 kV transportation system delivers power efficiently to the catenary. Supply reliability is enhanced by tying points together with two independent transmission lines. Supply points are generally spaced 60-80 km apart.

A simple automatically tensioned stitched catenary is used for speeds up to 160 km/h (100 mi/h); the Re 200 catenary is used for speeds of up to 125 mi/h (200 km/h).

The German Federal Railways (DB) is now testing the prototype of the E120 inverter, 3-phase, AC-motor locomotive. The E120 has an output of 5600 kW (7,500 hp) and a maximum speed of 100 mi/h (160 km/h).

Greece

In May 1981, Greece issued a call for tenders to reconstruct, electrify, and resignal 248 km of railroad linking Larissi and Idomeni -- bringing the line to the frontier with Yugoslavia. The system will operate at 25-kV, 50-Hz.

India

Assisted by a $400 million loan from the International Bank for Reconstruction and Development, Indian Railways will increase its rate of electrification from 150 to 500 route kilometers per year. Construction is progressing on a total of 889 route-miles (1,422 route-km). New construction will begin in 1982 on an additional 1,579 miles (2,526 km). Only 8.5% of Indian Railways' 60,693 km network is electrified.

Japan

By 1977, Japan had opened up 8,563 route-miles (13,700 route-km) of electrified railroads, completing about 1,625 new miles (2,600 km) within a decade. Additional construction proceeds at a pace of 200-300 miles (300-500 km) per year.

The Ministry of Transport has authorized the Japanese National Railroad (JNR) to build an additional 1,067 mm gauge line to connect with the bridge being built between Honshu and Shikoku Islands and to the Seikan tunnel that will link Honshu and Hokkaido by 1983.

Using AC electrification, the New Tokaido Line (NTL) is supplied at 25-kV, single-phase and the conventional JNR lines at 20 kV, single-phase at 50 Hz or 60 Hz. Static frequency converter stations are used to change 50 Hz to 60 Hz at some locations. Catenaries are end-fed from transformers; two transformers are usually located at each substation. Substations are spaced between 30-50 km apart. On all new electrification, autotransformers will be used, thus permitting increased substation spacing, reduced interference, and reduced cost.

New lines under construction include the Tohoku between Tokyo and Morioka (308 miles or 493 km) and the Joetsu between Omiya and Niigata (187 miles or 299 km). These are scheduled for completion in late 1981.

Technological innovations employed on the Japanese rail system include heavier compound catenary systems to permit train operations up to 160 mi/h (260 km/h) and locomotives capable of traveling in excess of these speeds.

The JNR is testing a new generation of railcars equipped with four 275-kW (368 hp) traction motors. These cars have an aluminum alloy body, thyristor control, and a prototype of JNR's minicomputer automatic train operating system. (23)

JNR has completed testing its ML-500 maglev vehicle that attains speeds up to 323 mi/h (517 km/hr) and is constructing a U-shaped guideway to test a new version of the maglev vehicle which boasts reduced air resistance. A more powerful I-shaped superconducting magnet is used to produce levitation, guidance, and propulsion, superceding the two separate magnets in ML-500. (24)

Korea, North

In 1980 Weiss reported that North Korea had electrified over 500 miles (800 km) of its mainline, a sizeable proportion of its total length. The 1978-1984 seven-year development plan calls for the electrification of 1,000 miles (1,600 km). (26)

Korea, South

A 25-kV AC system with a simple catenary covering 153 miles (246 km) has been in operation since 1975. Eleven traction substations are used. Korean National Railroad is in the process of electrifying an additional 316 miles (508 km), including the mainline between Seoul and Pusan. (26)

Mexico

In April 1981, orders had been placed for locomotives and fixed equipment to electrify 131 miles (210 km) of mainly double track route from Mexico City northwest to Queretaro (250 route miles). U.S. General Electric supplied 39 electric Co-Co locomotives, Model E60C. The line will be installed at 25-kV, 60-Hz catenary. The plan is to electrify 12,800 miles (8,000 km) of rail network eventually. (27)

South Africa, Republic of

As of December 1981, South African Railways reported 9,084 miles (14,534 km) of track electrified. The Brits-Shabazimbi and Pendoring-Atlanta sections in the Transvaal were completed during 1980 with 144 miles (230 km) at 25-kV AC. Firms involved in the electrification include: Elek Rail (Pty.), Industrial Electrical Co., Racec Electrification (Pty.), and Powerlines, Ltd.

Previously completed in 1978, the Sishen-Saldanha Railroad was the first major railroad of length to be electrified at 50-Kv AC, 50 Hz. Built to transport iron ore over a 536-mile (858 km) line from the minehead to the deepwater port, this single track system has six substations of 80 MVA, 1.55 miles (2.5-km) of constant tension catenary designed for a wind velocity of 75 mi/h (120 km/h). Interesting features include plastic insulators to reduce pollution effects, low-voltage traction capability, and different catenary configurations for mainline and yards. Each train utilizes three 3780-kW, 185-ton locomotives to haul 202 four-axle ore cars with a gross trailing weight of 22,300 tons.

The train travels about 30 mi/h. Two different overhead contact wire systems are employed on the line: an all-copper simple catenary (contact wire suspended by hangers from a messenger wire) on the coastal portions of the route, and a simple catenary with ACSR (aluminum conductor steel reinforced) messenger and copper contact wire for inland portions of the route. U.S. engineering firms are interested in this system because of the opportunity to observe performance of the catenary in environmental conditions similar to those experienced in the coastal areas of the Northeast Corridor.

