

compared with electricity. The best single surrogate to these factors was found to be annual fuel consumption per route-mile. However, dependency on variables uncorrelated with fuel consumption (e.g., bridge clearance and signal and communication compatibility) is still sufficient to require computation of ROR.

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Comparative Catenary Costs—European and U.S. Main Line Railroad Electrification

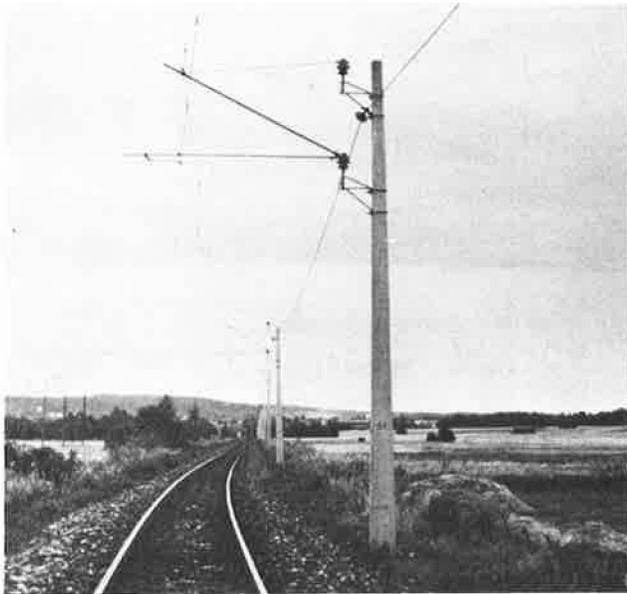
WILLARD D. WEISS, H. IAN HAYES, AND PETER L. SHAW

Recent comparisons of railroad electrification costs have reported costs of overhead contact systems (catenaries) for overseas electrification much lower than those of U.S. installations. Such direct comparison may not be valid for several reasons—the smaller load gauges, shorter trains, and lower labor costs on overseas railroads. To demonstrate a recent catenary installation on British Rail cost \$112,000 per single-track-mile (STM) (1982 prices), but this value would increase to \$201,100 per STM at U.S. cost levels on similar complex routes. Also, the U.S. projects compared (e.g., Northeast Corridor Rehabilitation and Pueblo Test Track) are not representative of main line railroads. More representative examples are the 78-mile Black Mesa and Lake Powell Railroad catenary (\$180,000 per STM at 1982 prices), and the 370-mile Mexico City-Queretaro Railroad catenary (bid at \$165,000 per STM at 1982 prices). An independent estimate was made for a hypothetical 300-mile U.S. main line catenary by using a typical 25-kV design, to be installed in 2 years. The resulting cost (\$162,200 per STM) is considered representative for the United States. This cost could double should track access be difficult and work

periods short. But, with good planning and improved equipment and experience, catenary costs on large-scale electrification could be reduced to approximately \$150,000 per STM at 1982 prices. In conclusion, main line catenary cost in the United States is expected to be higher than that overseas but will reduce with large-scale programs and improved equipment and techniques.

In an effort to approximate costs of U.S. main line electrification numerous comparisons have been made between costs of electrification in other countries and those experienced so far in the United States or estimated for prospective projects. These comparisons have generally concluded that costs in the United States [particularly costs for overhead contact system (catenary)] are considerably higher than

Figure 1. Main line catenary on Swedish State Railways, typical of many recent European installations.



those elsewhere. Some effort has therefore been made to ascertain whether this is true on a like-for-like basis and, if so, what can be done to reduce costs in the United States.

Some of the comparisons that have been made include the following:

Foreign--European national railroads (British Rail and Swedish Rail) and Sishen-Saldanha Railroad, South Africa

United States--Northeast Corridor (actual costs), North Jersey Coast Line (actual costs), Pueblo Test Center (actual costs), and Consolidated Rail Corporation (Conrail) Harrisburg-Pittsburgh (estimate)

