A REVIEW OF FACTORS INFLUENCING RAILROAD ELECTRIFICATION

A REPORT BY

RAILWAY PROGRESS INSTITUTE

Association of American Railroads

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INDUSTY
ASK FORCE
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DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
WASHINGTON, D.C. 20590

ASSOCIATE ADMINISTRATOR

February 20, 1974

Honorable Claude S. Brinegar
Secretary of Transportation
Washington, D. C. 20590

Dear Mr. Secretary:

On behalf of the Government-Industry Task Force on Railroad Electrification -- which is comprised of representatives from the Department of Transportation, Association of American Railroads, Edison Electric Institute and the Railway Progress Institute -- I am pleased to present conclusions and recommendations which are the consensus of the broadly-based Task Force, and a detailed discussion of factors that influence railroad electrification.

The purpose of the 27-member Task Force was to review those factors influencing railroad electrification within a government-industry interdisciplinary forum and to propose to the Secretary of Transportation appropriate public policies and actions regarding railroad electrification. The Task Force was established following a Department of Transportation sponsored rail electrification conference on April 20, 1971.

I am sure that members of the Task Force would welcome a meeting with you for further discussion of this subject.

Sincerely,

William E. Loftus

William E. Loftus, Chairman
Task Force on Railroad Electrification

John W. Ingram
Federal Railroad Administrator

CONCLUSIONS

The Task Force on Railroad Electrification was established to review and consider the major factors associated with electrification and to propose government and industry policy as to the development of railroad electrification. It did not undertake to deal with the questions of whether, where, when or why to electrify specific lines since those are economic and operational issues best left to individual railroad managements.

Based on studies available to it, the Task Force has arrived at these conclusions.

(1) Railroad electrification is the only available alternative to diesel-electric operations on high-density, long-haul railroad lines.

(2) Electrification offers the only feasible means to utilize coal or nuclear power for intercity movements of general freight and passengers.

(3) Modern rail electrification technology is available for application.

(4) While electrification has been shown to have a positive rate of return on the projected investment, electrification of high-density lines has not been widely adopted by American railroads because of more pressing capital requirements or more attractive investment opportunities.

(5) Railroad electrification presents a number of as yet unresolved

regulatory problems for railroads and utilities.

(6) The development of railroad electrification in an orderly and efficient manner can best be facilitated by a joint government-industry program where substantial improvements in national transportation efficiency can be achieved.

RECOMMENDATIONS

The Task Force recommends actions to be undertaken by government and industry in the interest of achieveing substantial gains in national transportation efficiency as well as promoting energy-effective transportation strategies. These recommendations take into account that the Nation is embarking upon efforts to become self-sufficient in energy and that, of all modes of transportation, only rail can be feasibly converted from petroleum fuel to coal or nuclear-fueled electric energy. The word "industry" is meant to include the railroads, the railway supply industry, electric utilities, electric manufacturers and suppliers, financial institutions and others concerned with railroad electrification.

(1) The Department of Transportation should be given appropriate planning and funding authority to cooperate with industry in development of and in financing railroad electrification where substantial improvements in national transportation efficiency can be achieved.

(2) The Department of Transportation should undertake a cooperative research and development program with industry to continue to advance the technology of railroad electrification.

(3) Legislation dealing with railroad improvement should permit assistance for railroad electrification projects where substantial improvements in transportation efficiency can be demonstrated.

Membership of Task Force

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Technical and Writers' Committee

A committee representing all groups on the Task Force drafted a preliminary report which was then reviewed and approved by the full Task Force. In addition to several key members of the Task Force, this committee included:

A. N. Addie, Manager, Advance Engineering, Electro-Motive Division, General Motors Corporation

R. Byrne, Manager of Research, Southern Pacific Transportation Company

M. D. Meeker, Manager, Railroad Electrification, General Electric Company

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TABLE OF CONTENTS

INTRODUCTION

The present and future role of railroad transportation in meeting its share of the nation's demand for transportation services has become a significant public issue. While most concern centers on the railroad bankruptcies in the Midwest and Northeast region, many of the technical and operating problems that are symptomatic of the bankrupt railroads are, to a lesser degree, also characteristic of the industry as a whole. In addition, the ability of the railroad system to continue to provide low-cost, energy-effective transportation is a major concern in the broader national problem of energy conservation.

The current problems and posture of the railroad industry are also a matter of concern over the longer term. The projected growth in demand for intercity freight transportation, growth in rail transit in urban areas and requirements of intercity rail passenger service argue strongly that other strategies must be developed for full utilization of a modernized United States rail system. The role of electrification in a modernized rail system has been under study and merits consideration for at least high-density, long-haul segments of the system.

