Institutional and Economic Issues

Electrification and Railroad Organization and Operations

E. R. Craven, Burlington Northern, Inc., St. Paul, Minnesota

The managements of several railroads today are asking themselves whether they should consider electrifying parts of their systems. There is a lot of activity in the East designed to upgrade existing systems and possibly to add some new line segments. There are two new projects under very serious consideration. One of these is a part of the Northeast Corridor Improvement Project, which will include electrifying the line from New Haven to Boston as well as modernizing the existing electrification between New Haven and Washington, D.C. The second project under consideration is installation of modern commercial-frequency electrification of Consolidated Rail Corporation's main line from Harrisburg to Pittsburgh. We now have two separate and distinct systems, the first a high-speed passenger operation and the second one of the highest density freight routes in the United States.

What about railroads in the Midwest and West? There is nothing new except for the electrification of individual, isolated sections for moving coal. The utilities have led the way in the West in implementing cost-effective electric railroad operations. In 1968, American Electric Power Company started their Muskingum operation in southeastern Ohio. Although it is only 24 km (15 miles) long, it has been very successful operating in a fully automated mode. Next to follow was the Black Mesa and Lake Powell Railroad, a 125-km (78-mile) operation in northern Arizona. The latest electric railroads in the United States are two in eastern Texas operated by Texas Utilities Services, Inc. All of these are coal operations.

Let us consider for a moment what has caused our present situation. At the turn of the century, the United States led the world in railroad electrification. As late as the early 1930s, it contained 20 percent of the world's total electrified lines. This is certainly not so today. Less than 1 percent of the railroad trackage in this country is now electrified. A look at the rest of the world shows that, outside the North American continent, electrification has become the standard way to expand high-volume main-line railroads. The United Kingdom, Germany, France, the Soviet Union, Taiwan, South Africa, Japan, Iran, and Brazil are proceeding rapidly in many locations.

If electrified rail operation has so many advantages, why has there not been more of it in North America? Three significant factors were involved.

1. At the end of World War II, Europe had to practically rebuild its rail system. The decision was made to start electrifying.
2. In the United States at this time, there were many demands for capital to be used to catch up with the maintenance and acquisition of equipment that had been deferred because of the war. This precluded the investment that electrification required. Also, at this time, the diesel electric era was getting a good start. This permitted a conversion from steam to a modern motive power system that required only the purchase of locomotives with small support systems. It was possible to buy one and try it; then if the purchaser did not like the change from steam to diesel (and there were many who were sure it would not work), large sums of capital had not been committed to trying the new system.
3. The electric supply systems and motive power in use on early operations were not advanced enough to be competitive with the highly developed diesel electric locomotive. The dieselization program extended over several years, and U.S. railroads could not see the reason for shifting to electrification. Fuel oil was abundant and cheap, and labor costs were not prohibitive. That brings us up to the present.

During the past few years, feasibility studies have been conducted by several major U.S. railroads that are considering electrification—Union Pacific Railroad, Southern Pacific Transportation Company, Southern Railway Company, Atchison, Topeka and Santa Fe Railway Company, Illinois Central Gulf Railroad Company, Canadian Pacific Ltd., and Burlington Northern, to name a few. In my opinion, there are three major items that have caused this interest to become more active—the increased cost of petroleum fuels, the prospect of a continual shortage of crude oil for years to come, and the question of how long the supply will last. Railroads were not too concerned when diesel fuel was 2.5 cents/L (9 cents/gal). Today that cost can run between 8.5 and 9 cents/L (32 and 34 cents/gal), and there is a shortage of fuel.

There is also concern over the fact that our transpor-

tation function is basically tied to one type of fuel. We cannot convert our power plants (the diesel-electric locomotive) from oil to coal, as some utilities are currently being required to do. To my knowledge, there is no way to convert a diesel to natural gas either. For the electric locomotive, although we would like to use coal as the basic fuel, there is the full range of nuclear power, hydroelectric power, oil, and gas available to generate the energy required. It should be plain that our national policy must be reshaped to take into consideration our increasingly urgent need to develop substitute sources of energy in this country, which requires the analysis of some alternative type of basic fuel. This in turn presents an opportunity for Burlington Northern and other western railroads to give serious consideration to the conversion of part of our operation to fossil-fueled electrical energy as a prime source of power.

Some studies have indicated that diesel-electric locomotives use about 1.6 percent of the fuel consumed in the United States. In the operation of Burlington Northern, we burn in the range of 3 800 000 L (1 000 000 gal) of diesel fuel a day. How long will this be available, at any price? There are methods of converting coal to oil and gas. Pilot plants are under construction and commercial plants are on the drawing boards. When and in what amounts will they be available? What will be the cost of these fuels?

