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SUMMARY AND GENERALIZATION OF THE CONRAIL ELECTRIFICATION STUDY RESULTS FOR APPLICATION TO OTHER RAILROADS

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16. Abstract

The recent railroad electrification feasibility study of the Conrail line segment from Harrisburg to Pittsburgh is reviewed in this report. Approach to design and operational strategy are discussed. A summary of costs and units for various investment and cost items is presented, escalated into 1980 dollars.

Of particular interest to the reader are the comments regarding the more general application of the methodology and cost figures to subsequent railroad electrification studies. In most cases, both methodology and cost figures have wider application and are so identified. Those factors which are site-specific or in other ways unique are also identified.

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1.0 INTRODUCTION

The objectives of this report are to examine the Gibbs and Hill (G&H) Railroad Electrification Feasibility Study of the Conrail route segment from Enola (Harrisburg) to Conway (Pittsburgh) via the Conemaugh line, extracting and presenting a summary of methodology and unit factors and costs. Comments and suggestions as to the broader and more general applicability of the approach and figures in this study refer to other railroad electrification studies are given in each section.

Where prices from Reference 1* on the G&H report are to be converted from their base year into later year prices, the following total escalation multipliers have been used:

1976-1977:	1.07
1976-1979:	1.25
1976-1980:	1.41
1977-1979:	1.17
1977-1980:	1.32

These figures are a composite. Labor escalators use an average of manufacturing labor and transportation and public utility labor figures as reported in the U.S. Bureau of Labor Statistics hourly earnings index. Materials and equipment escalators are a composite of the categories of electrical machinery and equipment and specialized industrial machinery as reported in the U.S. Bureau of Labor Statistics producer price indices. As these figures did not vary widely between categories, a single composite figure can be used with reasonable accuracy.

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*Reference 1: Schwarm, Edward G., Engineering Cost Data Analysis for Railroad Electrification, Arthur D. Little, Inc., for Department of Transportation, Transportation Systems Center, Contract DOT-TSC-1156, Cambridge, MA, 1976.

2.0 OPERATIONS ANALYSIS (G&H Section 1.2)

The operations study phase is a key input to the balance of the electrification study. It answers several very critical questions:

- How does or should the system operate under diesel motive power?
- How should and will the system operate under electric motive power?
- How much energy, both diesel fuel and electricity, will the operation consume?
- How many electric locomotives of what types will be required, and how many diesels will they replace?

Typical secondary but important data derived will be comparative schedule times, locomotive miles, projected locomotive productivity, etc.

2.1 Design and Operational Strategy

Several approaches have been used, from the simplest to the more thorough and complex:

1) Conversion of all traffic into tons of traffic per horsepower have assumed essentially average train characteristics and uniform spacing in comparing electric to diesel.

2) Documentation of the present diesel operation and making equivalent substitution of electric motive power on a performance basis.

3) Projection of present diesel operation to a more effective operation by extrapolation or simulation and simulation of electrified operation for comparison.

G&H chose the latter approach because of the importance of this study and criticality of decisions to be made from it, but have used average trains to simulate future operations.

2.1.1 Operations Criteria and Methodology

The following criteria were adopted:

- Certain local trains and all switching would be by diesel.
- Diesel-powered trains entering electrified territory would proceed by diesel to a designated power charge point.

- Helpers would be diesel.

- Drag operations (speed below 20 mph) would be discontinued.

- Generally increase speeds on compensated grades of 1% or less to 40 mph for TOFC/COFC, merchandise freights, generally all but bulk unit trains.

- Economic life of a diesel locomotive is 18 years, an electric, 30 years.

- Assumed an average train of less than 70 cars with an average car capacity of 70 tons in 1982 and 82 tons in 2010.

- Carloading to be 81% of car capacity over the study period, a ratio which has been constant for 15 years.

- Only the Conemaugh line will be electrified which, even though longer, has much lower grades than the mainline.

To begin the study, two peak operating days were selected from a heavy two-week period. Using train dispatchers' sheets, this operation was string-line plotted. This was used as a base line from which future scenarios were developed, one for 1982, another for 2010.