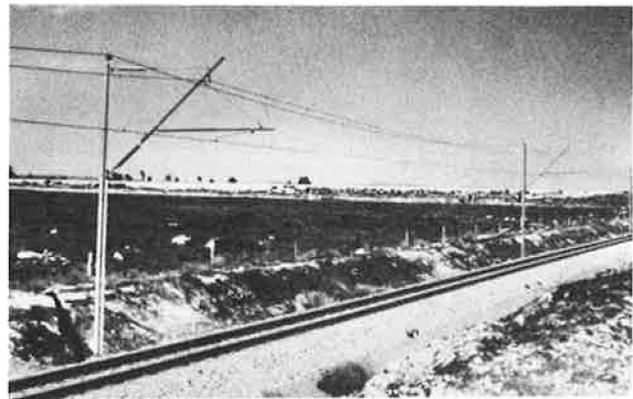
For overhead contact system installation, which normally represents one of the largest single cost elements in rail electrification, most of the foreign railroad costs were found to be in the range of \$70,000 to \$110,000 per single-track-mile (STM) at current prices. Those in the United States were found to range from about \$190,000 to as high as \$2.5 million per STM.

Probably neither of these cost ranges is indicative of what future catenary costs will be in this country; other North American projects that have either actual costs or firm bids should be more representative. Some of the reasons the preceding costs are not representative are presented and some costs that are more applicable are suggested in the following sections. Details of estimated costs of catenary for U.S. main line are presented for an overall final comparison. Note that similar exercises could be done for other aspects of electrification, such as power supply systems, signaling, communications, locomotives, and civil works, because valid reasons exist for variations in these costs as well. The present discussion is limited to only overhead contact system costs, however, because of the significance of this cost component in railroad electrification.

SUMMARY OF PREVIOUS COMPARISONS

Some of the main reasons why costs of European catenary (see Figure 1), particularly those of simple

Figure 2. The 50-kV Sishen-Saldanha Railroad catenary, designed for heavy-haul main line operation.



catenary at 25-kV ac, were found to be lower than anticipated U.S. costs are as follows.

1. The load gauge on most European railroads is considerably less than on U.S. railroads. On British Rail, for example, the vertical load gauge is 13 ft 1 in.; however, on most U.S. main lines it is at least 19 ft. The load gauge determines catenary mounting heights and clearances; therefore, it has a significant impact on the costs of poles, foundations, and other support structures.

2. Train loads in Europe are generally much lighter than those on U.S. railroads, comprising primarily passenger trains and light freight trains. Thus, catenary conductors are usually small, typically 600 A capacity, compared with probably 700 to 900 A for U.S. practice, and up to 1200 A on lines that have heavy gradients.

3. Often a considerable amount of the catenary cost is not recorded in the official figures because it is carried by the railroad organization and not the contractor. For example, some railroads will provide the contractor with work trains for catenary construction as well as administrative and planning staff for each project. Thus, those costs are normally not fully included in the quoted figures.

4. In Europe most railroads are extending existing systems. Thus, new conceptual designs are not required, and any cost associated with feasibility studies is generally absorbed into routine organizational overheads.

5. The catenary system design used in an individual European country is the result of many years of development and consultation involving the nationally owned railroad and local suppliers and contractors.

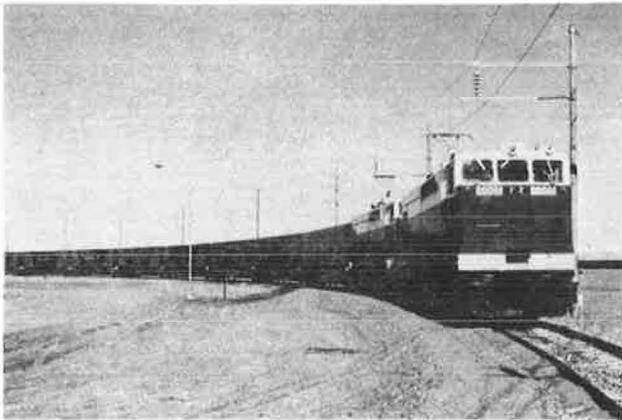
The Sishen-Saldanha Railroad (see Figure 2) is a new 540-mile iron ore line in South Africa that has recently been electrified at 50 kV by using a catenary design considered typical for modern freight railroads. The catenary cost on this line is not considered representative for U.S. railroads for the following reasons:

1. The line is a 3 ft 6 in. gauge and the contact wire height is only 19 ft 8 in., compared with a typical height of 22 to 24 ft required for U.S. main lines.

