Railway Electrification and Railway Productivity: A Study Report

S. R. DITMEYER, J. R. MARTIN, P. E. OLSON, M. F. RISTER, B. A. ROSS, J. J. SCHMIDT, and E. H. SJOKVIST

ABSTRACT

Various aspects of railroad productivity that might be influenced by the adoption of electrified railroad operation are evaluated. Productivity is considered from the viewpoint of motive power, transportation economics, signaling and train control, and railway operations.

The results of a productivity study undertaken by a subcommittee of the TRB Committee on Rail Electrification Systems are presented. This seven-member group evaluated various aspects of railroad productivity that might be influenced by the adoption of electrified operation. Primary emphasis has been placed on productivity improvements that might be anticipated with electrification of heavy-density main-line freight railroad operations.

Each member of the subcommittee has been involved in one or more North American main-line railroad electrification studies in the United States or Canada. In addition, each member of the subcommittee has been actively engaged in studies of electrification economics and is familiar with both North American and foreign electrification developments. A compilation is presented of recent U.S. and foreign electrification study results and experiences that relate to specific aspects of railroad productivity of diesel and electrified railroad operations and economics.

Railroad productivity is addressed from the point of view of motive power, transportation economics, signaling and train control, and railway operations.

BACKGROUND

During the four decades since World War II, while the major railroad administrations of Europe and other continents undertook to convert their rail lines to electrification, the United States has in fact steadily reduced the number of miles of freight operations conducted under electrification. The only new freight railway electrifications in North America have been either on short-line captive railroads or, just recently, on the somewhat special Tumbler Ridge Project in British Columbia, Canada. This last project, which connects directly with existing rail lines, does not have sufficient operating experience to provide any useful answers to the serious questions of the effect of railway electrification on operations and economics. Further, the short-line captive electrified railroads are too limited in the scope of their operations to serve as models for drawing valid conclusions about the effects of electrification on the subject being considered.

The dilemma facing the railway planner is that he must study the overseas experience, identify those aspects of such electrified lines that differ from diesel operation solely because of electrification, and then construct hypothetical models of known railroad operations in North America, incorporating the operating concepts gathered from this overseas study. At best, the result is a mental simulation of a railroad operation to which untested principles are applied and for which no opportunity exists to validate any part of the so-called model. When the model results are evaluated, it is necessary to distinguish carefully between true effects of electrification and consequential effects that are brought about primarily because a new, unconstrained look is taken at the railroad operations. In recognition of the lack of U.S. experience in new main-line railroad electrifications, with the exception of commuter and passenger operations, this paper is generally based on foreign operating experience, principally in western Europe, South Africa, and the Soviet Union, and on U.S. railroad electrification studies that have been carried out during the past two decades. In some instances even though the subject studies may initially have been performed in the late 1960s or early 1970s, they have been continually updated to reflect changes in equipment characteristics and improvements in electrification technology.

For purposes of this evaluation the term "railway productivity" has been defined in a broad sense to include effective utilization of capital, reductions in operating costs, savings in manpower, reductions in environmental impacts, and improvements in railway operations.

MOTIVE POWER CHARACTERISTICS AND COSTS

The electric locomotive and the diesel-electric locomotive have provided the subject matter for countless technical papers comparing their characteristics, capabilities, and economics (just as decades ago the electric locomotive and the steam locomotive did). A review of these comparison papers quickly establishes in the reader's mind the fact that published material presents in most instances an advocacy of one of the motive power alternatives rather than a comparison. A further complication in the appraisal of motive power characteristics, performance, and costs is the widespread adoption of the electric locomotive for high-traffic-density lines in western Europe, the eastern European countries, Asia, and South Africa and its almost universal rejection for such service in North America.

Locomotive Unit Horsepower and Tractive Effort

The most notable of the electric locomotive characteristics is that, rather than being a converter of new energy--in the form of diesel fuel or coal--to mechanical energy at the wheel-rail interface as are the diesel and the steam locomotive, the electric locomotive is a converter of externally supplied electric energy to mechanical energy. This permits an electric locomotive to develop much higher horsepower for a given size or weight than a comparable diesel-electric locomotive. When electric and diesel-electric locomotives are compared, it is important to have a clear understanding of tractive effort and power capabilities. An electric locomotive has no capability of providing higher maximum tractive effort than a diesel-electric locomotive of equivalent weight on drivers. An electric locomotive's maximum tractive effort is limited by adhesion between the locomotive wheels and the track. This assumes that both types of locomotives have good wheel-slip systems, and experience has shown that acceptable wheel-slip control can be achieved on both electric and diesel-electric locomotives.

The electric locomotive's ability to draw high horsepower from the catenary system (in some instances up to twice as much per unit for short periods) may be a significant asset in certain operating circumstances. In effect when a train is started or when a train is accelerated after a speed reduction or when an existing speed is maintained as grade increases, the electric locomotive can deliver outputs substantially in excess of its nominal horsepower rating. The diesel locomotive cannot match this short-time performance because of the lack of such horsepower overload capability in its diesel engine.

