Technological Issues

Locomotive Costs: A Railroad Electrification Issue

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In any railroad electrification project, the acquisition and maintenance costs of the electric locomotives are, of course, important considerations. Specifically, the costs of ownership of electric locomotives compared with those of the diesel-electric locomotives they will replace are very important.

In analyzing relative acquisition costs, we can draw information from those railroads that have significant experience with both diesel-electric and electric operations. Furthermore, we can examine the similarities and differences between electric and diesel-electric locomotives in order to identify factors that influence their relative costs. Considered together with the economic life of the two kinds of vehicles and the relative fleet sizes required to do the same job, these factors will provide a means to weigh the relative capital costs of the two kinds of motive power. In analyzing maintenance costs, we can again draw on the experience of existing railroads and also compare logically the two kinds of locomotives to arrive at reasonable conclusions about relative maintenance costs of electric and diesel-electric locomotives.

We can get some insight about acquisition costs from a 1976 report (1) that surveyed many of the railroads of the world and a number of locomotive manufacturers. The report found that a typical 2.24-MW (3000-hp) six-axle U.S. diesel-electric freight locomotive delivers about 1.9 MW (2550 hp) at the rail and costs $500 000, or $261/kW ($196/hp). In both the United States and Europe, the typical 3.73-MW (5000-hp) electric locomotive costs between $800 000 and $1 million and the typical 5.22-MW (7000-hp) electric locomotive costs between $1 million and $1.5 million. Averaging these, one would arrive at a cost of approximately $241/kW ($180/hp) for the straight electric locomotive, or about 92 percent of the cost of the diesel electric on the basis of power. It is worthwhile to look at several factors that can affect the prices of these two types of locomotives.

PRODUCTION VOLUME

Nowhere in the free world are electric locomotives produced in a volume comparable to the production of diesel-electric locomotives in the United States. Hence, the present price levels for electric locomotives do not reflect any economies due to volume. What kind of volume might we expect in the future?

There is general agreement among many who have studied the subject that about 10 percent of the U.S. railroad lines have a sufficiently high density to be candidates for electrification. This 10 percent covers about 35 000 km (22 000 miles) and carries approximately 50 percent of the total U.S. traffic. It has been estimated that the electric locomotive fleet required to handle all of this traffic would be between 3500 and 4000 units. The electrification of these 35 000 km would probably take more than 20 years. Hence, production of electric locomotives averaging 150 to 200 units annually will be required when electrification in the United States really gets going. That volume would provide for a reduced cost/unit both through the efficiency of repetitive production of a given design and the production efficiencies inherent in continuous manufacture of any product. Although it is true that production volume for electric locomotives will probably never approach the production volume of diesel electrics, it can benefit from the same economies that make the present diesel-electric locomotives manufactured in North America one of the most cost-effective products in the world.

Let us examine briefly the similarities and differences between the electric and diesel-electric locomotives. The principal item of equipment that relates specifically to the diesel-electric locomotive is, of course, the diesel engine. The unit cost of the engine is greatly affected by volume since the manufacture of the engine requires substantial metal-working operations, which lend themselves to automation as volume permits. The principal parts that are uniquely associated with an electric locomotive are mostly pieces of equipment that are built up through assembly and do not necessarily lend themselves to the kinds of economies that can be achieved through automatic machining. Considering the rest of each locomotive—the common parts, including the locomotive platform, cabs, trucks, wheels and axles, and traction motors—it is easy to see that, if the electric locomotive is kept similar in form and function to the present diesel, both the electric and the diesel can benefit from economies of scale. Hence, although the probable production of electric locomotives will be in the range of 200 units/year, whereas diesel-electric locomotive production is in the order of 1000 units/year, when production of the electric locomotive approaches 200/year it should have the benefits of economies comparable to those achieved with today's diesel electrics.

TRENDS IN COSTS OF MATERIALS

Costs of the materials are certainly a principal factor in the total cost of a locomotive. There is one major area in the equipment of an electric locomotive in which the cost is going down, despite the inflation in cost of practically all other materials. This area is that of solid-state electronics, both for power and for signaling. Increasing use of power thyristors, diodes, and such static control devices as microprocessors to replace engines, generators, contactors, and relays can only produce cost savings. We are all familiar with this trend in such products as electronic calculators. The General Electric Company has announced a new method of semiconductor manufacture called thermomigration for the production of high-voltage, high-current power semiconductors at substantially lower cost than was possible with older methods (2). And a Univac computer that sold for $2.5 million 25 years ago can now be duplicated for far less than $500 on a single board (3). The electric locomotive certainly enhances the capability for applying solid-state devices.