Traffic was allocated to the following train types:

- Passenger and mail trains; same as 1977.

- Unit trains; loaded with empty return, existing trains modified by expected car tare weights, total projected tonnage used to calculate number of trains.

- Merchandise freight; based total tonnage on anticipated gross-to-net ratio, factoring in projected changes in car load and tare weight. Ratio of loads to empties based upon observed patterns.

Track maintenance delays were projected as a ratio of traffic density. Windows will not be available.

Individual train type performances, schedule and energy, were determined by train performance calculator (TPC) computer programs. Diesel TPCs were compared to equivalent actual operations for verification.

A train dispatching simulator (TDS) was used to develop the following data:

- Generates and displays string-line plots
- Scheduled and unscheduled delays
- Net running times
- Total train hours
- Car and locomotive hours
- Average train speed
- Train, locomotive, car, and ton-miles
- Number of train starts
- Number of locomotives in the system
- Maximum number of locomotives at any time, and train causing maximum
- Problem condition messages

The following input data is required by the TDS.

- TPC simulations of each train type
- Line configuration
- Operating policies: priorities, speed limits, routings, schedule of dispatch
- Scheduled enroute work
- Unscheduled events
- Locomotive turn times

The annual tonnage was calculated by using ratio of annual tonnage to 2-day period peak tonnage apportioned by train types observed.

Annual train hours were developed by multiplying TDS developed total train hours plus delay times by the ratio of annual tonnage/ annualized 2-day peak tonnage.

The actual locomotive fleet is determined by the criteria of the TDS program based upon turn around times, availability of power, unit waiting times, deadheading to balance power, and periodic and un-scheduled maintenance.

Diesel fuel and electricity consumed is calculated by the TPCs and normalized to gallons or kWh per ton-mile.

2.1.2 Locomotive Selection and Powering Criteria

The diesel locomotive fleet will consist of a mix of:

Diesel HP	Rail kW	Wheel Arrangement	Weight Tons
2000	1270	Bo-Bo	132
3000	1900	Bo-Bo	132
3000	1900	Co-Co	198
3600	2200	Co-Co	198

It was stated that higher powered locomotives will become available towards the middle of the study period, and these have been factored in.

Electric locomotives actually used in the study meet the following general specifications:

Rail kW	Wheel Arrangement	Weight Tons
3800	Co-Co	190
4000/4400*	Bo-Bo	130
6000/6600*	Bo-Bo-Bo	190

(The units indicated* are designed to advanced standards of high adhesion and low track stress.)

2.2 Summary of Costs and Units

While a large quantity of total numbers of units, fuel, etc. were necessarily generated for the Conrail site-specific applications, the normalized and unit numbers will be of more general interest. It is these numbers which are presented here. In each case the medium growth scenario has been used.

Locomotive Productivity	1982	2010
Average annual unit miles, diesel	33942	40713
Average KTGTM/unit, diesel	57984	67170
Average annual unit miles, electric	39030	47946
Average KTGTM/unit, electric	143608	166834

Locomotive Substitution Ratio

The actual ratio of diesel locomotives to electric locomotives in the consists is 2.2 diesels to 1.0 electrics average over 29 years.

Average W.B. running times and speeds for heavy freights over route:

Diesel: 7.38 hrs, 37.48 mph
Electric: 6.75 hrs, 40.98 mph

Average E.B. running times and speeds for grain unit train:

Diesel 8.87 hrs, 31.18 mph
Electric: 7.49 hrs, 36.93 mph

Power at the rail/load ratio, typical, rkW/ton:

	Diesel	Electric
General freight, W.B.	.84	1.25
Grain unit train, loaded	.54	.80
Trailer van	2.44	3.19
Ore unit train, loaded	1.3	1.7

Energy consumption is not presented in normalized units, only in sum-total for the 29 year project which includes variables of traffic projections, train mix, etc. These totals for the electrification and diesels replaced by electrification for the total 24 year project are:

Electric energy used: 20,126 x 10^6 kWh
Diesel fuel not needed: 1,480 x 10^6 gallons

2.3 Generalization of Results

The approach used in operations analysis follows the general methodology used in previous studies. There are several areas which should be carefully considered before applying the detailed approach generally. These are:

- The 2-day traffic period is much shorter than usually found statistically sound; a full week closed around itself can be more representative of a railroad's operations.