Sri Lanka

As reported in 1980, the Ceylon Government Railway plans to electrify a 150-mile (240 km) network of suburban railroads. Design studies are under way.

Sweden

Approximately 95% of Swedish Railways service is conducted over the 4,375-mile (7,000 km) electrified network, consisting of special generators dedicated to rail electrification, frequency converters and 6-kV, 3-phase 50-Hz transmission lines, which interconnect all converter supply points, thus providing power to the 15-kV, 16-2/3 Hz system. Use is made of insulation overlaps separating adjacent catenary section, booster transformers and return conductors. Swedish Railways operates 187-type Rc thyristor-controlled electric locomotives rated at 4,825 hp (3,600 kW) for a maximum speed of 85 mi/h (135 km/h).

Switzerland

Of the 3,164 route miles (5,062 route km) of railroads in Switzerland, 99.4% are fully electrified. Swiss Federal Railways uses a single-phase, AC power system at a frequency of 16 2/3-Hz. Swiss Railways uses GE 4/4 III thyristor locomotives rated at 1,520-kW (2,060 hp) taking power from the 15-kV 16 2/3-Hz overhead system feeding four thyristor-controlled DC traction motors, permitting operation of the locomotive at 56 mi/h (90 km/h). (31)

Taiwan

A new 25-kV, 60-Hz electrification project is building 338 route-miles (540 route km) to be supplied from the utility's 69-kV network. Portions of the West Trunk mainline were completed in 1979. Catenary is designed to withstand severe weather conditions (high winds, temperature, and humidity) and possible earth tremors. Taiwan Railroad has purchased 84 GE Co-Co locomotives with a maximum rating of 2,850-kW for a top speed of 69 mi/h (110 km/h). Other locomotives have been purchased from Great Britain.

Thailand

State Railway of Thailand announced in 1981 that it plans to electrify 500 miles (800 km) main line from Bangkok to Chiang Mai in northern Thailand. Plans call for the purchase of 140 locomotives. (32)

U.S.S.R.

As of 1977, a total of 9,313 route-miles (14,900 route km) of electrified system draws its 25-kV, 50-Hz power from the utility's 110-kV network. The balance of the electrified track operates at 3-kV DC power. Three-phase transformers (two to end-feed the catenary and a third to supply local loads), substations spaced 45-50 km apart, capacitors for reactive compensation, and filters to reduce harmonics characterize the system.

Plans are underway to install an autotransformer system, similar to those currently in use in France and Japan. Designed for speeds up to 156 to 188 mi/h (250 to 300 km/h), the automatically tensioned equielastic double catenary features elastic droppers and midspan spaces so that vertical elasticity is more uniform over the entire span.

Locomotives on the system, built domestically, are rated for top speeds of 75 mi/h (120 km/h). Plans are in progress to use an 8,000-kW-rated Soviet locomotive designed for 125 mi/h (200 km/h) in the Moscow-Leningrad corridor. (33)

United Kingdom

In 1981, as a result of a joint study performed by BR and the Department of Transport, the Chairman of the British Railways Board announced a "commanding case" for considerable extension of railway electrification in Britain. The study estimated a real rate of return in excess of 11%. The study examined the economics of a 5,788-route-mile (9,260 route-km) system which contrasts in size with the current 2,325-route-mile (3,720 route-km) system in service. At present 48% of passenger train-km on BR is electric; freight electrification handles only 13% of train km.

The APT (Advanced Passenger Train) introduced on the London-Glasgow line is rated for a top speed of 150 mi/h (240 km/h). Like the French TGV, the APT features a tilting mechanism to improve passenger comfort through curves. The powered cars have four 1,000-hp thyristor-controlled, separately excited DC traction motors. To ensure good current collection from the 25-kV, 50-Hz OCS, only one pantograph is raised at a time. High-tension bus bars carry power along the roof between the two powered cars. A roof-mounted circuit breaker isolates the equipment in the two cars. (34)

Yugoslavia

Yugoslav Railways completed electrification of several routes in the western half of the country and plans to build another 625 route-miles (1,000 route-km) of electrification at 25-kV 50-Hz in the next four years. If completed in 1985 as planned. Yugoslav Railways will carry 70% of its freight traffic with electric traction. (25)

Zaire

Some existing and planned electrification at 25-kV, 50-Hz is reported. A study of railway electrification, funded by the World Bank, recommends electrifying 228 miles (365 km) Kinshasa-Matachi and purchase of six-axle locomotives rated at 2,600-KW.

Zimbabwe

The National Railways of Zimbabwe will complete a 25-kV, 50-Hz link of 206 route-miles (330 route-km) from Salisbury to Dabuka Yard south of Gwelo. A second phase of construction will take the line to the Mozambique border at Chicualacuala. A third stage, expected by 1989, will encompass conversion of the line to Bulawayo from Somabula.

Power supplies for the initial section will be to trackside substations at 88-kV, with intermediate switching stations midway between substations. Catenary characteristics include simple construction with a 107-mm^2 hard-drawn copper contact wire and a stranded 83-mm^2 hard-drawn copper catenary; a 110^2 stranded hard-drawn copper return conductor suspended over the catenary wire along the center-line of the track, a weight-tensioned catenary, and booster transformers at selected locations to reduce communication interference. The purchase of 30 electric locomotives and the conversion of 14 of Class DE 4 diesel-electrics are planned for the first stage of electrification. (35)

VI. ECONOMIC AND FINANCIAL ANALYSIS OF RAILWAY ELECTRIFICATION IN THE UNITED STATES

Because of a variety of study approaches to showing the rate of return for railroad electrification, there appears to be little consensus on the economic benefits or the appropriate financing arrangements for such electrification, should it occur. Great variations in estimated rates of return are associated with different environmental contexts, different assumptions about the future trends in diesel fuel price and electricity rates, and different projected traffic densities.