This paper, which represents the consensus of Task Force members, comprised of government, railroad, power and supply industry representatives, reviews the rail electrification issues within the context of operational, investment, technological, environmental and public policy factors.

RAILROAD ELECTRIFICATION IN THE UNITED STATES, EUROPE AND JAPAN

United States

Railway electrification in the United States dates back more than 70 years. It reached its peak during the 1930's but with the advent of diesel-electric locomotives, it ceased to expand and has since declined from a peak of over 2500 route miles to less than 1200 route miles today. Most electrification took place in the populous Northeast with extensive electrification on the Pennsylvania Railroad (now Penn-Central) along the Eastern Seaboard and some electrification to serve primarily rail commuter service on the New York Central, New Haven, Reading, and Long Island railroads. Another rail electrification installation was in the Cascade and Rocky Mountains by the Milwaukee Road.

Electrification projects in this country were undertaken to solve five basic operating problems.

1) Terminal and trunk-line tunnels were electrified to eliminate smoke, soot and noise associated with steam locomotives.
2) Passenger terminal and suburban services were electrified to speed services on these lines through utilization of the high acceleration capability of electric traction.
3) Because electric operation was required at terminals in some metropolitan areas, electrification of the main line track allowed the same engine to haul the train from terminal to terminal and added greatly to the efficiency of service to passengers.

4) Electrification of the Eastern Seaboard section of the Pennsylvania Railroad was done largely to increase track capacity - obviating the need to add additional tracks in high traffic density territory - and to improve operating efficiency over what was then possible with steam power.

5) Electrification on portions of the Milwaukee Road, Norfolk and Western, and the Virginian was installed to take advantage of the increased efficiency, speed and tractive power of the electric locomotives in hauling heavy freight trains over grades of two percent or more which resulted in widespread savings in operation, overhead, and maintenance for these railroads in comparison with steam operation.

Electrified systems in the United States have decreased in mileage since the 1930's partly as a result of the overall change to diesel-electric locomotives from steam operations. However, a new look at the role of rail electrification is appropriate because of changing energy costs, advances in electric and catenary technology, and possible changes in the traffic patterns of the rail system.

There are now over 100 miles of new electrified railroad operated by electric power companies. The Black Mesa and Lake Powell Railroad in Arizona and the Muskingum Railroad in Ohio incorporate some of the most modern electrified railroad subsystems available. Since both operations are related to coal mining activities, they enjoy certain economies not usually available with normal railroad operating parameters. Still, these operations present several techniques applicable to larger electrification projects.

In the United States, several large trunkline railroads are currently studying electrification to determine its economic efficiency in improved freight operations. In Canada, the Canadian Pacific Railway has a study of railroad electrification under way.

In the area of rail passenger service, a 1971 report by the U. S. Department of Transportation entitled Recommendations for Northeast Corridor Transportation stated that the Penn Central's Northeast Corridor is the only line with sufficient density on which improvement and expansion of electrification for intercity passenger service is justified.

Europe

The first successful demonstration of electric railway traction dates back to 1879 when an electric locomotive hauled passengers around the grounds of an exposition site in Berlin. The first application was to public transit, and by 1890, London had its first electric underground system. For several reasons, such as the generally shorter intercity distances within European countries and extensive public subsidy for railway programs and until recently the limited ownership of motor vehicles, Europeans are more dependent on their railway systems for intercity travel than we in the United States. Because of the availability of hydro-electric power in mountainous regions, there has been a trend toward extensive electrification of rail lines in Italy, West Germany, Switzerland, Norway and Sweden.

The destruction of much of the European rail plant and equipment during World War II made it particularly feasible for the various national railways to switch from steam power to electric rail lines in the process of reconstruction. Italy, for example, had to reconstruct virtually its entire railway system and did so in accordance with uniform specifications for electrified rail systems.

One interesting aspect of electric railroads in Europe is that the power is not standardized. Thus, some trans-European express trains are hauled by quadricurrent locomotives which are fed by 25 kilovolt (kv) 50 hertz[1/] (hz) alternating current in France, 3 kv direct current in Belgium, 15 kv 16.7 hz alternating current in Germany and 1.5 kv direct current in Holland.

Since travel by rail has been traditionally popular in Europe, and intercity distances are generally shorter, there are fewer automobiles per capita than in this country. Thus, rail travel is more competitive with other intercity modes of transportation.