Further, the electric locomotive can be designed, as a general rule, to deliver for the same weight and size unit from 50 to 100 percent greater nominal horsepower than a comparable diesel-electric. In certain operating circumstances, such as very long grades, this can be a valuable asset.

How can this greater unit horsepower characteristic of the electric locomotive be exploited to contribute to railway productivity? In subsequent sections of this paper the advantages of high unit horsepower will be considered from the viewpoint of locomotive cost, railway operations, and overall railway economics. In each of these areas higher unit horsepower should, in many instances, be able to enhance railway productivity.

Motive Power Unit Initial Cost

Locomotive unit cost comparisons must be considered from the viewpoint of both unit tractive effort and unit horsepower. When cost is considered, it should be recognized that current North American electric locomotive costs are based on a limited number of deliveries. It seems reasonable to anticipate some reduction in electric unit costs as electric motive power comes into common use, spreading production and research costs over a larger product base.

Current North American costs for the same continuous tractive effort unit indicate that the cost of the electric locomotive (based on recent sales and quotations) may be estimated at 1.5 to 1.7 times the cost of a comparable diesel-electric unit. On the basis of nominal horsepower unit ratings, the electric unit is estimated to cost 50 to 80 percent as much as a comparable diesel-electric unit.

It must be realized that actual locomotive prices may be materially influenced by specific customer requirements with respect to locomotive characteristics, numbers ordered, and prospects for future orders. These cost comparisons, however, should provide input to the question whether electric locomotive units initially cost more or less than comparable diesel-electric units.

Maintenance Costs

For several reasons, it has always been difficult to get a fair comparison between the specific maintenance costs (cost per year per locomotive, cost per unit mile, or cost per ton-mile) of diesel-electric and electric locomotives. Railroad administrations in various countries use different accounting systems. Costs of material and, in particular, labor vary considerably between different countries. The productivity of maintenance personnel depends on the facilities used, and the investment that can be justified for these facilities is very much a function of the number of locomotives to be maintained and the degree of standardization of locomotive models and their main components. The impact of changes in design on maintenance cost of electric locomotives in France has been shown by Gautier and Blanc (1) and by Nouvion (2). The utilization of the locomotive in different types of service also has a great impact on the maintenance cost. Finally, the quality achieved by the locomotive manufacturer plays a significant role.

For these and other reasons, no fair comparison can be made directly between maintenance costs obtained from different countries. Second, a comparison between diesel-electric and electric locomotives in one specific country is likely to be less reliable if the number of diesel-electrics is very small compared with the number of electrics, or vice versa. Therefore, the following countries have been excluded from a direct comparison: United States (very few electric locomotives), Canada (very few electric locomotives), Germany (diesel locomotives mainly diesel-hydraulic), and Switzerland (very few diesel-electric locomotives). Countries that, at least to a degree, meet the requirement of operating a sufficient number of both diesel-electric and electric locomotives include the USSR, South Africa, France, and Sweden.

Statistics related to specific maintenance cost are usually expressed in one of the following ways:

1. Cost per locomotive unit mile in a year,
2. Cost per unit of transportation work (e.g., gross ton-miles in a year), or
3. Cost per unit of rated output, for example, engine rating (gross or available for traction) or output at rail.

It is extremely important to compare maintenance costs only as they are related to the same definition. Because diesel-electric and electric locomotives generally do not use the same power output definition, the third type of statistics should be disregarded. Maintenance costs related to the first type are common but do not take into account the actual transportation work produced. Therefore, only the second type of statistics gives a fair comparison.

Various publications (1,3-7) describe in some detail the maintenance procedures for electric locomotives in Great Britain, France, Sweden, and Switzerland without comparing them with diesel-electric locomotives. Horine (8) attempts to show how the maintenance cost of rather old American locomotives varies with the age of the locomotive. The rest of the references may be classified into two groups:

(a) studies based on certain assumptions and (b) statistics from experience on railroads.

Category a includes the following. In 1974, Cogswell et al. (9) reported to the American Railway Engineering Association (AREA) that the maintenance cost for an electric locomotive per gross ton-mile hauled would be about 30.2 percent of the corresponding cost for a diesel-electric locomotive as an average. The range would be between 25.8 and 48.1 percent depending on a number of site-specific factors. Ephraim (10) estimated in 1977 that the ratio would be about 60 percent per annum in heavy-duty freight service but might be 30 percent or less in lighter freight operations. For the electrification of the main railroad on the Italian island of Sardinia, Mayer (11) estimated in 1982 that the ratio per ton-mile would be 20.2 percent.

Statistics from actual operations of diesel-electric and electric locomotives include the following. In the Soviet Union a report by Rakov in 1975 (12) gave statistics for 16 years of operation showing that the ratio for diesel-electric/electric locomotive maintenance per ton-mile had varied for individual years between 35.6 and 49.4 percent with an average of 43.1 percent. In 1976, Serdinov (13) reported that the ratio per unit mile was 55.6 percent. If only labor maintenance cost was considered, the ratio was 57.4 percent.