- To achieve a reasonably unbiased comparison, future power to weight ratios should be comparable for diesels and electrics. While it is generally accepted that electrics perform better and more economically at higher ratios, if one wants a faster railroad, this should be treated separately rather than penalizing an electrification program for providing it.

- Helpers gain substantial advantage when electrified. Their higher adhesion can be used in concert with a designed-in overload capability. Often they operate isolated from accessible day-to-day refueling facilities which electrics don't require. No rationale was given by G&H for recommending diesel helpers.

- The residual diesels, those used for local trains, switching, etc., have remained as a factor in the G&H electrification study. Actually, they are irrelevant except as they occupy a train position in the daily string-line plot. The study is simplified and accuracy maintained or enhanced by only considering those diesel consists actually replaced by electrics. The unconverted diesels continue to operate as at present and neither add nor detract from the electrified operation or analysis. The decision to keep certain operations under diesel power is usually made on the basis of operational factors rather than pure economics.

- In the G&H study full reliance was placed upon the logic of a train dispatch simulation (TDS) program. A program of this type is a convenient way of performing calculations and making string-line plots, but it is only as good as its programmed assumptions, logic, and methodology. It is difficult to observe its inner workings and the way the simulated line segment is actually operating. While much more laborious, manual simulation of a few days or a week of operations for a diesel and comparable electric system is not too difficult. With manual simulation a realistic operation can be evolved on a minute-to-minute basis, unusual phenomena quickly identified and handled, and the total operation more thoroughly monitored and understood. More importantly, site cognizant railroad operating personnel can enter into this process interactively, providing valuable insite into the applicability of the approach and accuracy of the results.

3.0 MOTIVE POWER (G&H Section 1.3)

One must not only select the types of electric locomotives which are suitable for the future electrification project, but also the diesel units which will optimally be used to provide an unbiased comparison.

3.1 Design and Operational Strategy

3.1.1 Diesel Locomotives

The diesel locomotive has been built in the 3000 diesel horsepower (Dhp) rating, which develops 2580 rail horsepower or 1925 rail kilowatts (rkW). Recently, with improvements in the diesel engine designs, 3600 horsepower (2310 rkW) units have become available. G&H has assumed that 4000 Dhp (2565 rkW) units will become available through the 1980's. Included among designs being tested, the Swiss built Sulzer ASV 25/30, 2420 gross kW engine now installed in Morrison-Knudsen modified locomotives is the only European unit being considered. The Canadian Alco-MLW engine of 3357 gross kW now operating at 2310 rkW is demonstrating the practicability of units of this larger size. G&H has concluded that improved slip controls will be installed in future diesels making their adhesion limits comparable to those of electrics. The possibility of introduction of 3-phase traction motors is the only major revolutionary change predicted.

The following diesel locomotives are being considered as applicable in this study:

Rated HP	Wheel Arrangement	Rail kW	Wt (Tons)	Remarks
3000	Bo-Bo	1860	130	Present newer units
3000	Co-Co	1860	190	Present newer units
3600	Co-Co	2280	190	Now available
4000	Co-Co	2530	198	By later 1980's
4000	Bo-Bo	2530	130	Longer range projection
4500	Bo-Bo	2860	132	Longer range projection
9000	BoBo-BoBo	5720	396	Married pair with tender - later availability

With improved adhesion and higher hp/ton ratios, the trend will be to four- rather than six-axle units, principally driven by economics.

3.1.2 Electric Locomotives

Based upon an examination of U.S. and European locomotive manufacturers, it was concluded that electric locomotives would be available to meet practical voltage and frequency requirements. The present thyrister control technique would meet stiff competition from rectifier-chopper control which gives much improved power factor, and the variable frequency ac motor drives which additionally give improved adhesion. Ac commutator motors were considered obsolescent, not finding a place in future designs. The following recommendations were made for features on future electric units:

- Fully suspended traction motors
- Guideless axle-boxes
- Low bar traction
- Low ratio secondary suspension
- Shortest possible rigid wheelbase compatible with longitudinal truck stability
- Full body, cab and controls at each end.
- Modular equipment arrangement

The French monomotor truck was rejected as being too sensitive to track conditions. We would refer the reader to Table 1.3-3 of the G&H study for further details on these features.