1/ International unit for frequency, previously known as 'cycles per second'.

European railroads have upgraded a considerable portion of their mainline routes which has further enhanced rail passenger service. In many cases, these improved lines have been electrified to gain the advantages of rapid acceleration and improved performance.

Japan

The first revenue operation by electric traction was inaugurated in Japan in 1895. The chief motivations in the early days of electrification was to serve urban and intercity passenger traffic and to do so with an energy source which did not have to be imported. The high speed exclusive passenger operation, begun in 1964 on the Tokaido line, is recognized world-wide as an example of modern electrification technology.

The remarkable development of industry and economy in post-war Japan, together with the size and population concentration of that country, have greatly increased the demand for passenger and freight rail transportation.

Like other densely populated countries which do not have their own petroleum resources, Japan relies on railroads even more for passenger service than it does to move freight. To meet the capacity requirements for ever-increasing demand, Japan has implemented a national plan to expand electrification.

The following table shows approximate railroad route mileage and degree of electrification of major North American and foreign rail systems:

Country	Railroad Route Miles	Electrified
Canada	41,000	nil
Mexico	15,000	less than 1%
United States	206,000	less than 1%
France	23,000	25%
Italy	12,000	47%
Japan	17,000	40%
Netherlands	2,000	52%
Norway	3,000	57%
Poland	14,000	17%
Sweden	7,000	60%
Switzerland	9,000	99%
U.S.S.R.	84,000	25%
United Kingdom	13,000	16%
West Germany	19,000	29%

MAJOR FACTORS INFLUENCING RAILROAD ELECTRIFICATION

BACKGROUND

History of Diesel-Electric Locomotive in the United States

Dieselization of the American railroads received wide-spread public notice in the early 1930's with the inception of passenger trains such as the Pioneer Zephyr, City of Salina, and Denver Zephyr which were powered by locomotives having diesel engines that generated electricity to power direct current electric traction motors. Development of the two-cycle diesel prior to World War II led to a 1350 horsepower (h.p.) freight locomotive. In the post-war era, the pre-war fleet of steam locomotives was overdue for replacement. Since the diesel-electric locomotive with its vastly superior thermal efficiency, broad tractive characteristics and attractive operating cost was available, rapid replacement occurred. This permitted large scale production of standardized locomotive design.

The diesel locomotive has evolved from the 1350 h.p. engine four-axle designs of the early 1940's to 3600 h.p. engine four and six-axle locomotives currently operating on U. S. railroads. Application of two engines per locomotive unit enable special purpose locomotives of 6600 h.p. on eight axles to be built.

The fleet of locomotive units in the United States decreased in number from roughly 40,000 low h.p. units including many older steam-locomotives in 1951 to about 27,000 higher h.p. units in 1971. During this time, the traffic volume increased from 650 billion ton-miles per year to 740 billion ton-miles per year. The operating economics of diesel-electric motive power in most cases provided the railroads with substantial returns on their investment.

History of Electric Locomotives in the United States

The early development of the straight electric locomotive preceded that of the diesel-electric locomotive. In its early application, the Pennsylvania Railroad utilized the tap changing transformer[1/] and series alternating current (AC) motor. The basic catenary voltage was 11 Kv and, because of commutating characteristics of series AC motors, the frequency was limited to 25 hz. In the late 1930's, the Pennsylvania's electrified system in the Northeast Corridor was extended. In the late 1950's the direct current (DC) series traction motor was applied together with mercury arc rectifiers to produce 3000 h.p. electric locomotives, many of which are still in use today. The modern electric locomotive has evolved additionally through the development of the solid state power and control devices which permit the rectification and control of the transformer output to supply the DC traction motors making locomotives of 6000 h.p. and higher possible.

1/ Transformer whose primary is equipped with controlled switches to control motor voltage.

Why Railroads Have Not Expanded Electrification in the United States

Incentives to add new electrified systems in the United States have not been large enough since World War II to overcome the following factors. Historically, the following issues have influenced decisions by the railroads not to electrify. These issues are of continuing concern.

1) Diesel-electric locomotives have become standard throughout the railroad industry and are relatively inexpensive to produce. Furthermore, the technology and operations of electrified railroads are quite different from diesel-electric operations.
2) Diesel fuel, until recently, has been relatively inexpensive and appeared to come from an infinite supply.
3) The investment in fixed electrification facilities may become subordinate to previous railroad mortgage commitments.
4) An investment in electrification creates a long-term obligation for a railroad and, thus, its credit standing and its ability to obtain capital for other necessary improvements is affected.
5) The long-term earning prospects for the railroad industry in general have not appeared strong in recent years, thus limiting interest in long-term railroad capital investments and precluding the opportunity to take full advantage of tax incentives when making large capital investments.
6) 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.
7) The first railroad to adopt modern electrification must be willing

to underwrite large engineering, development and learning costs for the construction of unfamiliar facilities and the production of parts and equipment not now available in quantity.