The Principal Studies of Rate of Return

According to rank, from lowest to highest, here are the estimated rates of return on railroad electrification.

Rate of Return	Source	Critical Assumptions
6-18%	S.R.I. (36)	1. Rise in income from electrification cost savings is offset by higher interest payments, resulting in lower earnings and erosion in equity. 2. Diesel fuel is assumed to rise in price from \$.27/gal in 1976 (\$1975) to \$.43 in 2000 (\$1975). 3. Freight rates are not permitted by ICC to rise to cover additional needs for capital.
7% (first year, full pay-back by 13 years)	Canadian Institute of Guided Ground Transport (37)	1. CP route from Thunder Bay to Winnipeg 2. Railroad does not pay the world price for oil. 3. 1 electric locomotive replaces 1.23 diesel electrics on the basis of horsepower and adhesion differences. 4. No difference in assumed economic life of electric and diesel-electric locomotives. 5. Cost of diesel is 31¢/litre (1980) vs. 3.64¢/KWhr. 6. Electric locomotives would replace diesel-electrics on a horsepower basis for express trains, but on an adhesion basis for lower priority trains. 7. Account is taken of losses from idling and spillage of fuel, and from losses (10%) of power at catenary and transformer. 8. Account is taken of density of traffic, and variations in grade.

Rate of Return	Source	Critical Assumptions
9-17%	T.S.C. (38)	1. Rail traffic growth is 2%. 2. No general inflation. 3. A rate of return (ROR) of 9-12% is calculated based upon an assumption that the gap in fuel prices between diesel and electric does not widen. Alternatively, TSC derives an ROR of 11-15% using a 1977 assumption that the difference in fuel costs grows by 2% per annum. In fact, from 1977 to 1980, TSC shows that diesel fuel price increased by 9%, as contrasted with a 5.8% growth in cost of electric energy to the user, in other words, a differece of 3.2 percentage points. Taking this factor into account, TSC raised its 1980 estimate of ROR to 13-17%.
"Over 13%"	Whitford (39)	1. Little increase in fuel price.
"Well above 15%"	Whitford (40)	1. Electrification of 25,600-mile system. 2. Diesel fuel is \$1.00/gal and electricity is 4¢/KWHR. 3. Unknown relative escalation in diesel/electrical costs.
15.5% to 21%	T.V.A. (41)	1. Great variation is due to wide discrepancies in projected relative fuel costs of diesel and electric traction. 2. 44-50 MGTM/year traffic density. 3. 750 track miles, Cincinnati to Atlanta.
17.7%	Gibbs & Hill (42)	1. 340 route-miles (Harrisburg to Pittsburgh). 2. 113 m NT/yr traffic density. 3. Reduction in number of locomotives required for the operations because of higher speeds, less down-time, and higher power-at-the-rail. 4. Maintenance costs of electric locomotives assumed to be 1/4th that of diesel (normalized to the ton-mile). 5. \$0.83/gal cost of diesel which escalates at 9% per annum; \$0.03/KWHR for electricity costs, which escalates at 6.64% per annum. 6. Most electric power will be generated by coal, not oil.

Rate of Return	Source	Critical Assumptions
23%	Gibbs & Hill (43)	1. Electrification of remaining 63 route-miles which are currently unelectrified between Harrisburg and Philadelphia. 2. Reduction in number of locomotives required for the operations because of higher speeds, less down-time, and higher power-at-the-rail. 3. Average diesel locomotive power at the rail = 1,223 total Kw/670 units = 1.8 Kw/unit. Average electric locomotive power at the rail = 1,326 total Kw/329 units = 4.0 Kw/unit. The electric:diesel power ratio = 2.2 4. See other assumptions above for Gibbs and Hill, Harrisburg to Pittsburgh.
20-26% ROI 14-21% IRR	MKT-RR Electrification Project (44)	1. Federal loan financing (Section 511). 2. 18-28 MGTM/year 3. Increasing traffic densities to 2000. 4. For the relative fuel escalation, as in other studies by Cooper, it is estimated that OPEC oil will escalate at a rate of 12% per annum; electricity, at 9% per annum.
37.8%	Whitford (45)	1. 3% per annum escalation in fuel price. 2. 2% per annum increase in freight volume. 3. 25,600-mile system. 4. Full equity funding over 50 years.

The previous synopses illustrate that the calculated rate of return on investment is very sensitive to assumptions regarding: (1) traffic density; (2) relative cost escalation of diesel and electric power costs; (3) relative substitutability of diesel, diesel-electric, and electric locomotives.