For South Africa, Wade in 1968-1969 (14) and Gosling in 1977 (15) have both reported that the ratio per unit mile was 25.6 percent and per ton-mile it was less (no figure quoted).

In France, Nouvion reported in 1971 (2) a ratio of 55.6 percent per unit mile and 33.3 percent per ton-mile. Three years later he gave a ratio of 32.7 percent per ton-mile (16).

Harley et al. reported in 1973 (17) for Sweden that the ratio was 42 percent per unit mile and 18 percent per ton-mile, and Salomonsson in 1982 quoted 25.4 percent per unit mile and 14.0 percent per ton-mile (unpublished data).

Although Great Britain and Japan do not meet the requirements for a fair comparison specified at the beginning of this section, the following statistics may be of some interest. Wade stated in 1968-1969 (14) that in Great Britain the ratio per unit mile was 28.9 percent, whereas Calder in 1977 (18) said that it could vary between 32.8 and 45.5 percent depending on what locomotive models were compared.

For Japan, Wade's ratio (14) was 48.8 percent per unit mile, whereas Mizuno in 1982 (19) quoted a ratio of 37 percent per unit mile.

In conclusion, experience has shown that the ratios for maintenance costs (electric/diesel-electric) fall within the following ranges: 25 to 56 percent on a unit-mile basis and 14 to 43 percent on a ton-mile basis.

Availability

It is a recognized characteristic of electric locomotives that they can be turned for dispatching more quickly than diesels because they require less servicing. There is no need to move to a fuel station for refueling. No lubricating oil must be added; no oil samples need be taken to evaluate diesel engine condition; no cooling water is required. The only periodic servicing necessary is to refill sanding bins and to check brake shoes. These last two items are shared with all diesel locomotives.

If the time needed for heavy overhaul is subtracted from the theoretical 100 percent availability of maintenance-free locomotives, the actual availability of diesel-electric locomotives in North America is about 84 percent; that is, they are not available 16 percent of the time. If the regular servicing (mainly refueling) takes 6 percent of the time, some 10 percent is needed for some kind of maintenance work on a diesel-electric locomotive. For an electric locomotive, the 6 percent for refueling disappears, and a conservative estimate of the time spent on maintenance work would reduce the 10 percent for the diesel-electric to about 6 percent for the electric locomotive. It is estimated that maintenance- and servicing-related availabilities are approximately 84 percent for diesel-electric locomotives and 94 percent for electric locomotives.

In specific cases--and this will be true of most rail operations able to justify electrification--the reduced terminal-to-terminal times possible with electric motive power can make a further contribution to electric motive power availability. If a train can be moved over the railroad in reduced running time, it follows that its locomotive is available for reassignment more frequently in a given length of time. However, because this availability factor improvement is specifically related to railway operations, it is not possible to estimate its effect on a generalized basis.

Shutdown Capability

Some expense and reduced wear benefits may be anticipated from the ability to shut down either the entire electric locomotive or a major portion of its overall system during periods of no demand, waiting, servicing, maintenance, or train delay. This shutdown capability translates into a not inconsequential reduction in energy consumption and engine running hours, which the diesel locomotive normally experiences during its long periods of engine idling operation.

LOCOMOTIVE MAINTENANCE AND FUELING FACILITIES

Electrification has the potential to reduce the number of units operated, reduce maintenance cost per unit operated, and reduce costs associated with locomotive fueling and servicing facilities. Savings may be realized in locomotive maintenance and fueling facilities and related manpower when a high percentage of traffic is electrified and a considerable amount of electrified route mileage has been attained. This saving will be a function of the percentage of diesel-electric-related facilities that have to be retained to meet the requirements of switching and light-traffic-density line-service motive power. In most instances electrification of such operations is not feasible.

Locomotive electrical maintenance force and facility requirements are comparable for electric and diesel motive power fleet operations. The traction motors are similar and require similar shop skills and machinery. Control systems are comparable in complexity as are power conditioning systems. The main generator-alternator of the diesel locomotive is replaced by a transformer, which requires very little shop maintenance. Auxiliaries in many cases are identical, but in overall count the advantage lies with the electric locomotive; there are fewer and less complex cooling systems, pumps, blowers, and filters.

With respect to locomotive mechanical system-related maintenance facility and manpower requirements, the diesel engine, associated fuel tank, lubricating oil system, and engine cooling system are completely eliminated. This implies that a considerable reduction may be possible in the number of shop craftsmen, such as machinists and skilled engine mechanics. Also, the requirements for major diesel engine rebuild facilities will be significantly reduced, although travel mileage to and from rebuild facilities may increase unless diesels are worked en route.

To the dieselized railroad, capital costs and operating expenses associated with locomotive fueling stations are not inconsequential. Among these costs are such elements as the cost of the fueling facility itself, including fuel storage tanks, pumps, nozzles, filters, and meters; fuel inventory costs; spilled fuel and waste water collection and treating facilities; engine cooling water treatment and dispensing facilities; lubricating oil storage and dispensing facilities; and transportation of fuel and lubricating oil to fueling facilities. To the extent that electrified operation permits the elimination or reduction in size of fueling facilities, some savings may be anticipated.