Potential Future Motive Power Developments

Several petroleum burning power plants have been investigated as possible alternatives to today's diesel engine as a general purpose locomotive prime mover for high horsepower freight service. Among these are the oil-fired gas turbine (Brayton cycle), Stirling engine, and rotary combustion engine (Wankel cycle). As yet, none of these engines has emerged as a superior prime mover to the diesel engine. The gas turbine, in its regenerative form with high efficiency components, closely approaches the efficiency of the diesel engine and offers the potential of higher power per unit. Production cost estimates indicate that the engine would be several times the cost of the equivalent diesel engine for freight service.

The Stirling engine, being an external combustion power plant, has relative freedom in the type of fuel consumed. Its efficiency is strongly dependent on the temperature at which it rejects heat and because about 60 percent of the heat input from the fuel must be rejected to a cooling system, the size of the cooling system limits the power that can be applied to a locomotive. Furthermore, the high levels of pressure in the cycle result in a very heavy engine.

The rotary engine has also been studied as an alternative to the diesel engine for locomotive use, but the thermal problems attendant in the sizes of engine required appear formidable.

As an alternative to petroleum-burning engines using fossil fuels, the coal-burning gas turbine has been investigated. However, the complexity of the coal-handling equipment and the serious problem of fly ash erosion have resulted in termination of its development.

The only viable alternative to the diesel engine, as a source of motive power for high horsepower freight locomotives appears to be the straight electric locomotive operating with an overhead electrified system supplied by a power-generating station. If the power were generated by a coal-burning or nuclear-powered plant, the present requirement for distillates could be eliminated on electrified lines.

An electric locomotive not needing to carry on-board generating capability constitutes a more compact design resulting in an increased power:weight ratio compared to a diesel-electric locomotive. In addition, since electric locomotives are not inherently limited by on-board generating capacity as is a diesel, and abundant amounts of power are available from the catenary, electric locomotives can develop short-time power ratings substantially in excess of a diesel-electric of the same rating. Both of these factors are of advantage in accelerating trains and in running trains at high speed.

The electric control characteristics of the straight electric locomotive are such that greater useful levels of effective adhesion have been demonstrated with straight electric than with diesel-electric.

The impetus of a major rail electrification would undoubtedly spur United States locomotive manufacturers to further develop electric locomotive technology as has been the case in Europe.

Future Traffic Growth

The market share of intercity freight handled by railroads has remained relatively steady over the last few years. However, there has been a generally rising trend in tonnage originated and in revenue ton-miles generated by railroads. In its 1972 National Transportation Report, the Department of Transportation projected that railroad revenue ton-miles will approach one trillion by 1980, an increase of nearly 25 per cent when related to 1972 rail traffic. This projected growth requires careful planning for expansion of the locomotive and car fleets, and for consolidation and upgrading of track and fixed structures.

Plant Consolidation

Railroads constantly assess the changing nature of traffic so that new facilities may be added as needed, and obsolete facilities and operations retired as they become uneconomic. Many heretofore profitable branch lines are now retired because of the decline of traffic thereon. Regulating authorities have been petitioned to allow railroads to retire many other unprofitable low-density lines.

Innovative operational practices have resulted in more productive use of mainlines. Railroads with centralized traffic control systems operate with bi-directional movement of trains on single, multiple or combination tracks which are supplemented with passing sidings. These changes, and many others, result in a railroad trunk line system of concentrated, high-density traffic linking major traffic centers. Growing demands will be made on this network as traffic volume and density continue to increase. Therefore, railroads will have to consider the most efficient future use of the track network and other fixed facilities, as well as freight car and locomotive fleets, to accommodate more traffic over consolidated systems.

OPERATIONS

Operational Characteristics of Electrification

Electrification has been examined as to the advantages and disadvantages posed for railroad operations. The railroad benefits are related either directly or indirectly to the different performance characteristics of the electric and diesel-electric locomotive. Some of the electric locomotive characteristics are:

- High horsepower;
- Increased availability and reliability;
- Low maintenance;
- Fast turn-around time;
- Improved tunnel operation; and
- Improved acceleration.