Several attempts are underway to provide a more complete model of the costs and benefits of railway electrification. Booz, Allen, and Hamilton (46) has prepared a parametric analysis of railroad electrification economics which adds important variables. Some of the many variables described in the two-volume report include:

- Number of tracks
- Total route-miles by curvature
- Yard and siding track-miles
- Percentage of down-time of different locomotives
- Speed by grade
- Turnaround time
- Unit cost of electric horsepower for electric motive power at rail
- Catenary voltage
- Substation spacing
- Unit cost of substation
- Miles from substation to utility connection
- Cost of line construction per mile
- Average cost per route-mile of signal and communication modifications
- Civil reconstruction investment
- Hp/ton for varying types of service, by grade of route, diesel locomotives
- Speed by grade, diesel locomotives
- Down-time, diesel versus electric locomotives
- Average lifetime of diesel fleet
- Average age of diesel fleet
- Average lifetime of electric fleet
- Average age of electric fleet
- Unit cost of diesel power
- Unit cost of electric power
- Differential traffic density (subtraction of weighted average for traffic density in forward direction from traffic density in reverse direction)
- Differential in elevation between ends of route
- Electrical energy efficiency
- Power consumption (new power requirement plus net incremental lift energy)
- Unit miles of maintenance (horsepower miles divided by horsepower per unit)
- Unit cost of maintenance per mile
- Unit cost of wayside facilities maintenance
- Route-miles of wayside
- Diesel net incremental lift energy
- Electrical consumption at the rail by type of service, by direction
- Fuel consumption efficiency (gallons per watt-hour)
- Lubrication oil costs
- Unit-mile cost of diesel locomotive maintenance
- Emissions, diesel locomotive
- Conversion factor, diesel emission to electric utility emissions (with and without Federal controls)
- Traffic growth projections
- Inflation rate (general)
- Inflation rate of alternative fuels
- Electric energy cost escalation

To contrast the purely economic model of Booz, Allen, & Hamilton, one may set up a financial model to assess the impact of railway electrification on earnings, profits, freight rates, railway indebtedness, rate of return on total investment, and net worth. (47) Such a model was issued in January 1980 by the Stanford Research Institute. The principal finding of this study is that because the ICC policy has not in the past permitted an increase in freight rates to cover additional costs of capital, the assumption of debt by the railroads will raise interest payments by the railroads (unless the capital cost is subsidized), lower earnings, and erode the rate of return on total equity.

The analysis is based upon an estimate of the impact of the electrification of a 9,000-mile U.S. network involving 14 different railroad lines. Using many of the ratios between diesel-based and electric-based traction systems supplied by Arthur D. Little's technical study (50), its study concludes that electrification would reduce U.S. oil consumption by only 1% of the 1978 import rate. (48)

During the period 1980-1981, the Department of Transportation, Transportation Systems Center (TSC), spearheaded an inquiry about the economic and technical aspects of rail electrification. The TSC approach used the aforementioned disaggregate models, coupled with line segment traffic density and design information furnished on a confidential basis by the individual railroads cooperating in a government-industry joint inquiry. The purpose of the computer simulation exercise was to contrast the benefits of individual line electrification on selected corridors with the total system benefits should all the lines in the study choose to be electrified as a merged system.

The project is monitored by the Federal Railroad Administration. As of December 1981, results from this study are pending.

Updates of Costs of Railroad Electrification

In Table 2, Cooper and Buck (49) provide the following estimate of per mile costs for electrifying a 26,000-mile system of railways in the United States.

TABLE 2

Capital Cost Estimates for Fixed Facilities

Equipment Items	$/mile (1980$)	Assumptions
Catenary Wires	250,000	Based on a 25-kV, single-phase alternating current system.
Electrical Substations	45,000	Based on center feed substations with rotary converters.
Phase Breakers	5,000	Based on 15 miles of transmission line per substation hookup.
Transmission Lines	7,500	
Signal Modifications	50,000	
Bridge Modifications	30,000	
TOTAL	387,500	

TABLE 3

Capital Cost Estimated for Diesel and Electric Freight Locomotives

Locomotive Type	Power (hp)	Capital Cost Dollars	Capital Cost Dollars/hp
Diesel	3,000	890,000	297
Electric	5,100	1,300,000	255
Dual Mode	3,000	250,000	83

According to the rate listed in Table 3, the total 26,000-mile system would cost $32 billion in 1980 dollars.

A TSC estimate of capital costs of the 26,000-mile system is more modest. It fixes the cost at $20.7 billion in 1980 dollars. This estimate is based upon the following estimated unit costs of railroad electrification.

TABLE 4

Capital Investment Item	1980 Capital Cost/Route-Mile (thousand $)
Wayside Equipment:	
Single track	473
Double track	780
Locomotives:	
Diesel-electric	791
Electric	1,540

The TSC costs are, in turn, based upon estimates of 1980 costs developed by Gibbs and Hill for the recent Conrail electrification feasibility study.

These figures may be contrasted with 1976 dollar cost estimates prepared by Arthur D. Little and reported by SRI International (50) and with 1977 data of estimated costs presented by the TSC (51).

TABLE 5

Capital Investment Item	Unit Capital Cost ($-thousands)	
	1976	1977
Catenary, per track-mile	86	
Electric substation located every 40 miles along a single-track route	442	
Electric substation located every 40 miles along a double-track route	627	
Communications and signalling, per route mile	62	
Wayside equipment:		
Single track/route mile		228
Double track/route mile		381
Locomotives:		
Diesel-electric		500
Electric		1,000

One may conclude that costs of the wayside equipment have doubled in the period 1977-1980. This economic fact partially offsets the doubling of diesel fuel cost ($0.42 to $0.85 $/gallon, 1977-1980) in the analysis of rate of return on investment in rail electrification. Another factor mitigating against conversion to electrification is that over the period 1977-1980 electric energy cost ($/kWh hour) is reported by the Transportation System Center to have risen from $0.027 to $0.042. (52)

VII. RESEARCH AND DEVELOPMENT (R&D) ACTIVITIES

DOT-FUNDED R&D

Much of the contemporary research on rail electrification funded by the FRA revolves around finding successfully implementable, cost-reducing technologies which will bring rail electrification an even higher rate of return as an investment.