The saving in maintenance and fueling facility investments and operations will be very much route specific and will be materially influenced by the percentage of rail operations that may be electrified. Further, it must be recognized that these savings will be of a long-term nature and that these costs in the initial stages of electrification may actually increase because of the requirements for new electric-locomotive-related facilities before it is possible to reduce or eliminate diesel maintenance and servicing facilities.

ENERGY COST AND AVAILABILITY

The cost and availability of diesel fuel as compared with electric energy is a major factor in the decision to adopt electrified railway operation. Because the electrification decision is a long-term one influencing the manner of railway operation for many decades, current and assumed fuel conditions in most instances play a major part in the electrification decision. National concern over oil availability and prices has been a major factor in the decision of many railway administrators in western and eastern Europe, Asia, and Africa to adopt electrification.

Although diesel fuel prices have stabilized and actually declined during the 1980-1985 period, the basic long-term picture of oil resources versus supply remains unchanged. Also, it must be recognized that the world economic and market pressures that have stabilized and then reduced the price of oil-based fuels are subject to change because of international, economic, or political conditions.

Most energy economists anticipate that both electric energy and oil costs will increase at rates related to, but somewhat higher than, the overall inflation rate. Further, the rate of electric energy increase will be from 1 to 3 percent lower than that of oil. Although oil is today in oversupply, it is well known that the exploratory drilling and development of identified fields, both domestically and worldwide, is today at a very low level. Further, the members of the Organization of Petroleum Exporting Countries (OPEC) and probably other exporting nations will, to the extent that their economies permit, endeavor to change the current supply-demand situation.

Because of the indeterminate nature of future fuel availability and costs, North American railways face the problem of making a decision with, in many instances, the most important variable in the economic equation--the electric energy-diesel fuel price differential--for practical purposes almost indeterminate. This situation is further complicated by the lack of a clearly defined and legislated national energy policy in the United States.

Two recent North American main-line railway studies of the Southern Railway and the Missouri Kansas and Texas (MKT) Railroad have indicated substantial fuel cost savings even with present fuel price relationships--$16 million per year for Southern railway and a 25 percent reduction in fuel costs for MKT.

Although electrification in most instances will require substantial investments in signaling system modifications, these modifications, if an innovative approach is adopted, may present in themselves unique opportunities for increased railroad productivity.

In recent electrification studies, the cost of signal reconstruction and interference correction has been estimated at slightly greater than $100,000 per route mile, an amount equal to about 43 percent of the cost of the catenary alone, or 23 percent of the total cost of an electrification project. This reconstruction leaves the owner with a signal system that is no worse than the one before electrification but one that is no better.

A great deal of work is now taking place on new concepts in fully integrated railroad command, control, and communications systems (C^3 systems) to replace the current signaling and communications systems. The new C^3 systems are based on modern avionics technology and have sufficiently low costs and high benefits that it is extremely likely that they may substantially supplant conventional signaling and communications systems within the next 10 to 20 years.

All current systems are based on fixed blocks, which have been the standard since the first railroads were built 150 years ago. Telegraph wire lines were first put into service 145 years ago, electric track circuits 115 years ago, electric wayside signals 80 years ago, and central traffic control (CTC) 50 years ago. Even the most modern CTC system still uses wire line and cabling to send control instructions to wayside cabinets that contain the relays to control the wayside signals that control the movement of trains over the fixed blocks. All those elements--wire line and cabling, wayside cabinets, wayside signal, fixed block track circuits--require expensive modification and shielding if they are to be used on an electrified line.

The new C^3 systems will do away with all those elements. Train control instructions can be sent directly to locomotive cabs via digital data links instead of wayside signals. The instructions will appear on a CRT or as hard copy from a small printer. Precise train location and speed will be determined with a receiver set on the locomotive that receives signals from navigation satellites, and the location information can be sent to the dispatcher and other trains via the data links. The trains will no longer require spacing at fixed block intervals; instead, moving or dynamic blocks surrounding each train will permit a significant improvement in route capacity. The data links and satellite receiver sets will operate at frequencies far removed from that of the electrification and thus will be compatible without major reconstruction costs.

Because the new C^3 systems will have no wayside signals or wayside cabling, their costs will not vary with mileage but rather with the number of trains being operated. However, for comparison purposes, a new C^3 system on a moderately trafficked line with signals is estimated to cost less than half that of a new CTC system.

The benefits of a new C^3 system--improved safety, increased route capacity, lower capital and maintenance costs, potentials for fuel savings, and so on--will occur whether or not a line is electrified. However, once a C^3 system is installed, the cost of electrification could be reduced by nearly one-fourth because many components of the train control protection system would no longer have to be reconstructed or shielded to be compatible with electrification.