These characteristics result in both advantages and disadvantages to rail operations. Some of the advantages are that the straight-electric locomotive can attain two-to-three times the horsepower that a diesel-electric locomotive can within the same space configuration. It requires significantly less time for servicing between runs, and major overhauls are both less frequent and of shorter duration. Its overall maintenance cost can be 30 to 50 percent of costs for comparable diesel-electric locomotives. Electric locomotives would not suffer the loss of power associated with diesel-electric locomotives when traversing tunnels which could be a significant advantage in certain mountain operations. The higher horsepower available with electric locomotives would permit faster over-the-road transit time because of increased speed capability, where track conditions permit, and improved train acceleration. The effect of these advantages will vary from railroad to railroad and tends to be of more significance with higher usage, density, and character of the freight carried. Thus, electrification can contribute opportunities for significant service and productivity improvements.

Electrification can result in disadvantages as well. One is the loss of flexibility in motive power use. The diesel-electric locomotive can be shifted to different operating locations to meet seasonal traffic demands. Since total electrification is not realistic, it can be foreseen that the extent of electrification and the requirements to interface power will not permit the flexibility available with diesel-electric locomotives. Another disadvantage is that during construction of the catenary, the interference with ongoing rail operation can be a major cost element. In the electrification of an existing railroad, provision of overhead catenary has the effect of reducing vertical clearance which could limit maximum height cars. These clearance incursions could be designed for but would affect project cost thereby affecting its economic feasibility. Also, the restoration of service due to a rail mishap which damaged both track and catenary may take longer than were the track alone damaged.

When planning electrification, consideration should be given to the fact that future changes in railroad grade, alignment and structures or the additions of sidings and spurs would be more expensive if electrification were implemented. Finally, there is a greater element of hazard - to both rail and non-rail personnel - from high-voltage catenary wires.

Technical and Economic Analysis of Electric Operation and Train Dispatching Policy.

With the higher horsepower available in electrified service, trains can be run faster than when non-electrified. Present rolling stock and track capabilities are based on the present operating speeds. Therefore, technical and economic analysis efforts in such areas as track-train dynamics, high-speed freight cars, and optimal train lengths and schedules is desirable to identify and analyze the full costs and benefits of railroad electrification.

Traffic capacity of track becomes critical as maximum capacity is approached and consideration is given to increasing the number of tracks. Questions of land use and investment in additional trackage must be balanced against increasing the capacity of present track. The latter can be achieved through improved signaling and greater over-the-line speed (including acceleration-deceleration capability and higher maximum speed).

There are inherent differences in optimal train operating practices between trains whose power source is on-board (such as diesel-electric) and trains whose power source is wayside (such as straight electric) and, therefore, technical consideration must be given to achieving a physical layout of tracks and signals appropriate for the type of operation under consideration. Since most United States railroad operations are now based on diesel-electric powered trains, consideration of electrification should include estimates of the costs involved in rearranging the physical plant to exploit the maximum benefit from electric locomotion. Typical of the kinds of changes which may be required are:

Signal spacing;

Interlocking arrangements;

Crossover designs;

Track layout; and

Track alignment and superelevation.

Motive Power Reliability

Railroad requirements for motive power differ substantially and depend upon the geographic region served, nature of traffic handled, transportation schedules and operating philosophy. An underlying matter of concern, however, is the operational reliability of locomotives and the capital investment needed for additional locomotives to replace units undergoing unscheduled maintenance and repairs.

Horsepower per locomotive unit has gradually increased as a result of diesel engine and electrical system innovation and development. Several railroads use locomotives of 3600 h.p. and higher.

Reliability and dependability are more critical with higher horsepower locomotives than with lower power units because a road failure on such a unit means a greater reduction in power of the entire locomotive consist. Hence, when higher horsepower units sustain road failures, schedule interruptions can be more severe.

Railroad experience with modern, high horsepower locomotives emphasizes that greater equipment reliability must be achieved to reduce both road failures and premature defects found during locomotive inspections. Not only must reliability be improved to handle current traffic demands, but to meet future growth without excessive capital spending for back-up motive power.

Operating and Maintenance Costs

Railroads are universally dedicated to minimizing locomotive out-of-service time and to reducing maintenance costs. In addition, the costs of fuel and lubricants make up a substantial part of the total operating expense for locomotives. Diesel-electric locomotives can run long distances without servicing. The usual practice is to perform major servicing at terminals where fuel, lubricating oil, water, and sand are available and running repairs can be made. Time required for servicing is subtracted from the time a locomotive is available for service. 'Turn-around' time can be an important and implicit cost consideration.