Since the umbrella of technological alternatives in rail electrification is well known and is being tested in actual construction projects, less R&D emphasis is placed on new equipment design, and more is placed on test track operations.

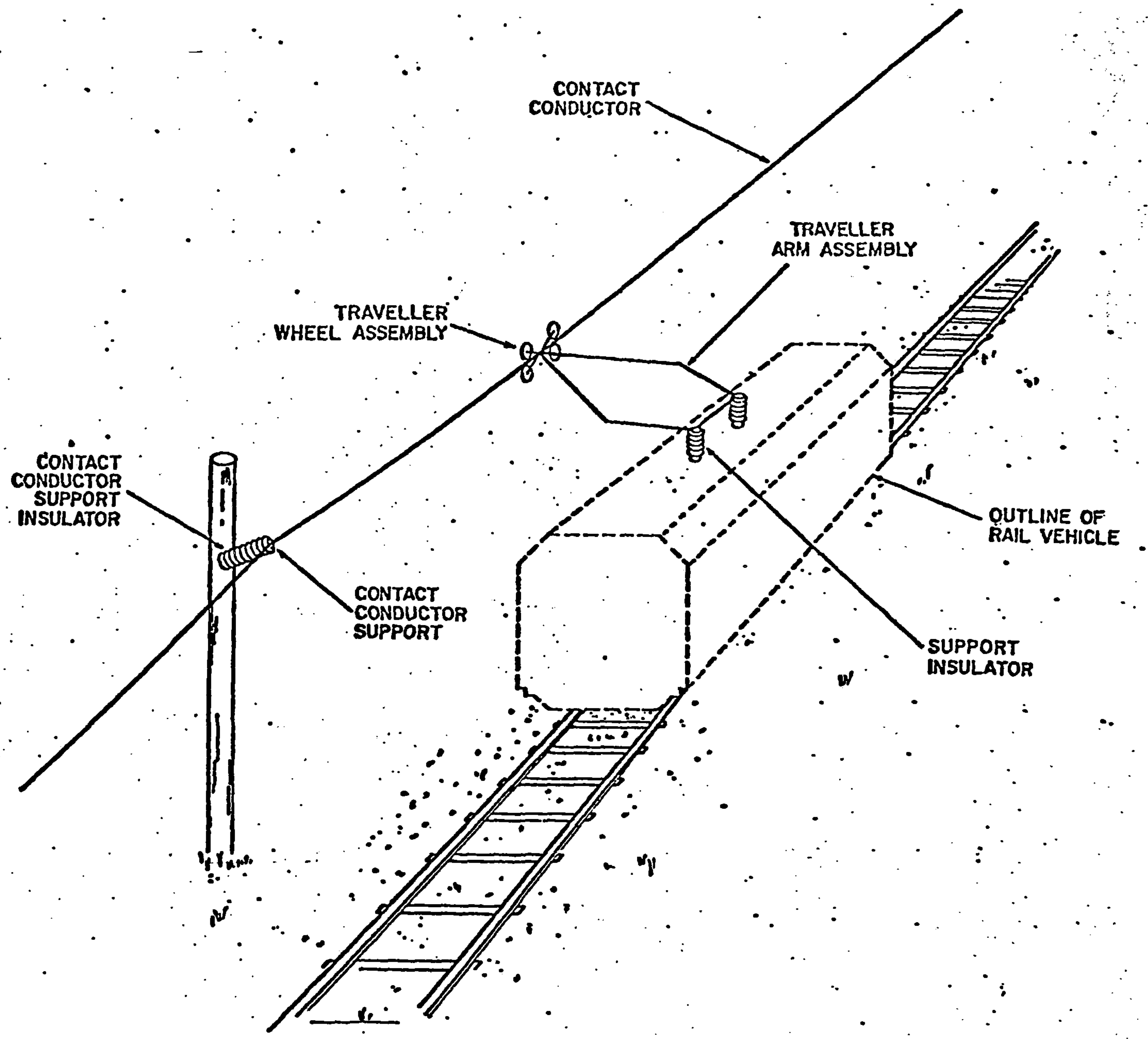
A TSC study updating the cost of rail electrification components finds that recent inflationary patterns have doubled the cost of locomotives and wayside equipment, thus offsetting to some extent the impact of increased diesel fuel/electric traction power cost shifts. (53)

In October 1981, the American Electric Power Service Corporation, Battelle Columbus Laboratories, and Ohio Brass Company presented to the FRA a final report (54) on the analysis of a low-cost catenary design. The system requires only a single contact conductor, a traveller wheel assembly which rides on the contact conductor, and contact supports including insulators. (See Fig. I.) Computer models were developed to test various conductor diameters and tensions, different span lengths among supports, and various traveller speeds. The report indicates no initial design difficulties and sketches the steps necessary for the development of a working prototype.