ELECTRIC LOCOMOTIVES TODAY

Let us look at what is available today in electric locomotives. Modern technology and the development of the alternating-current rectifier locomotive have made possible the use of high-voltage commercial-frequency power. This allows for a much lower cost power system because the need for special conversion equipment is eliminated. We also have a thyristor propulsion control system that features easily maintained solid-state equipment that provides smoother acceleration over the entire speed range. Another modern development is individual-axle wheel-slip control. The conventional wheel-slip control system on diesels corrects the slip by reducing the torque on all axles even though only one of them has lost adhesion. To improve adhesion or the total pulling capability of the electric locomotive, a system has been designed that corrects wheel slip on the slipping axle only, allowing the other axles to continue at full tractive effort. A final example of recent locomotive development is the use of a vacuum circuit breaker. For primary protection on the electric locomotive, a virtually maintenance-free vacuum breaker is used.

The straight electric locomotive can attain two to three times the tractive power that a diesel-electric locomotive can within the same space configuration. It requires significantly less time for servicing between runs, since it does not need fuel, water, or lubricating oil, and major overhauls are less frequent and of shorter duration. The overall maintenance cost of an electric locomotive is 30 percent of that required for a diesel. There are some 3000 wearing parts in a diesel that are not found in a straight electric locomotive, which is considered to have twice the economic life and, because of the lower maintenance requirements, has a substantially higher availability for service. The electric is not power limited. Burlington Northern is looking for a locomotive for our coal operations with power in the range of 6 MW (8000 hp). It is possible to acquire 7 to 9 MW (10 000 to 12 000 hp) if the situation requires it. The diesels are limited today to 2.7 MW (3600 hp).

What effect does this have on our organization and operations? If these figures are correct, we should be able to operate through a given territory with half the present number of locomotives. We would need fewer locomotive maintenance facilities. The number of people needed would be fewer. Operation would be improved by at least 25 percent. Both British Rail and French National Railways confirm the lower cost of electrified operation, but it is impossible at this point to convert their costs to dollars.

Burlington Northern is considering a 25 and 50-kV system. Practically all new electrification construction in the United States will be either 25 or 50 kV. Depending on the clearance restrictions a railroad is confronted with, 50 kV may have the advantage. Incidentally, it was the development of the vacuum circuit breaker that allowed the quantum jump from 25 kV and the development of a 50-kV electric locomotive. Operating at the higher voltage reduces the current required by half for the same output. Thus the catenary current rating can be significantly reduced, compared with a 25-kV system. This means that substations can be spaced further apart—65 km (40 miles)—and, therefore, that there can be fewer substations. The implied savings are obvious.

Possible side effects of electrification should also be discussed. One effect that is receiving a lot of attention today is interference to signaling and communications. The conductivity of the soil, whether it is a single- or double-track railroad, the distance between the catenary and parallel wire circuits, the length of the circuits, mutual inductance, the current and frequency of the power in the track circuit, and the design of the catenary all play controlling roles in interference. On a single-phase system, the traction current travels from the substation through the catenary system to the locomotive. The current returns from the locomotive to the substation through the running rail as well as through the ground. Magnetic and electric fields created by the single-line transmission circuit can now induce various interferences. The amount of interference created is dependent on the voltage, frequency, and current flows through the catenary system. It is important that the signal and communications engineers work hand in hand with the electric design engineers. This, of course, results in a very expensive control system and adds to the cost of electrifying. The large single-phase load that railroads will require could present some difficulties for the utility if this represents a large percentage of the load. Although preliminary studies indicate that this is not insurmountable, it nevertheless is a problem that must be looked into.

What are maintenance costs of the new support systems—the catenary, substations, signals, and communications? There is no way to make a simple comparison with the cost of maintaining an old existing plant. How many people are involved? What about replacement parts? The best guess now is that it would cost $950/km ($1500/mile) for catenary and $3000/substation/year. Until figures based on actual experience are available, these numbers should be suspect.