Labor Requirements

As railroads have undergone technological changes, there have been changing requirements for employee skills and work assignments. Dieselization had an important influence on crew requirements and modifications to the size of operating districts. Also, there occurred a transition in servicing and maintenance skill requirements. Further changes are envisioned in employee skills if straight electric locomotives become a significant part of the locomotive fleet. Training programs would be needed to smooth transition for operating crews, and servicing and maintenance personnel.

In addition, other skills would have to be developed to handle installation and maintenance of catenary, pole structures, sub-stations and associated fixed plant facilities.

Appropriate supervisory forces with technical, administrative, and operational skills to fit electrified operation would also be needed if electrification were implemented.

CAPITAL NEEDS

Basic Requirements

The substantial capital investment required to provide the catenary system, modifications to the signal and communication system necessitated by electrification, substations, transmission system extensions, and an electric locomotive fleet are obstacles to the adoption of electrification by American railroads. With the exception of commuter lines, the minimum length of viable electric rail operation is generally several hundred miles long and hence, it is generally not feasible for a railroad to electrify only a small segment of its system. As indicated in the discussion on Why Railroads Have Not Expanded Electrification in the United States, large scale electrification has been and is today beyond the financial capability of most of the nation's railroads, and even for those companies potentially able to finance electrification, it represents a critical capital investment decision.

The capital investments associated with electrification fall into three broad categories:

New fixed facilities;

Modifications to existing facilities to make them compatible with electrified operation; and

A new fleet of electric locomotives.

New fixed facilities might include the catenary system, substations, catenary sectionalizing facilities and in some instances, utility transmission extensions.

Catenary system cost estimates on recent studies have ranged from

$50,000 to $70,000 per track mile depending upon terrain and other physical conditions. Of this cost, about 40 percent is for materials while the remainder is for engineering and installation costs.

Substations are another significant element of electrification investment and are estimated at $200,000 to $300,000 each with a spacing highly dependent on voltage and traffic conditions.

The investment required to expand an existing electric power transmission network to serve an electrified railroad will range from little additional facilities required in some parts of the East, Midwest and South, to substantial investment in facilities which would be required in some Western states where there is only a limited transmission network. Some combination of railroad and utility financing could support this need, but the critical need for investments to meet increasing demands in both these industries may make it difficult to do so.

Plant Improvements Must Accompany Electrification

It should be understood at this point that unless railroad track and terminal facilities are improved, electrification will not in itself upgrade rail service. However, if properly implemented, electrification could open potential new markets to the railroad industry because under optimum operating conditions, an electrified rail line would require less motive equipment and could hence achieve a higher frequency and better level of service than could an equal number of diesel locomotives. Electric locomotives would permit faster train runs resulting in improved schedules, more efficient operations and increased reliability of service due to less down-time and turn-around time.

RESEARCH AND DEVELOPMENT NEEDS

Technological Issues

While railway electrification is neither new nor untried, significant engineering questions remain which need to be addressed in undertaking a railway electrification. Decisions reached with regard to technical questions and development of improved technology have an impact on the economic and operational issues discussed above. For example, development of techniques to reduce or eliminate interference between electric traction systems and signal and communication lines affect the ultimate installation and maintenance expenses of electric transmission and catenary lines. Similarly, the adoption of standardized motive power affects the first cost of that equipment and its operational expense. Specialized designs could lead to proliferation of incompatible, customized equipment. On the other hand, too stringent standards tend to reduce innovation and could lead to equipment poorly matched to its assignment. Both of these situations could adversely affect the economics of electrification. All of the above factors need to be considered relative to the particular operating, environmental, and engineering characteristics of the rail line being studied. Research is necessary to enable the rail industry to determine answers to the following questions.

1) Where do careful engineering and economic studies of specific lines in the context of those lines' particular operating, environmental, and geographic conditions indicate that electrification is economically advantageous?

2) Where do technical problems (and valid estimates of the cost of their solution) preclude implementation of railway electrification of what specific routes?

3) Where can additional effort in research and development possibly lead to sufficient reductions in the total cost of electrification so that it becomes economically advantageous on specific lines or routes which, without such cost reductions, would not be appropriate for electrified operations?

The technical capabilities required to implement railroad electrification are available today in the United States. These include the design, manufacture, application, and installation of necessary power transmission and distribution systems, catenary, and electric locomotives.

Limited application of modern electrification technology has already been made in the United States, demonstrating:

Modern, light-weight catenary construction;
High voltage (25 kv and 50 kv) commercial frequency operation;
High-speed current collection;
Compatible signal and communication systems; and
Solid state, high-voltage, locomotive drive systems.