Another cost-saving technology currently under study is the development of an all-aluminum catenary. In a study funded by FRA, Alcoa discussed, in March 1981, the design of a simple catenary consisting of ACSR messenger, solid 6201-T81 aluminum contact wire, aluminum hangers, and related clamps, designed for high-speed power collection in a nominal 600 amp system. This design is being tested against a baseline system with an ACSR messenger with a 4/0 hard-drawn copper contact wire and stainless steel hangers. A computerized optimization study by Alcoa suggests that the aluminum system could be 10% less expensive than the copper alternative. As of mid-1981, physical testing of prototypes was still in progress. (55)

In April 1981, Electrack, Inc., submitted a draft report (56) to the FRA describing electrical traction power supply configurations for 10,000 miles of a proposed U.S. rail electrification project. In order to select the most cost-effective power supply configuration for each route within the overall system, a cost analysis of the technically acceptable power supply configurations and catenary system was offered.

Topics in the analysis included: substation spacing, voltage unbalance and flicker, and electromagnetic interference. Candidate railroad/routes included: the Atchison, Topeka and Santa Fe (Chicago to Los Angeles); CSX (Chicago-Washington, DC-Baltimore); Chicago and North Western (Chicago-Council Bluffs; California Jct., IA-Fremont, NE); Conrail (Cleveland, OH-Newark, NJ; Pittsburgh-Johnstown, PA; Harrisburg-Parkersburg, Pa; Chicago-Selkirk, NY); Norfolk & Western (several Virginia lines); Southern (Cincinnati-Atlanta); Southern Pacific (El Paso-Los Angeles); and Union Pacific (several midwest lines).



R.L. Retallack; George R. Doyle, Jr.; Lynn A. Schneider & John M. Sheadel. "A Low Cost Catenary Design-Analysis." Report prepared for U.S. DOT/FRA and U.S. DOE. FRA/ORD-81/73. October, 1981.

FIGURE 1. GENERAL ARRANGEMENT OF SUBASSEMBLIES FOR A LOW-COST CATENARY SYSTEM.

This detailed analysis includes: assessment of train power demand, railroad fixed plant, overhead clearances, traction system factors, interference problems, safety, environmental considerations, construction cost, and land acquisition.

Other studies involving modelling of the economic benefits and costs of electrification have been reported in the previous section.

In January 1981, the Transportation Systems Center issued a staff study report (57) on electricity pricing policies and practices applied to railroad electrification. It concluded that pricing policies of the electric utility industry would probably follow current practices for serving large industrial users. However, special charges may be assessed to the railroads for any required utility construction, for standby facilities to cover operational contingencies, and for penalties for disturbances to the electric utility system that must be corrected by the utility. The railroad load on electric utilities has both negative and positive aspects. Disadvantages include low substation load factor, rolling peak load, and poor load quality. The positive aspects include long daily load period and an acceptable overall load factor.

In February 1981, the Transportation Test Center issued a report on bedline testing of the Faiveley single and dual stage pantographs. Specially instrumented pantographs were run over an isolated and grounded (deadline) catenary to assess the current collection performance of a pantograph of various styles of catenary. Results showed that the deadline technique was successfully implemented and that the Style 5 catenary, which had been proposed for the New Haven to Boston section of the North East Corridor, has much improved performance over other existing catenary designs. Data on predicted performance are given for various styles of catenary at various pantograph speeds of travel.

TOPICAL LISTING OF OTHER R&D ACTIVITIES, 1980-1981

Power Supplies and Transmission

Novel aspects of the Sishen-Saldanha (South Africa) rail electrification include three-phase transmission lines at six feed points. The 50-kV system permits wider spacing of substations, in this case at 110-mile intervals. Each feed point consists of a substation and track feeder station that are physically separate. The track feeder stations (TFS) are located trackside and are fed from the utility's substation by two secondary 50 kV aerial feeders, each of a different phase. Phase breaks are located approximately equidistant between the adjacent TFS's and the TFS feed point to the catenary to maintain phase separation of adjacent catenaries. (57)

For maintenance or in the event of a failure in either transformer or feeder, one transformer can feed both sections of the catenary by closing a tie circuit breaker located at the TFS. Thus, the transformer is rated for emergency overloads, as well as for increased loads, as traffic capacity doubles in the future. (57) Ohio Brass and IECO jointly developed the design for the 50-kV phase breaks. The system has been functioning well since 1978, according to an analysis published in 1980. (58)

Techniques to calculate the maximum voltage drop and its location on a line that is powered from two remote sources operating in parallel are described in an 1980 article issued by Day and Zimmermann. (59) This calculation permits a cost-effective selection of conductors and substation spacing, since limiting voltage drop has a bearing on the efficiency of energy utilization.

In 1981, the Electric Power Research Institute requested proposals to study the technical issues and problems associated with railroad electrification and to review the solution techniques and computational tools required for analyzing the impact of railroad load on electric utility systems. Areas for future research were to be identified. The project has not had any product since it is in its inception. (60)

Innovations in the use of overhead catenary supports to carry utility transmission lines to a substation in West Germany were reported in October 1980. (61) Although the erection of a 110-kV transmission line on the catenary supports can only be successful in special cases, because of the technical and economic disadvantages inherent in the system. Implementation was successful in this case, however.

In June 1981, Soviet Railways issued an article on the use of traction batteries which permit operation of electric locomotives on shunting operations or on branch line traversing, where electrical power sources have not been installed. (62) Nickel-iron batteries have been widely used in the U.S.S.R. and are cheaper and longer-lasting than the more traditional lead/acid batteries elsewhere. However, even these have insufficient energy density to make them economically useful. This article mentions a sodium-sulphur cell, under development by British Rail, with an expected tenfold improvement in energy density over current batteries.