VOLUME OF TRAFFIC

One of the key factors to be considered in electrifying a railroad is traffic volume. Many studies and assumptions have indicated that an annual movement of 27 Tg (30 000 000 tons) would be adequate to economically justify the conversion. Naturally, there are different types of traffic. The Northeast Corridor is basically a passenger operation that requires high speeds—190 km/h (120 mph). In our section of the country, we have a lot of manifest trains traveling 95 to 110 km/h (60 to 70 mph) and, in our particular situation, heavy coal trains traveling 80 km/h (50 mph). The electric locomotive is ca-

pable of handling any of these. The Burlington Northern's initial candidate for electrification is the line from Lincoln, Nebraska, to Alliance, Nebraska. In this area, about 34 Tg (38 000 000 tons) are currently being moved annually and this could increase to more than 90 Tg (100 000 000 tons) by 1980. The number of trains could increase from 15 to 50/24-h period. This potential increase in such a short period of time is related entirely to the movement of coal out of Wyoming and Montana.

We at Burlington Northern are taking a long view and making major investments to provide an expanded efficient transportation system for western coal. This is essential to the electric utility companies because assurance of a continuing fuel supply at relatively stable prices is a critical factor in the planning of new generation stations. We have seen that the availability of low-sulfur coal can stimulate major investments in coal-fired generating plants. I do not think it is possible to weigh the outlook for the movement of coal without considering the impact that major railroad electrification programs would have on utilities.

Electrification could require substantial amounts of coal, and railroads would then indirectly become major customers of the coal industry as well as of the utilities. This would not solve all our country's fuel problems, but it would be a beginning to the railroads' answer to the energy situation. The long-term strategy is aimed at a shift away from dependence on petroleum fuels. Railroad electrification may well serve the new national energy policy in a more direct way since, at today's level of technology, electrification offers the only available opportunity to convert a significant share of transportation requirements from petroleum to coal, nuclear power, or hydroelectric energy sources. It has been estimated that conversion could be justified for 32 000 km (20 000 miles) of the country's rail system. This length of track handles approximately 50 percent of the total traffic and would require a fleet of approximately 3500 to 4000 electric locomotives. To put this in perspective, the total U.S. railroad fleet of diesel locomotives numbers about 30 000. What is the cost of this conversion? Some estimates say $10 billion.

From an energy standpoint, this produces a potential market of 72 to 90 PJ (20 to 25 billion kW·h) of electricity annually and is the equivalent of 13 to 16 Mm^3 (85 to 100 million bbl) of oil. This seems like a large number, but it represents only about 3 percent of the electric energy used in the United States and, because of the relatively high load factor of electric railroad use, only 1.5 to 2 percent of the power demand.

The cost of an electrified operation, depending on the geographical location, can vary from $55 000 to $80 000/km ($90 000 to $125 000/mile). This involves catenary, substations, and signal and communications modifications. The main solution to the inductive interference indicated above is to bury signal power cables and use microwaves for communications. Electric locomotives cost from $700 000 to $1 000 000 each. We are thus talking about a lot of money.

The benefits of railroad electrification are

1. Reduced locomotive maintenance costs,
2. Longer locomotive life (electric = 30 years; diesel = 15 years),
3. Increased reliability of service,
4. Some increase in line capacity,
5. Overload capability for acceleration,
6. More tractive effort, and
7. More stable long-term energy costs.

The drawbacks of conversion to electrification are

1. The all-or-nothing aspect of the decision entailed in the financial commitment required, particularly in the face of inflationary capital interest rates, which demands very critical and detailed examination of the operational cost factors of the overall program;
2. The high initial capital investment in facilities and locomotives required to convert a portion of the existing plant;
3. Restricted service application, since electric locomotives require catenary and support systems; and
4. The dependence of economies on a high volume of traffic.

PROGRESS TO DATE

The first electric locomotive in the United States was conceived by Thomas Edison about 100 years ago and first put on a track in 1880. The pioneering main-line project was the electrification in 1895 of a 6-km (4-mile) tunnel through the city of Baltimore on the Baltimore and Ohio Railroad Company. The locomotive used was built by General Electric in Schenectady and operated on a 600-V direct-current trolley. It had four direct-current motors and had maximum power of 805 kW (1080 hp). Within the next 20 years, more than a dozen other railroads followed suit, electrifying the tough portions of their runs to solve specific problems, such as smoke in tunnels and terminals, or to supply high tractive effort to cross steep mountain grades. The New York Central System put the S-class locomotives in service on their 600-V system in 1906. Some of them are still operating in Grand Central Terminal. The Chicago, Milwaukee and St. Paul Railway Company put 3-kV direct-current locomotives into service in 1915 to get over mountains. Then in the 1930s the Pennsylvania Railroad completed its 11-kV 25-Hz alternating-current system and introduced the famous GG-1 locomotive, of which 139 were built and approximately 100 are still operating 40 years later.