The following locomotives are being considered as applicable to this study:

Manufacturer	Wheel Arrangement	Rail kW	Wt (Tons)	Remarks
General Motors (GM10)	BoBoBo	6600	200	Available
Brown Boveri	BoBo	4400	130	New
Brown Boveri	BoBoBo	6600	190	New
ASEA	BoBoBo	6600	190	New
ASEA (RC4)	BoBo	4000	130	Available

The most probable trend is towards the four-axle, 3-phase, variable frequency, asynchronous drive locomotive according to G&H predictions.

3.2. Summary of Costs and Units

Because of the variation in locomotive power classes, G&H have expressed locomotive costs in dollars per rail kilowatt. The 1977 prices escalated to 1980 dollars are as follows:

Diesel locomotives	Present 3000 Dhp	New High Powered
Four-axle	$430	$590/rkW
Six-axle	$495	$690/rkW

Electric locomotives

Four- or six-axle $620/rkW equipped with dynamic but not regenerative braking, dual voltage (12.5/25kV), and dual frequency (25/60 Hz).

3.3 Generalization of Results

The extension of the assumption that six-axle units, both electric and diesel, will not be widely used in the future is possibly much less valid for heavy western unit train operation where difficult grades are encountered. Using six-axle units would reduce the number of units per consist with consequent reduction in locomotive maintenance.

The trend in diesel ratings to 3600 hp (2280 rkW) is applicable to a wide group of other railroads, the actual depth of penetration of this concept depending upon elimination of drag operations. The move to 4000 and 4500 hp units is not quite so predictable, and we must wait to see if units in this size are acceptable to the railroads. This evaluation could take a long time, possibly out of the time frame of predictions for near-future studies. It appears that development of the diesel locomotive, now a mature design and device, will be evolutionary rather than revolutionary. Essentially they will be a lot like the latest units, possibly with ac traction and somewhat more horsepower (10-25% in 10-20 years).

Electric locomotives have reached a much higher level of development in Europe than in the United States. The only U.S. built locomotive which appears to be of latest design is the General Motors built GM10 which uses an ASEA designed and built traction system and trucks. Clearly, the design concepts to be used already exist in Europe, and U.S. electric locomotives will be ruggedized versions of these designs. Variable frequency, 3-phase, asynchronous drive is the likely winner. Those broad specifications for electric locomotives indicated in Section 3.1.2 are probably the unit types which will be used through the balance of this century.

4.0 TRACTION ENERGY (G&H Section 1.4)

The objectives of the work in this section were to:

- Develop cost projections for diesel locomotive fuels (including substitutes for No. 2 diesel fuel) and evaluate supply constraints.

- Develop cost projections of electric power for traction purposes and evaluate supply constraints.

4.1 Design and Operational Strategy

The G&H forecast of fuel cost for the period 1980-2010 was based primarily upon projections published by two organizations: the Electric Power Research Institute (EPRI) and Arthur D. Little, Inc. In the course of developing its forecast, G&H also examined forecasts prepared by the federal government, petroleum industry associations and two oil companies. The net result is that G&H expects the price of No. 2 diesel fuel to escalate at an annual rate of 9% from the mid-1980s to 2010. As a reference point, the actual 1980 cost was taken to be 83¢ per gallon ($35/barrel).* This projection is compared with two previous pre-Iranian crisis projections made by Arthur D. Little, Inc. in Figure 4.1.

G&H also examined the likelihood of alternative fuels being used to supplant or reduce consumption of No. 2 diesel fuel, and concluded that the probability of such substitution was small during the next 30 years.

In developing electricity price forecasts, G&H first examined price forecasts of fuels used by utilities. These fuels included coal, oil, natural gas and uranium.