Since electrification will permit different strategies of operation, further research and development should be encouraged to insure that full advantage is taken of electrification's capabilities. Areas of

R&D effort should include:

High-speed train operation and train dispatching philosophies;

Signal and communication systems;

Transmission lines and catenary installation techniques; and

Locomotive propulsion systems.

High-Speed Train Operation and Train Dispatching Philosophies

Regular, high-frequency train operations can have a beneficial impact on electric operations through improved load factors on the power production and distribution facilities. It can also have benefits through better utilization of mainline tracks, yard facilities and resources, and can improve overall rail service.

Signal and Communication Systems

One of the important factors in electrifying a railroad is compatibility of signal and communication systems with the propulsion power supply. These systems include both the railroads' signals and communications as well as nonrailroad-owned, along-the-wayside or transverse communications. To assure the best and lowest cost fulfillment of the compatibility requirement, research and development in the following areas is desirable:

Electromagnetic interference studies and tests;

Equipment designed for optimum compatibility; and

Minimum cost modifications to existing equipment.

Transmission Lines and Catenary Installation Techniques

In the electrification of existing rail lines, it is important that catenary installation be accomplished with a minimum disruption of service. Techniques and equipment to do this have been developed for several installations in Europe. Continuing development effort is desirable to fully understand the European techniques and subsequently to provide the necessary catenary installation techniques and equipment applicable to the United States which will minimize service disruption during installation.

Locomotive Propulsion Systems

Continuing locomotive research and development should be encouraged in the areas of:

Adhesion to permit higher tractive effort per locomotive axle;

Alternative drive systems to achieve more economical and reliable propulsion systems; and

Propulsion motor suspension and drive transmission to enhance ride quality and drive reliability, and to minimize shock and vibration forces between locomotive and track structure.

Technical standards

Undoubtedly, future railroad electrification will develop on a railroad-by-railroad basis. This could lead ultimately to a system of electrified trunk sections throughout the nation, carrying a substantial percentage of the nation's ton-miles. In order that motive power and equipment can be readily interchanged and run through various railroad properties, certain standards should be set from the outset. These would benefit regular through-train operations, and improve inter-running capabilities in times of national emergency as well as having a favorable effect on the cost of equipment. Standards fall into three major categories: electrical standards; clearance standards; and human factors/safety standards.

A) Electrical Standards

Standards for motive power and power supply employed by common carrier railroads should be established. Work presently under way by an American Railway Engineering Association (AREA) committee is leading to the establishment of the following standard motive power operating voltages:

Single Phase 50 kv (+5% -15%), 60 hz ;

Single Phase 25 kv (+5% -15%), 60 hz ; and

Single Phase 12.5 kv (+5% -15%), 60 hz.

Additional standards should be developed for the recommended overall power supply voltage regulation and associated loading conditions for trunk-line common-carrier railroads.

B) Clearance Standards

The railroad industry should adopt standards for theoretical clearances between energized portions of catenaries and wayside installations, and between energized portions of catenaries and vehicles as a function of the voltage standards listed above. This subject is also presently under active consideration in the AREA Committee on Electrical Energy Utilization.

The feasibility of development of a standard electric locomotive wayside clearance diagram should also be examined, with particular emphasis on pantograph clearances.

C) Human Factors/Safety Standards

The railroad industry should consider adopting standards for the control layout of electric motive power to promote ease of interchanging motive power. Standards should be adopted for the protection of employees and the general public from shock hazard generated by motive power and wayside equipment. Grade crossing hazards will require particular study where high voltages are involved.

ENERGY AVAILABILITY, NATURAL RESOURCES AND THE ENVIRONMENT

Energy Requirements of the Railroad Industry

Diesel fuel oil used by the railroads represents less than four (4) percent of the petroleum used for transportation purposes and less than two (2) percent of the Nation's total use of petroleum. Hence, even if as much as half of the energy now provided by diesel fuel for railroad operations were supplanted by coal or nuclear-fueled electric energy, the savings in total petroleum consumption would be less than one (1) percent. Nonetheless, railroad electrification would have a positive effect on the Nation's balance of payments by reducing the need to import foreign oil.

Energy Effectiveness

A comparison of fuel consumption for mainline railroad operations versus large diesel trucks hauling heavy-duty semi-trailers indicates that the motor carrier expends 3-6 times as much energy per net ton-mile as does the locomotive. Moving freight by rail requires less energy per ton-mile than moving it by motor carrier, air carrier and, in some cases, water transport. Total energy requirements are roughly the same for straight electric and diesel-electric locomotives under the same operating conditions.