2. Local labor costs on the Sishen-Saldanha line were quite low, compared with U.S. labor costs.

3. Numerous components were made locally, at costs considerably less than that of American-supplied hardware.

Figure 3. One of first new generation railroad electrification installations in North America, the BM & LP Railroad in Arizona.



4. Construction took place with only six trains per day (three each way) operating on the line, terrain was relatively easy, track curvature was slight (minimum radius 3,300 ft), and a service road paralleled the line throughout.

On the other hand, the examples of cost experience in the United States cited previously are all disproportionately high for the following reasons:

1. Northeast Corridor--The Northeast Corridor Improvement project comprises rehabilitation of existing equipment, catenary is compound with heavy conductors, poles have overbuilt transmission lines, and individual line sections being reconstructed are generally less than 0.5-mile long.

2. North Jersey Coast Line--On the North Jersey Coast Line catenary is compound equipment. The project is short (5 miles), which necessitates high mobilization costs. Soil conditions are extremely poor (in some swamp areas deep pile-foundations were used for catenary poles), and special support structures are required for overbuilt catenary and signal feeders.

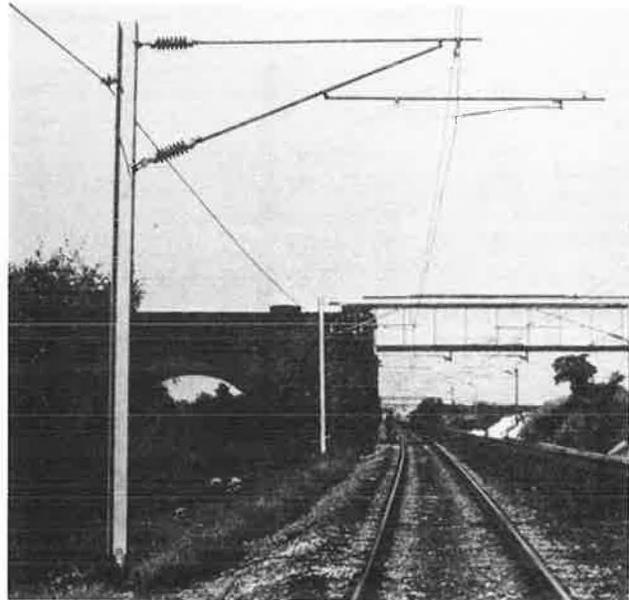
3. Pueblo Test Center--At the Pueblo Test Center catenary is compound equipment. The project is small (15 miles), and special design features were incorporated (e.g., variable-height cross-arm connections, adjustable bolted-base poles, and special catenary test section).

4. Conrail, Harrisburg-Pittsburgh--The costs for the Conrail Harrisburg-Pittsburgh project are only an estimate. Support design comprises headspan with guyed wood poles located 18 ft from track centerline. Extensive multiple-trackage on the line.

Two other recent projects in North America that may be more representative of U.S. main line costs are the 50-kV Black Mesa and Lake Powell (BM & LP) Railroad electrification in Arizona, built in 1972-1973, and the planned 25-kV electrification of the Mexico City-Queretaro Railroad, which was bid near the end of 1980.

The BM & LP (see Figure 3) is only 78 miles long so its cost may be slightly higher than that for a typical main line installation of several hundred miles. Also, catenary cost for 50-kV power supply is generally 4 to 5 percent higher than 25 kV. The BM & LP catenary cost was \$5.54 million, or \$71,000 per STM. When escalated to 1982 dollars at 10 percent per year this becomes approximately \$180,000 per STM.

Figure 4. Mark III main line catenary on recent British Rail 25-kV electrification between Weaver Junction and Glasgow.



The Mexico project, however, should parallel more closely the future U.S. experience for 25-kV catenary and, although not yet constructed, firm bids were submitted in November 1980. The low bid for the catenary was \$32.4 million. Most bids, however, including that of the one American bidder, were approximately \$50 million, or \$135,000 per STM. When escalated 10 percent per year, the current value would be approximately \$165,000 per STM.

Both of these projects should be representative of future U.S. main line catenary costs because they involve similar designs and similar construction and operation conditions. This conclusion is corroborated by independent estimates made by engineers of International Engineering Company (IECO) and Electric on costs for typical main line electrification in the United States.