ELECTRIFIED RAILWAY SUBSTATION AND CATENARY SYSTEM

The electrified power delivery system must be included in any balanced appraisal of electrified railway productivity. The substation and catenary system represent a capital investment of from $150,000 to $200,000 per electrified track mile, the carrying charges on which must be paid from savings due to electrified operations. Further, the catenary system and substation facilities (if substations are railway owned) will require the organization of a dedicated maintenance force with dedicated depots, vehicles, and other necessary equipment, owned by either the railroad or a contractor.

On foreign electrified railway operations, annual catenary maintenance costs have been in the range of 2 to 4 percent of capital investment. It does not appear unreasonable to anticipate a comparable cost for North American operations.

RAILWAY OPERATIONS AND ECONOMICS

Although, as stated in the introduction, this paper places primary emphasis on main-line freight railroad electrification, the operational and economic benefits to commuter and passenger service productivity will also be addressed. The analysis of each operation includes references to the previously cited motive power and facility characteristics as they may apply to the overall railway operations.

Passenger Service

The greatest single implication of electrification for passenger train operations is attributable to the characteristics of the electric locomotive. The full-time and short-time high horsepower ratings possible in a single electric locomotive greatly surpass what is probably attainable in a single diesel locomotive of comparable weight. It is highly unlikely that a lightweight four-axle locomotive can be built in the United States with a diesel engine rated at more than 4,000 hp. On essentially the same chassis, an electric locomotive can easily be rated at 7,000 hp for continuous duty and at approximately 10,000 hp for short-time duty, as when accelerating after a station stop or following a track slow order or other speed restriction.

This ability to accelerate a passenger train to top track speed is very important in reducing overall running time. It is much more cost-effective and easier to achieve a reduction in total running time by such means than to make track modifications that would permit a higher maximum speed. To a great extent, this short-time power rating can partially offset the need for permanent track realignments that would serve only to reduce some permanent speed restrictions.

The stream of economic and productivity benefits that flows from this characteristic may be summarized as follows: better utilization of passenger cars and locomotives; higher track capacity; higher top speed capability and shorter travel time, thus improving marketing appeal; reduced track maintenance for a given top speed because of lighter-weight locomotives; and faster turnaround time for electric locomotives, leading to a smaller locomotive fleet.

Commuter Service

The principal productivity improvement in commuter rail operations attributable to electrification lies with the high, short-time, power-overload capability of electric traction. Because the traction horsepower is not limited by any on-board prime mover, the power available to accelerate the commuter train after a station stop is limited by the thermal capacity of the traction motors and related electric power conditioning apparatus. The power supplied by the catenary can readily support a temporary 50 percent increase in electric traction horsepower drawn by a commuter train during acceleration.

In many instances, the electrified multiple-unit train may offer the most economical alternative for frequent-stop, high-traffic-density commuter operations. The multiple-unit train, having distributed traction power, can achieve great operating flexibility with respect to the size of the train. The length of the train can be readily converted from two to six cars, for example, with no loss in performance with regard to top speed or acceleration. This flexibility might not be available as readily and economically if a given electric locomotive were assigned to various consist lengths of trailer cars.

Freight Service

If railroad electrification is to develop on a significant scale in North America, it must provide measurable productivity improvements in freight operations on heavy-traffic-density main lines. Experience in Europe and South Africa indicates that train weights and speeds comparable with those of North America can be handled economically and efficiently by electric motive power. Numerous examples of such operations can be cited in the USSR, Poland, Sweden, Germany (both East and West), South Africa, and other countries. An application of the previously cited electrification productivity factors to an actual railway operation, comparing electric versus diesel operation, follows.

Railway Characteristics

To consider the economics of straight electric versus diesel-electric in a freight service operation, some assumptions must be made about the operating environment, type of service operated, and physical characteristics. Any saving (i.e., productivity improvements) incurred results from certain combinations of these factors.

First, the line must have high traffic density. This is a necessity because the basic property of an electrified operation is that of a high initial capital cost, which is recovered by future savings or improvements in motive power costs, fuel expense, and rail operations. In order to recover these expenses, the saving per train mile operated must be at least equal to all electrification-related costs and investment carrying charges.

Next, the line must allow a relatively high rate of speed to be maintained. In this regard, the curvature must be light enough to allow minimal reductions from timetable speed. Gradient is of less importance than curvature reduction, and in this respect, Southern Railway's Cincinnati-Chattanooga-Atlanta line is a prime example. Most sharp curves and some major grades were both eased and relocated in the 1960s. Today, this line permits freight train speeds of 50 mph and TOFC train speeds of 60 mph.

The blend of traffic, especially a mixture of freight and passenger traffic, can provide opportunities for high locomotive utilization, assuming that servicing and turnaround times are rapid enough to fit frequent schedules. Also of prime importance is the requirement for a balanced, two-way operation. If locomotives must be deadheaded back to be in place for a mostly one-way operation, then operating and investment savings are rapidly lost.

Assuming a major trunk line with these characteristics running through mountainous terrain with the modern curvature alignment that is becoming prevalent as 100-year-old roadbeds are improved, economic results in terms of operating productivity will be examined.