The expected useful life of a piece of equipment is certainly important in considering its total ownership costs. There is no question that the actual useful life of both diesel-electric and electric locomotives is significantly longer than the nominal economic life attributed to them. Many diesels are running more than 20, even 30, years. On the other hand, as Table 1 shows, many electric locomotives have run more than 50 years. The New York Central System's S-class locomotives are still in operation after 70 years, and 106 of 139 GG-1s are still operating. The old locomotives of the Chicago, Milwaukee, St. Paul and Pacific Railroad Company and 1920-vintage Mexican locomotives were still operating when a decision was made to cease electrified service. Throughout the world, 30 years seems to be the accepted figure for the economic life of an electric locomotive, while 15 years is the accepted economic life of a diesel-electric locomotive.

An electric locomotive can be manufactured with two or three times the continuous power rating of a diesel-electric locomotive. This is, of course, because the electric does not have to carry its prime mover on its back. Also, by exploiting the thermal capabilities of electrical apparatus, the electric locomotive is capable of short-time power ratings that are double the continuous rating. This is not possible for the diesel electric. The question then is, How large a fleet of electric locomotives is required to do the same job as a given number of diesel-electric locomotives? There is no simple answer to this question. For high-speed manifest freight service over relatively level terrain, it may be possible for one electric locomotive to replace as many as three diesel electrics. On the other hand, in heavy freight service over extremely difficult terrain with sustained need for high tractive effort, one electric locomotive may be capable of replacing only 1.5 diesel-electric locomotives. In general, one electric will probably replace two diesel-electric locomotives.

A further consideration is that, when an existing railroad route is electrified, the diesel-electric locomotives that had previously been used on that route must be accounted for. This should not be a problem, since attrition alone on the rest of that railroad's system would normally require more replacement locomotives than those released by the electrification. Looking at it in gross numbers, the diesel-electric fleet in the United States comprises about 30 000 locomotives, with nearly 1000 needed every year just as replacements. As mentioned previously, approximately 4000 electric locomotives would be required over the next 20 years if all of the promising routes were electrified. That would result in an average rate of acquisition of 200 electric locomotives each year. Hence, attrition can more than handle the diesels displaced. Further, more than sufficient time will be available to plan for the use of these diesels, since the time for electrification on any given project will be a minimum of 3 years from decision point to operation.

MAINTENANCE

It is generally agreed that the maintenance cost of a fleet of electric locomotives will be significantly lower than the maintenance costs on an equivalent fleet of diesel-electric locomotives. Widely different figures have appeared in print; some suggest that maintenance of electric locomotives is as much as two-thirds the maintenance cost for diesels, and others suggest that it is as low as 20 percent of the maintenance cost of diesels. A general consensus appears to be that the maintenance cost of a fleet of electric locomotives is approximately one-third the maintenance cost of the equivalent fleet of diesel-electric locomotives. Much of the difference in the figures quoted results from different interpretations of the costs that are applicable to maintenance. As was

Table 1. Life spans of electric locomotives.

Railroad	Locomotive Type	Power (MW)	Year Placed in Service	Year Taken out of Service	Life (years)
New York Central System		1.64	1906	–	71+
New York, New Haven and Hartford	EP-1	1.06	1906	1936	30
Railroad Company	EF-1	1.19	1912	1953	41
Butte, Anaconda and Pacific Railway Company		0.81	1913	1967	54
Norfolk and Western Railway Company	LC-1	2.39	1914	1950	36
Chicago, Milwaukee, St. Paul and	Box cab	2.24	1916	1974	58
Pacific Railroad Company	EP-2	2.39	1918	1961	43
	EP-3	3.13	1920	1954	34
New York, New Haven and Hartford Railroad Company	EP-2	2.39	1923	1958	35
Mexican railroads		2.01	1924	1974	50
Norfolk and Western Railway Company	LC-2	3.54	1924	1950	26
Virginian Railway Company	EL-3A	3.54	1925	1960	35
Great Northern Railway Company		2.88	1927	1956	29
Pennsylvania Railroad	P5-A	2.80	1932	1962	30
	GG-1	3.45	1935 to 1940	–	40+
New York, New Haven and Hartford Railroad Company	EP-5	2.98	1954	–	23+