In the mid 1950s, ignitron rectifier locomotives were put in service on the New York, New Haven and Hartford Railroad Company. The significant contribution of these locomotives is that the rectifier direct-current traction motor propulsion system made practical the use of high-voltage commercial-frequency power on the catenary. Then in the early 1960s the Pennsylvania Railroad purchased 66 new 3.3-MW (4400-hp) freight locomotives that ushered in the solid-state era with the introduction of the silicon rectifier.

The utilities then led the way in applying this new technology to implementing cost-effective electric railroad operations. In 1968, the American Electric Power Company began operation of a 24-km (15-mile) coal-hauling railroad in southeastern Ohio. This was the first commercial-frequency electric railroad operation in the United States; it operates at 25 kV and 60 Hz. It is a fully automated, two-train operation in which coal is loaded into one train as the other train runs the 24 km, dumps its coal, and returns for more. No one rides the locomotives; speed and braking commands are supplied in a fail-safe manner to the locomotives by passive transponders that are mounted between the track at specific intervals along the track. The locomotives were also the first in the United States to be built with thyristor propulsion control. This system has been operating successfully now for nearly 10 years, and the trains have made thousands of automated round trips.

Another pioneering electric railroad operation was the Black Mesa and Lake Powell Railroad, a 125-km (78-mile) railroad in the desert of northern Arizona that runs from a large open-pit mine at Kayenta on the Black Mesa—altitude = 2 km (6700 ft)—to the huge new Navajo

Power Station at Page, Arizona, on Lake Powell—altitude = 1.3 km (4300 ft). The purpose of this railroad is to haul coal from the Black Mesa Mine to the power plant. The Black Mesa and Lake Powell is the first 50-kV installation in the world. The advantages of using 50 kV were overwhelming, since the number of substations required for this railroad could be reduced from three to one.

The latest electric railroads in the United States are two in eastern Texas operated by Texas Utilities Services, Inc., to haul lignite from lignite mines to power plants.

A final illustration of the significantly higher level of power possible with an electric unit and the greater overload capability of an electric locomotive compared with a diesel is found in the high-speed passenger locomotives that operate in the Northeast Corridor. These have a continuous power rating of 4.5 MW (6000 hp), with 7.5 MW (10 000 hp) available on a short-time basis for acceleration of the train. They have demonstrated a capability of accelerating a seven-car train from a standstill to 160 km/h (100 mph) in 2 min.

This may be seen as a golden opportunity but, when we realize that electrification of railroads has been in existence since 1895, our progress would have to be classified as not too great.

I would like to close with my opinion of what will happen. We will see electrification of the main trunk lines on western railroads. The economic considerations are favorable, and few will dispute the arithmetic. When will this occur? That is hard to predict. One of the key issues may well be the federal energy policy that is being put together now. We do not know what it will contain. Today we are in a wait-and-see position. When you consider what alternatives there are, it seems that railroad electrification presents one suitable means for the transportation industry to do its share in conserving energy.

Financial Considerations of Railroad Electrification

Richard Fishbein, Kuhn Loeb and Company, Inc., New York

Several years ago, the Federal Railroad Administration organized a task force to study railroad electrification in the United States. The task force was composed of representatives of railroads, equipment manufacturers, electric utilities, and trade associations and government officials. The report of the task force (1) included the conclusion that, notwithstanding the technical feasibility and operating benefits of electrification, the principal obstacles to electrification in the United States were financial considerations. In particular, the following issues were named as having influenced decisions by railroads not to electrify:

1. Investment in electrification creates a long-term obligation for a railroad and thus affects its credit standing and ability to obtain capital for other necessary improvements.
2. The long-term earnings prospects for the railroad industry in general have not appeared to be strong in recent years. This has limited the interest in long-term railroad capital investments and precluded the opportunity to take full advantage of tax incentives when making large capital investments.
3. The economic benefits of electrification occur gradually over a long period of time, but the large investments necessary to initiate the flow of benefits must occur first and over a short period of time.
4. The investment of fixed electrification facilities may become subordinate to previous railroad mortgage commitments.

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

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

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

It is clear that the railroad industry cannot possibly, with its own resources, finance such sums. During the last 10 years, capital expenditures by class 1 railroads averaged approximately $1.5 billion annually, most of which was expended on rolling stock. Only about $400 million/year was expended on roadway and structures. Electrifying the railroads would be the largest investment in roadway and structures the railroads would make since the laying of the original track in the nineteenth century.

The declining fortunes of the railroads and the diffi-