The fundamental benefit would be in fuel cost savings per train mile operated. An evaluation at each individual substation location to determine the price per delivered kilowatt-hour may not be possible in a generalized study, but it is assumed that the rate to be paid for electricity will be relatively constant and vary with time of demand. If electricity rates are higher during peak periods, railroads may find frequent scheduling in peak power demand (and thus peak rate) periods unavoidable.

Further, assuming that sufficient tonnage is available to be moved in both directions, with a reasonable mix of foreign, originated, and terminated loads, the amount of electric energy used (in lieu of diesel fuel) will return a significant saving to the railroad, based on the Southern Railway and MKT Railroad studies. Unless utility rates become appreciably higher (or diesel fuel costs substantially lower), it must be assumed that electric locomotives will haul the same tonnage at a lower variable cost per mile. Where grades require a higher ratio of horsepower per ton, electric locomotives will cost less in fuel and variable maintenance expense at all traffic-density levels. When the cited conditions exist, the saving will increase directly in proportion to ton-miles hauled.

Electric locomotive costs now average about 1.66 times those of comparable diesel units. The cost differential may be reduced as electric motive power comes into common use, spreading production and research costs over a larger product base. Even if there is little change in this cost differential in the near future, the available horsepower--nominal and short-time--of the electric unit is greater than that of diesel with the advantage that fewer units are required. A factor that may mitigate this advantage is that the diesel-electric has made great progress in increasing rail adhesion up to 24 percent, and state-of-the-art electric units may be losing the unit-for-unit tractive effort advantage. North American electric locomotives are also rated currently at 24 percent adhesion. However, the electric units can be concentrated in fast, main-line through freight or limited pick-up and set-out service, where their higher unit horsepower and lower energy and variable costs can provide maximum savings.

Considering a moderate reduction in through locomotive units, a second source of savings can come from faster turnaround due to minimal servicing and inspection time requirements. Because there is no fueling and no internal power plant to adjust and monitor, minor cleaning, sanding, and inspection will allow the units to return to service sooner. This will allow them to remain in revenue service a greater number of hours each year and could reduce the total number of locomotives required in the fleet.

Fewer road failures because of the inherently simpler electric motive power will be another benefit. If this is coupled with improved over-the-road time (depending on the gradient and speed restrictions on the line), an additional reduction in the number of units required can be effected. This benefit will exist mainly where service is frequent enough to require motive power as soon as it is available.

Future energy source reliability, both in availability and price, must be a consideration. Currently, the unstable Middle East situation could cut off a major source of world oil supply with one adverse move. Even with North American oil reserves and a deregulated market, there is no guarantee of a constant diesel fuel supply for rail transportation. Further, it appears safe to assume significant diesel fuel price increases during any oil crisis. The supply of electric power tends to be more stable, and although the price is steadily rising, it is probably more predictable for long-range planning. On the average, it is concluded that the fuel cost per train mile will be more favorable with electricity. The Southern Railway estimated in 1983 a fuel saving of $16,000,000 per year if they electrified the Cincinnati-Atlanta route. This figure was based on a 4.10¢/kW·hr and a 90¢/gal energy price. It is reasonable to use the kilowatt-hour fuel bill as constant with cost increases related to general inflation in planning for 5 years or more, whereas there will be more fluctuation and thus another element of risk when future diesel fuel expense is estimated.

Freight Train Operating Productivity Improvements

The relationship between the revenue earned and the amount expended to earn that revenue is the basic operating efficiency measurement that is generally monitored in rail operations. This measurement, known as the operating ratio, is extremely sensitive to variations in train movement expenses, rate changes (and thus revenue changes), or any combination of the two. Fuel and locomotive costs to move a train have increased to the point where they represent more than half the total cost of moving a train. The size of the train crew will generally not be affected by electrification. Railway planners and managers must continue to make strenuous efforts to hold the line on increasing motive power costs.

The maintenance of a locomotive fleet for moving trains represents a significant fixed cost. Although much of this cost is examined under shop and field handling considerations, the ability to reduce servicing and inspection time with electric units will contribute to a higher locomotive availability rate. Because freight cars also incur costs as a function of time, any incurred car cost attributable to locomotive servicing can be reduced with electric locomotives because of reduced unit turnaround or servicing time. In a prior assumption it was stated that the line segment has a sufficiently high traffic density to require fast locomotive turnaround with crews in place and ready for duty.

Reliability is related to locomotive servicing, both in terminals and on the road. Electric locomotives have fewer moving parts to wear and to require lubrication and therefore will inherently incur less down time than diesels. Car-hire costs in and between terminals decrease as delay is reduced, and train crew costs likewise drop with fewer on-road breakdowns. Beyond this direct savings, train delay has a domino effect on the line segment operation because other trains are delayed awaiting these locomotives or connecting cars. Further, trains meeting the delayed train are likewise delayed. Southern Railway currently averages a $260/hr cost for through freight train delay, so it is evident that these costs can represent a significant portion of the operating expense.