REPRESENTATIVE CATENARY COST IN THE UNITED KINGDOM

A further analysis of European catenary costs is made by using experience from the United Kingdom to reconcile some of the apparent differences with costs in the United States. The costs that were incurred on the latest British Rail electrification (see Figure 4) were put into the same categories used for U.S. cost estimates and escalated to 1982 dollars. A summary of these costs is as follows:

Item	Cost/Single-Track-Mile (\$)
Direct costs	
Material	54,900
Labor	30,200
Construction equipment	6,000
Indirect costs	20,900
Total	112,000

Recently published papers by British Rail engineers highlight the 42 percent reduction in costs achieved in real terms during the last 15 years. Costs incurred in the mid-1960s escalated to current price levels would be more than \$190,000 per mile.

If the current U.K. system were installed on a U.S. project with U.K. person-hour allowances, in-

stallation techniques, and track complexities, the adjusted U.S. cost would increase considerably, as shown below:

Item	Ratio	Cost/STM (\$)
Direct costs		
Material	1.33	73,000
Labor	2.40	72,500
Construction equipment	1.60	9,600
Indirect costs	2.20	46,000
Total	1.80	201,100

The major influence is labor cost, both directly in the labor category and indirectly in other categories.

In reality, U.S. main line freight railroads do not have the track complexity typically encountered in Europe, and actual costs for a U.S. system are estimated to be at lower levels, even after allowing for the larger physical size of catenary poles, supports, and conductors. A representative U.S. main line catenary cost estimate is summarized in the following paragraphs.

REPRESENTATIVE CATENARY COST ESTIMATE

Based on actual project experience along with a dozen or more detailed engineering cost estimates and hard-money turnkey construction bids prepared during the past few years, an independent estimate was made of current catenary construction costs for a hypothetical main line U.S. railroad, 300 STM long, by using a typical 25-kV catenary design. A summary of the estimated costs is as follows:

Item	Cost (\$000 000s)	Cost/STM (\$)
Direct costs	33.82	112,700
Materials	25.57	85,200
Labor	5.90	19,700
Construction equipment	2.35	7,800
Indirect costs	14.84	49,500
Total	48.66	162,200

Note that indirect costs include design, supervision and administration, tax, insurance and fringe benefits, site and office expenses, bonds, permits, interest during construction, direct labor contingency, and profit. The above estimate is based on the following assumed parameters, which are considered representative for a typical U.S. main line installation.

The railroad conditions assumed are as follows:

- Number of tracks--One, with passing sidings;
- Load gauge--21 ft;
- Percentage of curves--40;
- FRA track class--Class 4;
- Maximum speeds--60 mph freight, 80 mph passenger; and
- Wind and ice loading--National Environmental Satellite Center classified as heavy.

The catenary characteristics assumed are as follows:

- Catenary power supply--25 kV ac single-phase;
- Catenary current capacity--700 A;
- Catenary style--Simple;
- Tensioning--Automobile-tensioned;
- Tension section lengths--1 mile;
- Pole type--Galvanized steel wide-flange;
- Foundation type--Concrete sleeve backfilled, pole direct-embedded and grouted;
- Contact wire--4/0 American Wire Gauge (AWG) hard-drawn copper;

- Messenger wire--300 kcmil aluminum conductor steel reinforced (ACSR);
- Ground/return wire--2/0 AWG ACSR;
- Maximum structure spacing--210 ft;
- Contact wire height at support--23 ft 6 in.; and
- Pantograph width--6 ft 6 in.

The construction conditions assumed are as follows:

1. Three hundred track-miles will be electrified;
2. Daylight track possessions will have 6 hr per day (of which 1 hr is nonproductive), Monday through Friday;
3. Construction duration will be 2 years;
4. Hi-rail vehicles will be used rather than work trains; and
5. Vehicle communications will be by radio.

The material cost estimate was prepared on the basis of current prices for materials, obtained through vendor quotations on recent similar projects. Note that these values may vary somewhat from location to location.

Costs for materials represent about 60 percent of the total catenary cost. Approximately 75 percent of the material cost derives from the poles and cross arms (40 to 45 percent for poles, 30 to 35 percent for cross arms). Because the pole size and spacing are affected directly by the contact wire height the influence of load gauge on catenary cost becomes apparent. The typical pole assumed for this estimate is a 31-lb/ft wide-flange section.