Table 4.1 shows current prices and inflation rates chosen by G&H for these fuels.

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*Fuel cost can vary considerably from this value depending upon the sulfur content, country of origin and transportation charges.

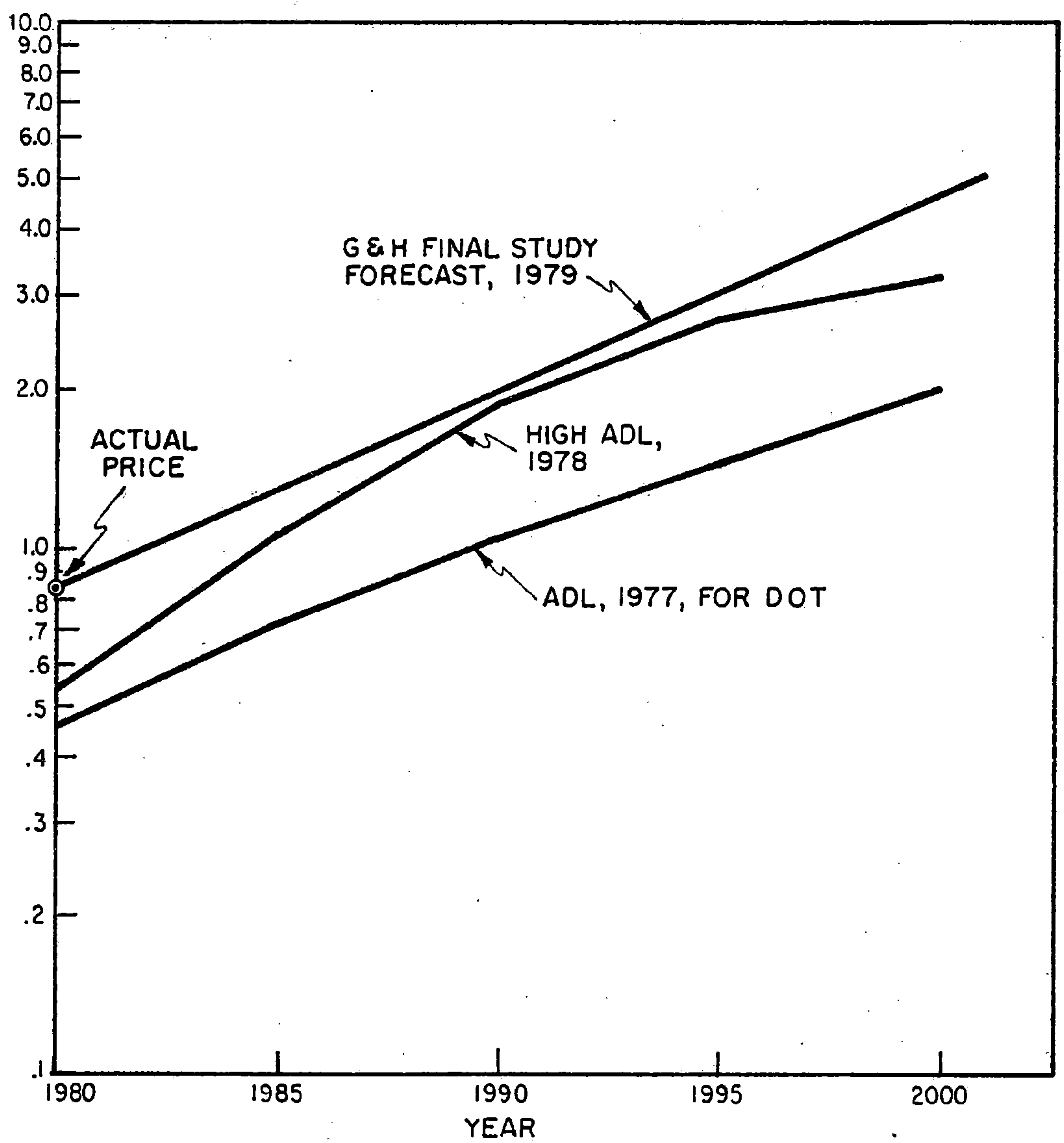

FIGURE 4.1 COMPARISON OF DIESEL FUEL PRICE FORECASTS EASTERN RAILROADS.