The Canadian Institute of Guided Ground Transportation recently issued a report (63) which assessed the technical and economic feasibility of superconductive wayside energy storage systems, that store train-braking energy for several hours using niobium-titanium materials which sustain high current and flux density for indefinite periods of time. Although technically possible, an estimated low rate of return on investment forestalls further technical development at this time.

Overhead Catenary Systems

The Alcoa/IECO study of aluminum catenaries presented findings on a feasibility study of the use of hard alloy aluminum in contact wires (as opposed to copper or bronze). (64) Research at the Transportation Test Center using controlled physical testing was to have determined wear and performance characteristics. Subsequently, that aspect of the testing program was dropped.

A simulation study was undertaken to compare a low-cost, catenary-elevated contact conductor where power comes from an overhead traveler mounted on an extensible arm to a more conventional simple catenary configuration currently employed on the Muskingum Railroad in Ohio. (65) The overall installed cost of the lower cost system was estimated at less than one-half the conventional system. Savings come from shorter poles, single-post insulators (as contrasted with insulator/arm systems and guy wires), lower unit cost of the structures, fewer structures required on the curved track portions, and lower material and installation cost for the conductor. This system is claimed to handle the required mechanical loads for velocities up to 50 mi/h (81 km/h). Physical testing of prototypes is recommended in the report.

A survey of low-cost catenary configuration undertaken by Input/Output Computer Services for the Transportation Systems Center reviewed catenary developments in several foreign countries. (66) It was noted that British Rail and SNCF have developed and installed, on operating freight lines, simple single-wire (trolley wire) catenary systems suitable for speeds up to about 50 mph. They have also installed on operating freight lines two-wire (simple catenary) systems suitable for speeds up to 120 mi/h. Operating speeds have been increased by using constant-tension designs and by introducing springs or flexible wires which provide a "soft" support for each contact wire at the pole.

Constant tension designs maintain a fixed tension force on the horizontal plane, by use of pulleys and counterweights. The contact wire is thus unhampered in operation regardless of the temperature variations that can cause changes in the sag of the wire. However, these catenary designs cannot be easily adapted for application on U.S. rail lines, since the heavier U.S. trains require a larger current capacity and thus heavier wires than in British or French trains.

Designed to withstand the rigors of near-desert sand and wind conditions, as well as the humidity and salt of the South African coast, the overhead contact wire system of the Sishen-Saldanha Railroad is a closer prototype of the heavy-duty freight applications likely to be found in the United States. Daniels of IECO reports on the successful application of an international consortium design consisting of two different overhead contact wire systems: an all-copper simple catenary on the coast; and for inland, a simple aluminum conductor steel reinforced (ACSR) messenger and contact wire. Synthetic insulators were shown to have improved performance in coastal (more polluted) atmospheres. Cost-savings are noted. (67)

Other cost-saving experiments are listed: use of wide-flange section poles at the Pueblo Test Center; developments of longer tension lengths (Sishen-Saldanha); use of wider pantographs to permit increased pole spacing; rigid disc insulators, steel conductors in grounding and bonding; and compacted conductors to reduce wind loading. Interest in the single-wire trolley system continues because speeds above 60 mi/h can be achieved and that spans in excess of 200 feet can be constructed using this technology. (68)

The experience of Japan's overhead contact system was reported in Japanese Railway Engineering in 1980. (69) For the high-speed lines (Tokyo to Osaka), a decision was made to replace the composite compound catenary with heavy catenary. It was found that a higher tension was necessary than previously, since oscillation fatigue of wires was occurring because of contact wire push-up. A tension value of 5.5 tons was preferable to the previous 3 tons, with the composite compound catenary. On other, less traveled lines, a simple catenary trolley structure was appropriate, provided extra maintenance was performed: strengthening grounding conductor wires and insulators for the feeder wires, improving insulation in areas subject to saline exposure, improving steady arms and crossing clamps, increasing automatic tension adjusters; and increasing use of hanger covers to protect messenger wires.

A review of corrosion effects in the Kammon undersea tunnel (Japan) provides interesting insight into the relative durability of overhead equipment. (70)

All except hard-drawn copper wire and aluminum-coated wire showed more than 15% reduction in fatigue strength after three years. Aluminum showed a 50% loss of fatigue strength after three years. Titanium and titanium alloys were particularly corrosion-resistant.

Locomotives and Train Sets

New developments in both passenger and freight electric locomotives and train sets are reported for the period 1980-1981. The following are the highlights of the passenger developments.

In February 1981, the French-built TGV created a world speed record of 238 mi/h (380 km/h) for a commercial train. (71) Unlike earlier speed tests, this record was set without appreciable damage to track. Increased speeds were attained because of increased catenary tension, low floor levels to increase stability, and redesigned rubber damping element in the spring to assure reduced sway. Low forces exerted by the TGV will reduce maintenance costs, and permit use of less expensive ballasted track, as contrasted with the more expensive concrete slab track. (71)

Advanced Passenger Trains (APT) have demonstrated their worth in technical proving trials and were entering commercial service between London and Glasgow in June 1981. Important features of the APT include lightweight construction, articulation, suspension, tilting body, body-mounted traction motors and hydrokinetic brakes. In separate tests, the APT proved it could reduce running time on the Northeast Corridor, using train performance calculations which compared the train to the baseline upgraded Metroliner. Its advantage lay in its tilting capability and improved speeds on the severe curves between New York and Boston. (72)