Note: 1 MW = 1341 hp.

pointed out in a recent article (4), "Special care should be taken to insure that all costs associated with maintaining and servicing diesels are compiled. Special maintenance accounts, heavy repairs, and fringe benefits are frequently omitted in manufacturer's cost figures but must be included when comparing different types of motive power."

It is certainly understandable that the maintenance cost for an electric locomotive should be substantially lower than that for a diesel-electric locomotive. The engine-related parts of a diesel-electric locomotive comprise the bulk of the moving, wearing parts and such replaceable renewal elements as fuel and air filters; hence, these are the parts that require by far the greatest amount of maintenance on the locomotive. The parts peculiar to the electric locomotive are, by contrast, generally rugged, static, nonwearing apparatus, such as the power transformer and the thyristor power supply. This equipment is extremely long lived and requires very little maintenance other than a route inspection from time to time. In addition, the electric locomotive requires no time for fueling; therefore, a minimum of service is required between runs. The electric locomotive's maintenance characteristics also permit a smaller inventory of spare parts and an attendant reduction in the carrying cost of that inventory.

As the conversion from diesel operation to electric operation proceeds, no significant investment will be required in new maintenance facilities for the electric fleet. The facilities and equipment needed for the diesel fleet will be more than adequate for the replacement electric fleet. As a matter of fact, if the electrified operation being considered is for a new or rapidly expanding operation in which new maintenance facilities would be required regardless of whether the operation were to continue with diesel electrics or be converted to electric, the investment in an electric maintenance facility would be substantially less. If it were not true for any other reason, it would be true because the fleet of electric locomotives to be maintained at that facility would be substantially smaller than the equivalent fleet of diesels.

Experience on the world's railroads corroborates the significantly lower maintenance expense of electric locomotives and shows general agreement that the maintenance expense for electrics is approximately one-third that of an equivalent diesel operation. At the Railway Systems and Management Association's Conference on Railroad Electrification in September 1973, it was reported that British Rail has found diesel-electric maintenance three times as costly as electric maintenance (5) and that electric maintenance costs on Japanese National Railways were approximately 35 percent those of diesel maintenance (6). French National Railways reported maintenance costs for electrics that were 34 percent of those for diesel electrics in 1970 and 33 percent of those for diesel electrics in 1972 and 1974 (7). It was added that "General introduction of thyristors on electric locomotives . . . reduces electrical equipment maintenance by 40 percent." This latter fact results from the replacement of the tap changer, a piece of equipment with many moving, wearing parts, by the rugged static thyristor power supply. Swedish State Railways has reported that in 1971 the cost of electric locomotive maintenance averaged 42 percent of that for diesel electrics on the basis of cost per locomotive kilometer and 18 percent of that for diesel electrics on the basis of cost per megagram-kilometer (6). An article that summarized maintenance costs from a number of domestic studies on both diesel and electric locomotives found that, on the average, electric maintenance costs 30 percent as much as diesel maintenance (4).

There is, of course, no substitute for one's own experience in arriving at the correct locomotive costs to be used in studies leading to such important decisions as that on electrification. Unfortunately, by definition, those who must make the decision do not have their own experience and must depend on that of others. It is important that, in considering each specific route segment, there be an application study to determine specifically what the relative fleet requirements would be for the type of service contemplated. It is also important that each railroad's specific maintenance practices be considered in the determination of the relative maintenance costs.

Summarizing all of these considerations, it seems clear that the wealth of experience throughout the world indicates some general factors that can be used as points of departure. On the basis of an equivalent fleet

1. The costs of acquiring electric locomotives will be about 90 percent of those for diesel electrics, and it is expected that that percentage may decrease in the future.
2. The economic life of the electric locomotive will be twice that of the diesel electric.
3. The maintenance costs of the electric locomotive will be approximately one-third of those experienced with diesel-electric locomotives.

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