Energy Availability and Cost

Availability of energy would be expected to be reflected in economic evaluation of electrification proposals through operation of the laws of supply and demand. However, we often find in the complex socio-economic system now prevailing that there is a lag between supply and demand tension. The future availability of diesel fuel is a source of understandable apprehension.

Until the late 1960's diesel fuel prices and electric energy prices were relatively stable, and fuel and electric energy were easily available. In the past few years, rising cost trends in both diesel fuel and electric energy have become apparent. These increases have been as great as 30 to 50 percent in some instances. Last year for the first time, some railroads had difficulty in meeting their diesel fuel needs. This difficulty is expected to increase at least in the near term.

Prospects for the availability of electric energy are more favorable than for diesel fuel because most electric power plants under development today are planned for either coal or nuclear fuel. Indications are that adequate coal and nuclear fuel resources are available to support utility generation and other requirements for several centuries. Most utilities are developing and implementing long range plans to provide for necessary new facilities and for their associated fuel requirements in the coming decades. The cost of these fuels is increasing, though not at the same high rate as is petroleum.

Among the major modes of intercity transportation of motor carrier, air carrier and rail, only railroads - by electrification - can be converted from petroleum fuel to coal or nuclear energy source. Coal resources in the United States are estimated to be enough to supply the country with sufficient energy for over 200 years.

The cost-effectiveness study conducted for this Task Force indicated that the economics of rail operations are quite sensitive to fuel costs. Major price changes in diesel fuel oil would have a significant and adverse effect on railroad earnings. Thus, two of the most compelling arguments for significant railroad electrification in the United States are the cost and availability of diesel fuel. The availability of coal and nuclear power to generate electricity to meet the additional load is not in question; however, the cost of these fuel sources as well as the cost of electric energy over the long term can be expected to increase significantly.

Utility regulatory concerns

In some instances, electric utilities have expressed concern that expansion of railroad electrification might subject them to regulatory difficulties. A number of Federal laws and regulations, chiefly the Public Utility Holding Company Act and the Federal Power Act, tend to prevent combination and joint action of utilities in certain ways. The kind of joint action necessary to serve railroads passing through the service areas of several utilities could subject the utilities to additional forms of regulation. Joint financing of catenary systems, joint service, joint billing and other activities could be involved.

While these concerns do not affect all utilities uniformly, as many are currently subject to the forms of regulation which might ensue, the matter is considered of sufficient importance in enough locations to warrant further legal research.

Noise

In conformance with the Noise Control Act of 1972, the Environmental Protection Agency is looking into the environmental impact of railroad operation. Diesel-electric locomotives produce noise inherent in reciprocating diesel engines such as noises from exhaust fans and cooling fans. Aside from diesel-engine noise, wheel-rail noise and retarder noise predominate and are common to all train movements regardless of how powered. On the whole, straight electric is quieter than diesel-electric.

Emissions

Central station electric generation is based primarily on the conversion of the energy in fossil fuels, water power, and nuclear fuels to electricity. The mix of primary energy sources varies considerably from region to region, and even among the various power supply systems within a given region. For example, power systems in the Northwest are chiefly dependent on water power, in the Northeast and Southwest they rely largely on petroleum products, and in Pennsylvania, Ohio and West Virginia, coal is the predominant fuel. In all these areas, nuclear fuels are becoming increasingly important.

Emissions from electric power plants are regulated by Federal, state and local authorities. At the present time, utilities believe they will only be able to meet 1975 emission standards for coal burning plants as set forth by the Environmental Protection Agency by burning low sulfur fuels. These fuels are in short supply, and government and industry are working to develop techniques for removing sulfur from coal, before or after combustion. Progress in this direction is promising. Presently, about half of the electricity generated by steam electric power plants in this country is generated from coal. About four percent is derived from nuclear fuels. By the year 2000, it is expected that 40-50 percent of the electricity generated in the United States will come from nuclear power plants.

Based on 0.4% sulfur fuel for diesel locomotives and 2.5% sulfur coal for electric power plants providing energy for electric locomotives, the power plant emission for the latter would exceed diesel engine emission by about 15% for equivalent operations. Of course, the characteristics of the emissions would vary considerably as the diesel engine emission is a line source and the electric engine emission is a point source at the power plant, and because the diesel engine emissions are close to ground level while electric power plant emissions provide an opportunity for dispersion of pollutants through the use of tall stacks.