On certain line segments, speed restrictions and grades slow the operation of diesel-powered trains. Electric locomotives have an ability to accelerate more rapidly following a speed restriction and can maintain a relatively more constant speed over grades because of their higher short-time and nominal horsepower ratings. This advantage may be reduced if the line segment is basically level without speed restrictions, but in much of the terrain having potential for electrification, this advantage may exist to varying degrees.

This improved train-handling capability will be especially important when there is a mixture of freight and passenger trains. Improvements in freight train accelerating capability can contribute significantly to reducing potential conflicts with the shorter, faster passenger fleet or with high-speed freight trains.

In instances where electrification makes possible a faster, more reliable over-the-road operation, the potential exists for tapping previously hard-to-reach markets. Although much rail traffic is in the bulk-commodity category related to the "smokestack" industries, recent years have seen a decline in this transportation market. If railroads can reach other markets, they can retain a high degree of plant utilization. However, much of this new traffic is highly competitive, and service must be reliable because shippers are now leaning toward "just-in-time" delivery. Considering the narrow profit margins available, railroads will secure this market only through increased reliability, lower operating cost, and competitive door-to-door delivery times. Although electric locomotives are not the sole answer, they can, in selected locations, contribute to reduced locomotive costs, increased on-time ratios, and decreased over-the-road times needed to compete for this traffic.

Operations will also benefit from better train control and handling with electric locomotives. Possibly greater tractive effort at the rail and higher horsepower available to the engineer, together with reliable regenerative braking, make consistency of train operation easier to obtain. This can make progress toward more balanced trains in opposing directions. Currently, track superelevation on curves must compromise between the highest train speed and that of the slowest train, generally upgrade. Any ability to speed up the slower trains will reduce this imbalance and could possibly allow somewhat higher speeds in some locations where the tonnage or upgrade train speed can be significantly increased. This more constant train speed can significantly benefit track maintenance. Where train speed imbalances on curves exist, the slower trains tend to stress the inside rail because the high center of gravity of today's cars transfers the majority of car weight to the inside wheel. Further, where track and train speeds are inconsistent, the potential for derailment due to track deterioration is much higher. The outside rail on these curves is subjected to high wheel wear on the gauge side, which could be reduced if a better match between superelevation and train speed were possible. Needless to say, more consistent train speed will lead to longer rail life, which considering the present price of premium or hardened rail, can represent a significant indirect cost saving.

Mentioned earlier was the high cost of car hire. Although much of this cost is mileage related and will remain constant regardless of a 5-mph or 50-mph train speed, roughly one-third of this cost may relate to time. In that case, the railroad operation must be scrutinized to determine any savings. Passenger operation generally has captive cars that remain within a fixed-charge category based on the trip more than on the hours. In freight operation, many routes may concentrate only home road and privately owned cars, and thus no saving is possible, but in other cases, the hourly charge paid to foreign car owners can be reduced with faster transit times and more reliable schedules made possible through use of electric locomotives.

The potential to handle traffic increases with little additional investment is present with the electric locomotive alternative. Shorter track occupancy times due to faster turnaround times, more reliable locomotives, and faster over-the-road schedules (where possible) can allow the handling of traffic increases without additional locomotive purchases or the construction of additional tracks. This characteristic is railroad specific, but in many instances where the line segment is near saturation, an improvement in train service can be an alternative to increasing the physical size of the plant.

Fuel Handling, Shop Facilities, and Environmental Impacts

In the days of steam locomotives, railroads established fueling and watering points where needed along their route, as well as both minor and major repair facilities. This is still true for the diesel-electric, although these points are not nearly so numerous. Fueling points remain every 100 to 150 mi, although through trains ran 300 to 500 mi between fueling. Electric locomotives do not require refueling facilities nor the handling of lubricants, and if an all-electric operation is contemplated, the potential exists for significant servicing area savings.

Activities related to the purchasing and shipping of lubricants and fuels can be reduced, as can the ownership of fuel cars along with their associated switching and handling costs. Storage tanks can be eliminated and personnel reduced to that required to comply with Federal Railroad Administration (FRA) inspection laws and the minor repairs required by electric locomotives. Locomotives would not have to be cut off from their trains and run to the fuel racks, which in turn could eliminate unnecessary yarding of the train. Southern Railway has this problem on continuous unit coal trains and has had to construct main-line fueling facilities solely for these trains.

Inventories of fuel and lube oil can be greatly reduced. Significant funds could be tied up in the large inventories of these supplies. Further risks related to the speculative nature of purchasing an item subject to such price fluctuations can be reduced. Metering and control of diesel fuel can be eliminated along with the possibility of theft.

These savings will accrue to a maximum extent only in the case of 100 percent electrification with total elimination of diesel locomotives. Most Class I railroads will never do this and will want to have the flexibility of running local and certain other trains with diesel power even though they operate in electrified territory. This decision will mean that some diesel fueling facilities will still be necessary. Selective studies may identify those facilities that may be eliminated, but the major savings will only come about through reduction in size, staffing, and supplying of the remaining locations.