TABLE 4.1

FUEL PRICES IN CONRAIL AREA AND
PROJECTED ANNUAL AVERAGE INFLATION RATES

Fuel	1980 Price ($/$10^6$ Btu)	1980-2010 Inflation Rate (%)
Coal	1.20	7.0
No. 2 Fuel Oil	6.04	9.0
No. 6 Fuel Oil	4.86	9.0
Nuclear	0.91	7.5
Natural Gas	1.82	9.5

G&H then discussed the cost of supplying electric power with four utilities which would provide service in the areas west of Harrisburg. None of these utilities had provided service to electrified railroads, so that rate schedules set up for such service were not available. G&H subsequently based their cost projections on calculated energy and demand requirements at each substation using standard industrial rate schedules. The specific utilities contacted and their rate schedules are listed below.*

1. Duquesne Light Co. - Schedule L
2. Pennsylvania Electric Co. - Schedule LP
3. Metropolitan Edison Co. - Schedule TP
4. West Penn Power Co. - Schedule 47

Composite energy and demand charges were developed for the route west of Harrisburg, based upon the generating mix of each utility (percent nuclear, coal, hydro, etc.) and the projected annual amount of energy and power required from each utility along the route. These composite charges were 2.75¢ per kWh and $3.24 per kW.

G&H then used the estimated 1987 generation mix of each of the four utilities to establish weighted average escalation rates for the total fuel costs of each utility. These fuel rates were then combined with a common 6% inflation rate for other operating expenses to create a weighted average annual cost escalation rate for each utility.

4.2 Summary of Costs and Units

The projection for diesel fuel costs used in the G&H study is a 9% per year escalation of the approximate early 1980 price of diesel fuel, 83¢ per gallon. This projection is compared to earlier projections using

*Source: 1979 Electrical World Statistical Report.

a much more analytical approach in Figure 4.1. The escalation rate for these served as a basis for the G&H selection of 9% per year. A newer, post-Iranian crisis analytically based projection will be very much needed in the near future to provide a more accurate assessment of the situation.

The composite electrical power charges based upon a weighted average of the serving utilities expressed in 1980 dollars are

Demand - $3.24/kW/month
Energy - $0.0275/kWh

The composite energy escalation rate for all four utilities, based upon the percent of total energy each would supply to Conrail, is 6.64% per year. All utility demand charges were assumed to escalate at 3.5% per year based upon an imbedded cost structure for capacity expansion.

4.3 Generalization of Results

The diesel fuel price forecasts used by G&H are based upon pre-Iranian crisis escalation rates and post-Iranian present price, probably the best assumption available at the time. Because of the incremental jump in the crude price, one must evaluate the effect of the various factors upon the escalation rate also. Admittedly, previous projections have fallen far short of the actual price increase rate. Naturally, in view of the great uncertainty in the future oil prices one should use the latest forecast data. Also, it is prudent to do a number of operating cost forecasts based upon a range of oil prices in the following decades.

The methodology used to derive future electricity costs seems logical and suitable for use elsewhere.

Electric power costs are local items, and therefore not generally transferrable. We would only note that the G&H total energy cost of 2.6¢/kWh is equal to the national average of energy costs for large power customers in 1978. Some utilities are already applying rate multipliers for low power factors, sometimes when below 95%. It is also expected that the rate for single phase power will be somewhat higher, particularly from the smaller utilities where this load makes a substantial technical impact. Both of these factors should be checked with the potential serving utilities when considering a new electrification project. In outlying areas, connection costs may become a major factor as transmission line branches often have to be run substantial distances. The costs of these extensions are usually passed onto the customer as an initial connection charge. In some cases it may be a major factor in selecting location and sizing substations.

5.0 MAINTENANCE (G&H Section 1.5)

There are three major maintenance expense categories which are related to electrification programs. Each category is discussed separately in this section.