If wood poles are used instead of steel an initial overall savings of approximately \$10,000 to \$15,000 per mile may be achieved, after considering the extra costs of reinforcing with a guy. This savings, however, depends heavily on the cost and availability of wood poles in the area concerned. The expected project life and maintenance philosophy are also of major importance in the pole selection.

One of the most significant variables in the catenary cost is labor because much of its cost depends on the physical working conditions, such as track occupancy, accessibility, climatic conditions, total project size, and general employment practices. Again, labor rates will vary from location to location within the United States and premium rates will have to be paid in remote or inaccessible areas.

Costs for construction equipment are based on an assessment of the various types of equipment required for each activity, applying average monthly ownership and operating costs for each type. These costs include depreciation, fuel, repair labor, parts and supplies, and interest on invested capital. Again, the productivity of much of this equipment will depend on the site conditions, particularly track possession periods. Any reduction in the occupancy periods assumed will increase the job duration correspondingly and, hence, the cost of major equipment items as well as labor.

One way in which European experience is applicable to U.S. main line electrification is the widespread use of purpose-built mechanical equipment, which is essential if the unit cost is to be brought down to affordable levels on major projects. Both on-track and off-track equipment is required for use on U.S. projects, with the objectives of

1. Optimum use of installation processes,
2. Reduction of construction crew size, and
3. Maximum use of track occupancy.

The consideration of track occupancy is particularly critical in U.S. main line project situations and is probably the largest single factor that causes the

Table 1. Estimates of catenary cost for hypothetical 300-mile railroad.

Track Occupancy (hr/day of working time)	Unit Cost (\$/STM)	Total Cost (\$000,000s)	Cost Penalty (\$000,000s)	Construction Delay (years)
Good, 6 or more	149,000	44.7		2
Poor, 4-5	208,000	62.4	17.7	3
Bad, <4	300,000	90.0	45.3	4

diversity of unit rates given in various U.S. electrification studies. Provision of good track occupancy for electrification crews avoids a major cost penalty when pricing a catenary system.

For example, estimates of catenary cost made for varying conditions of track occupancy on a hypothetical 300-mile railroad are given in Table 1. The progressively larger cost penalty in Table 1 is caused by underuse of labor and by the proportionately larger nonproductive element of construction equipment operation and cost. Additional penalties will also be incurred because of increased financing costs and deferment of electrified operation.

Recent developments in Europe and elsewhere have concentrated heavily on the use of off-track installation processes. This effort has met with some success and warrants further study for application on U.S. railroads.

CONCLUSIONS

Hardly any recent railroad electrification experience in the United States or overseas is representative of anticipated catenary costs for U.S. main line electrification. One possible exception is the Mexico City-Queretaro project, for which catenary bids were approximately \$165,000 per STM at current dollars. An independent estimate made by IECO engineers for a standard design of 25-kV catenary on a hypothetical U.S. main line resulted in a cost of \$162,200. For 50-kV electrification, which may be adopted in much of the United States, the catenary cost would be 4 to 5 percent higher, with corresponding reductions in costs of power supply equipment.

These figures should be representative of a large portion of the projected trackage to be electrified, for example, in the FRA 26,000-mile network. Costs on individual lines will vary from these values if track occupancy and other site conditions differ appreciably from those assumed. For example, Electrack estimates for the FRA network gave a median cost of \$154,800 per STM. Individual projects may range from \$144,700 per STM on a Western route segment to \$199,300 per STM on a mountainous route segment in the Northeast.

Major reductions in the costs of equipment and hardware will occur when large-scale railroad electrification programs are initiated, partly by economies of scale and partly by natural evolutionary development and optimum designs.

In conclusion, the cost of railroad electrification for U.S. main line routes is expected to be somewhat higher than the cost experienced overseas. Furthermore, the cost of any traction system in similar circumstances will also be much higher than experienced on lightly loaded or trafficked routes. These catenary costs can be estimated reliably by engineers experienced in the design and construction processes. The end result of a railroad electrification project on any U.S. main line railroad route would be creation of a larger transportation tonnage capacity and the potential for more profitable operation.

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