Any reduction in the use of fuel oil will reduce risk of both pollution and penalty fines. Sources of oil spills are attributable to locomotives in derailments, damage to company oil tank cars in transit, spillage during refueling, and loss of fuel from storage tanks or transfer lines. All fueling facilities today must have elaborate containment systems to control any spills. To quantify these savings would require in each case a determination of the level of remaining diesel operation to identify the reduction in fueling apparatus, tanks, personnel, and fuel handling.

Electric locomotives have a repair expense estimated to be 40 to 80 percent (depending on the U.S. railroad considered) of the repair costs of a diesel unit. The possibility also exists to lower fixed expenses through the reduction of major repair installations brought about through the reduced maintenance requirements of the electric locomotives. The greatest benefit would accrue to the 100 percent electrified railroad, whereas rail systems maintaining a percentage of diesel operation still would need some diesel-related facilities.

Southern Railway, in its 1983 study to electrify the line from Cincinnati to Atlanta, estimated that no shops would be closed because of numerous diesel-operated intersecting lines and that initially one shop for electric units would have to be constructed at a cost of $16.5 million. Each railroad operation appears to be case specific, with the major savings incurring to railroads achieving near 100 percent electrification.

CONCLUSION

Electrification offers an opportunity to substantially improve the productivity and transport capability of North American heavy-traffic-density, high-speed main-line railways. Electrification has compiled a worldwide record in meeting rail transportation requirements efficiently and economically. The electric locomotive's higher per-unit horsepower, greater availability, longer life, lower maintenance costs, and lack of dependence on petroleum fuels enable electrification to provide railway planners and managers with a proven technology for improving current and future railroad productivity.

REFERENCES

1. P. Gauthier and A. Blanc. The Impact of Electric Locomotive Design on the Organization of Maintenance. IEE Conference Publication 50, 1968, pp. 251-297.
2. F.F. Nouvion. Electric or Diesel Traction: The Right Basis for Comparison. Railway Gazette International, Vol. 127, 1971, pp. 377-380.
3. A.H. Emerson. Operational Experience and Maintenance of Electric Locomotives. Journal of the Institute of Locomotive Engineers, Vol. 53, No. 296, Paper 652, pp. 727-836.
4. H. Lilljeqvist. Über den Unterhalt der elektrischen Triebfahrzeuge der Schweizerischen Bundesbahnen. (The maintenance of electric traction vehicles at the Swiss Federal Railways.) Elektrische Bahnen, Vol. 45, 1974, pp. 31-39.
5. B. Marklund. Reliability Analysis and In-Situ Testing Augments Programmed Maintenance. Railway Gazette International, Vol. 136, 1980, pp. 775-777.
6. E. Meyer. Maintenance of Electric Locomotives and Railcars as Carried Out by the Swiss Federal Railways. IEE Conference Publication 50, 1968, pp. 32-44.
7. F.F. Nouvion. Design of New Motive Power for Ease of Driving and Maintenance. IEE Conference Publication 50, 1968, pp. 298-344.
8. J.W. Horine. Electric Locomotive Maintenance Cost Equation. Applications and Industry 50, Sept. 1960, pp. 233-236.
9. R.U. Cogswell et al. Electrification Economics. AREA Proceedings 75, Jan.-Feb. 1974, pp. 642-656.
10. M. Ephraim, Jr. Maintenance and Capital Costs of Locomotives. In Railroad Electrification: The Issues, Special Report 180, TRB, National Research Council, Washington, D.C., 1977, pp. 13-15.
11. L. Mayer. L'Electrificazione della Linea Dorsale Sarda (The Electrification of the Main Railroad on Sardinia). Ingegnerta Ferroviaria, Vol. 37, 1982, pp. 687-694.
12. V. Rakov. Technical and Economic Aspects of Electrical Traction on USSR Railways. Rail International, Vol. 6, 1975, pp. 41-45.
13. S.M. Serdinov. Electrification of USSR Railways: The 1964-1974 Decade--Results and Problems. Rail International, Vol. 7, 1976, pp. 249-263.
14. C.C.H. Wade. Some Aspects of Electric and Diesel Traction in Railway Modernisation. Journal of the Institute of Locomotive Engineers, Vol. 58, 1968-1969, pp. 387-407.
15. A.J.G. Gosling. Review of Railway Electrification in South Africa. IEE Conference Publication 50, 1968, pp. 345-376.
16. F.F. Nouvion. Electric or Diesel Traction: How the Balance Has Shifted. Railway Gazette International, Vol. 130, 1974, pp. 300-303.
17. E.T. Harley et al. The Management of an Electrified Railway. Presented at Conference on Railway Electrification, Railway Systems and Management Association, Chicago, Ill., 1973.
18. G.S.W. Calder. Maintenance of Diesel and Electric Motive Power. In Railroad Electrification: The Issues, Special Report 180, TRB, National Research Council, Washington, D.C., 1977, pp. 39-42.
19. J. Mizuno. Analysis of Tractive Electric Power Consumption and Study on Energy Saving. Rail International, Vol. 13, 1982, pp. 85-88.

Publication of this paper sponsored by Committee on Rail Electrification Systems.