5.1 Locomotive Maintenance

To perform an economic comparison of diesel motive power to electric motive power, the full maintenance costs of each type must be developed. As electric locomotives require substantially less maintenance due to their simplicity and higher reliability, the differential in maintenance costs represents one of the major economic advantages of electrification.

5.1.1 Design and Operational Strategy

Maintenance costs were developed for diesel locomotives using the following basic elements:

- Supervision and support
- Facility maintenance
- Locomotive servicing
- Scheduled inspection and preventative maintenance
- Scheduled overhauls
- Unscheduled running repairs
- Unscheduled heavy repairs

Data for these inputs were gathered from Conrail prepared standard reports, interviews with cognizant personnel, and visits to maintenance facilities. For comparison, R-2 reports of eight other railroads were also reviewed. From this data, essentially in 1977 dollars, total maintenance costs for the road unit fleet were developed. From known average unit annual mileage and productivity, these costs were prorated to provide maintenance costs per unit-mile and per trailing gross ton-mile, principally based upon Conrail experience. An annual inflation rate of 6% was used to escalate to 1980 dollars. This rate was justified "by the longer life and higher reliability of components, which partly compensate for higher initial item-prices." It was assumed that diesel locomotive availability would improve substantially over the next 30 years, with half of this improvement occurring between 1977 and 1982.

Substantially less experience exists in establishing maintenance costs for modern electric locomotives under U.S. railroad operating conditions. For base data, maintenance costs for the ASEA Rc series locomotives operated by the Swedish Railway (S.J.) and Brown Boveri/Swiss Locomotive Works high powered Ae 6/6, Re 6/6 and Re 4/4 operated by the Swiss Federal Railway (SBB) were evaluated. It was recognized that these figures applied to European operations involving much higher hp/ton powering, i.e., no drag operations, shorter and lighter trains, better track conditions, and a more thorough preventative maintenance program. The S.J. has determined that their electric locomotives cost 42% of their diesel locomotive maintenance on a unit mile basis. Similar ratios were found in other studies. Estimates of this ratio on an equivalent rail horsepower basis of .33 and, on an equivalent unit weight basis (drag operation) of 0.60 were also considered. A final estimate of modern electric locomotive maintenance cost of 80% of the cost of the three Swiss units was used in the study.

5.1.2 Summary of Costs and Units

The following cost figures were used for locomotive maintenance, all expressed in 1982 dollars for the medium growth scenarios:

	Diesel	Electric
Cost per mile	$2.49	$1.35
Cost per trailing KGTM	1.47	.37

Diesel maintenance cost expressed in 1980 dollars was $2.27 per unit-mile.

Availability has also been estimated, and the following figures have been developed:

	Conrail Diesel	Swiss Electric
1977	81.3%	94%
1982	87.0	
2010	92.0	

The utilization of the various locomotives was also evaluated for 1977:

	Annual Unit-Miles	Annual Unit Productivity (TKGT Miles)
Conrail Diesel	35,989	53,636
Swiss Ae 6/6	80,256	50,557
Swiss Re 6/6	130,943	77,624
Swiss Re 4/4II	102,500	39,855

It is more typical for diesel units to run in the range of 60,000 to 80,000 miles per year in U.S. operations, and Conrail diesel productivity can be expected to improve with an improved fleet. The Ae 6/6 is an earlier design and the newer Re 6/6 is the latest of their high-horsepower six-axle units which accounts for its high productivity.

5.1.2 Generalization of Results

The diesel maintenance cost figures are substantially higher than those indicated by other U.S. railroads operating similar locomotives. The composite cost of diesel locomotive maintenance excluding facilities maintenance, but including servicing costs, was developed in 1976* using inputs from several high density railroads. This figure, escalated into 1980 dollars ranged from $0.78 to $1.02 per unit-mile. Considering that facilities maintenance costs are 17% of the G&H figure, the G&H number reduces to $1.88 per unit-mile, approximately twice the equivalent cost range stated above. It appears that Conrail maintenance costs are significantly higher than for many other railroads, and their cost figures should not be applied to the general case.