Two new Japanese test trains, the 961 and the 962, were reported in 1981 to have attained speeds of 198 mi/h and 143 mi/h (317 km/h and 229 km/h), respectively. Running resistance of the 961-class train is about 20% less than the current trains in service. An improved pantograph design reduces power-collecting noise and electronic interference. (73)

In 1980 the Electro-Motive Division of General Motors delivered to Amtrak a new model AEM-7 locomotive which performed a tested profile run from New York to Washington in 2 hours and 40 minutes. The locomotive has a nominal 7,000 diesel equivalent horsepower, with a maximum speed of 125 mi/h (201 km/h), and 28,100 lbs continuous rail tractive effort (T.E.) at a base speed of 70 mi/h, and 50,000 lbs short time rail T.E. available for acceleration. Important features of the electrical equipment and control systems of the AEM-7 include: a patented magneto-elastic transducer to measure force swings in the traction motor reaction rods; wheel slip control circuitry; roof mounted dynamic brake resistors; a chevron primary suspension system; a unitized carbody and underframe; blending of disc and tread brakes; thyristor convertors; and traction motors of ASEA designs. (74)

In 1980 Italy was testing a new E633 electric prototype, including thyristor control, to eliminate power dissipation at start-up, and the fuller use of both traction and adhesion. (74)

Freight or Mixed Freight/Passenger Systems

In 1980 German Federal Railways was testing prototypes of the E 120 designed to be equally efficient in hauling heavy freight and express freight of high-speed passenger trains. The E 120 has a top speed hauling passenger trains of 100 m/h (160 km/h). It can haul a 2,700-ton freight train at 50 mi/h (80 km/h). (75)

Prototypes of a new 10,000 hp electric locomotive were being tested in 1980 on the North Caucasus Railway (U.S.S.R.). The new locomotive, VL-84, has a top speed of 75 mi/h (120 km/hr), tractive force up to 50 ton, and ability to operate to -60°C. (76).

During 1981 Garrett/AiResearch Manufacturing Company completed a study of the dual-mode locomotive (DML), a modified, standard diesel-electric locomotive which can also operate as a catenary-powered electric locomotive. (77) Using simulation techniques, the study showed that the DML permits reduction in required locomotive fleet size, since it has higher power capabilities. ROI's are calculated for partial and full DML electrification, showing results in the range of 20.8% to 24.4%. (77)

In Britain, GEC Traction has developed its STAR (Slow Thyristor and Resonance) chopper circuit to give even lower capital costs and higher energy savings. The STAR circuit uses a reverse conducting thyristor in the commutating assembly. The devices in the main thyristor assembly have both higher voltage and a higher current grading, thus reducing the number of such devices required and lowering the total cost. These regenerative choppers permit greater economy from energy savings. (78)

Signalling and Communication

In June, 1981, Kaiser Engineers reported that work was on an FRA-sponsored program to examine the effects of railroad electrification on signal systems and train control. The objectives were: (1) to see whether more economical designs for the overall signal system and electrification system design for the Northeast Corridor were available; and (2) to develop a project plan by which signal and communication system R&D should be conducted to reduce EMI and provide improved train control. A draft report has been completed.

In 1980-81, Kaiser Engineers was under contract to Dynamic Science to design an electromagnetic compatibility test facility for the FRA at the Transportation Test Center in Pueblo, Colorado. This facility has been completed and will be used primarily to test signal and communication systems and components and how they function on an electrified railroad.

A task force has been assembled to develop test programs, methodologies, and schedules for the FRA's research and development program concerning signal and communications at the Transportation Test Center. In the planning stage is an electromagnetic compatibility test site nearly 3 miles long which will offer facilities for testing systems and components and will provide information regarding the mitigation offered through shielding, underground installation, separation, and length of exposure.

Abroad, Ishikawa has reported on the methods to reduce electromagnetic induction involving the use of cross bonds with insulated rail joints in the middle of the track circuits in the 50-60 Hz switching equipment on the ATC System in Shinkansen. It was necessary to double the insulation in order to cope with mechanical problems uncovered in operations. (79)

In France, tests with the TGV-PSE show that for speeds of 163 mi/h (260 km/h), outside signalling is impossible; instead the rail is used to convey information signals. The signalling circuit is checked to assure immunity from electrical interference generated by the traction return current. There was an advantage in creating a special field with two pickups to eliminate, as much as possible, the influence of traction return current -- the position of the pick-ups with regard to the rail being a compromise between the level of information and pickup damage by accidental shock impact. Signals appear to the driver on the inside of the cab. (80)

VIII. CONCLUSION

This report has reviewed the status of railway electrification in North America and selected countries, with particular emphasis on the period 1980-1981. The report covers electrification in place and under construction for all U.S. railroads. It reviews construction activities in selected countries, with particular attention to Asian and African countries not discussed in previous reports. It summarizes planning and feasibility study activity reported by U.S. and selected foreign railroads.

The report summarizes the key assumptions implicit or explicit in the array of studies recently released on the subject of projected rates of return on investment in railroad electrification. It is interesting to note that the range of such estimates, depending upon assumptions, varies from 7% to 38%. Critical assumptions include the traffic density projected for the corridor to be electrified, the assumed changes in the future relative prices of electric and non-electric power sources, and the availability of venture capital to underwrite the proposed projects.

During 1980-1981 considerable amounts of research continued to flow from engineering and architectural firms, from government-sponsored research and testing programs, and from organizations representing the supply side of the components industry. Highlights of engineering and technological developments are noted in brief in this report.

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