The cost of maintenance of modern electric locomotives using a composite of their Penn Central E-44's, Swedish Rc series, and Swiss high powered units* gave a cost of $0.28 per unit-mile in 1976 dollars. Extrapolated to 1980 dollars, this is $0.39 per unit-mile. These figures include facilities maintenance.

The application of amotorized maintenance facilities improvements to direct locomotive maintenance costs is a highly site-specific element. Any specifically developed investment requirement should not be applied generally.

The maintenance of locomotives is made up of a virtually fixed annual cost for periodic inspections and preventative maintenance (independent of mileage) and a separatable per-mile cost. With typical well-utilized road units these two cost elements are nearly equal on an annual basis. It has been customary to pro-rate the fixed cost on a per-mile basis resulting in a usable average per-mile maintenance cost. With the relatively low production of the older Conrail locomotives, this total per-mile cost is higher than for typically newer fleets partially due to the adverse ratio of fixed to variable costs.

Maintenance costs presented on a per trailing-gross-ton-mile (production) basis are not generally applicable, because the production capability of locomotives is dependent upon individual railroad and service requirements and capabilities. Production dependent maintenance figures should be developed for each application from the basic per unit-mile cost figures.

Availability of 85% for diesel locomotives is generally attained in well maintained fleets. While efforts to improve reliability are improving this availability, a future figure much above 88% is difficult to justify. Availability of 94% for electric units is presently achievable and will probably not be improved much with the future designs, as periodic maintenance requirements utilize most of the unavailable time.

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*Reference 1, Paragraph 3.8.1, page 90.

5.2 Reduced Track Maintenance

Because of the higher performance of electric locomotives, often less locomotive weight is required to meet tractive effort requirements. Also, existing track may have higher density, and trackage can be reduced.

5.2.1 Design and Operational Strategy

In the G&H study it was determined that with the higher performance of electric motive power, 36.7 miles less track in 1982 and 75.1 miles less track in 2010 will be required than if diesel motive power had been retained. The fact that this track will not have to be maintained results in a saving which is credited to electrification.

5.2.2 Summary of Costs and Units

A mainline track maintenance cost of $5,000 per mile has been estimated. Annual escalations of 4.6% for labor and 6% for materials have been used. This results in a savings of $22 million over the project life of 29 years.

5.2.3 Generalization of Results

The approach used in the G&H study is applicable to other studies in which reduction in track mileage or the need to increase track mileage can be reduced due to electrification. This savings should be annualized and included as an annual increment in the DCF cost analysis.

The other element of reduced track maintenance arises from the fact that a diesel locomotive consist weighs more than an equivalently performing electric locomotive consist. As wear out of rail is primarily a function of tonnage transported over it, this can be converted directly into cents per unit-mile of electric or diesel operation. The cost development in Reference 1 expressed in 1980 dollars is approximately 2.1¢ per diesel unit-mile. In most studies, this element has been considered small enough to neglect.

5.3 Catenary and Substation Maintenance

5.3.1 Design and Operational Strategy

The maintenance of the catenary, substations, and sectionalizing stations is presented in an apparently current dollar lump sum for the entire 29 year project. The annualized cost, which was not presented separately, was escalated at 4.6% per year for labor and 6% per year for materials.

5.3.2 Summary of Costs and Units

The current dollar total cost presented was $65.6 million. While the split between labor and materials was not given, it appears that the first year cost on a current dollar basis would be about $1-million. Assuming 1019 miles of catenary, the maintenance cost is $981 dollars per track mile for catenary, substations, and sectionalizing stations.

5.3.3 Generalization of Results

While the cost estimate of $981 average per catenary-mile is quite a bit lower than the Reference 1 estimate of $1,945 per catenary mile. This difference can be partially reconciled on the basis that the former figure reflects costs for maintenance of a two, three, and four track line, while the latter is based on more common two- and single-with-long-sidings type of railways. We feel the G&H cost figure would be very low except for readily accessible three or more track systems.

6.0 ELECTRIC POWER SUPPLY (G&H Section 2.1)

The objectives of this section were to

- Determine the most feasible electrification supply plan for the study route.
- Determine electrical system capacity requirements, equipment requirements and the cost of implementing this part of the system.

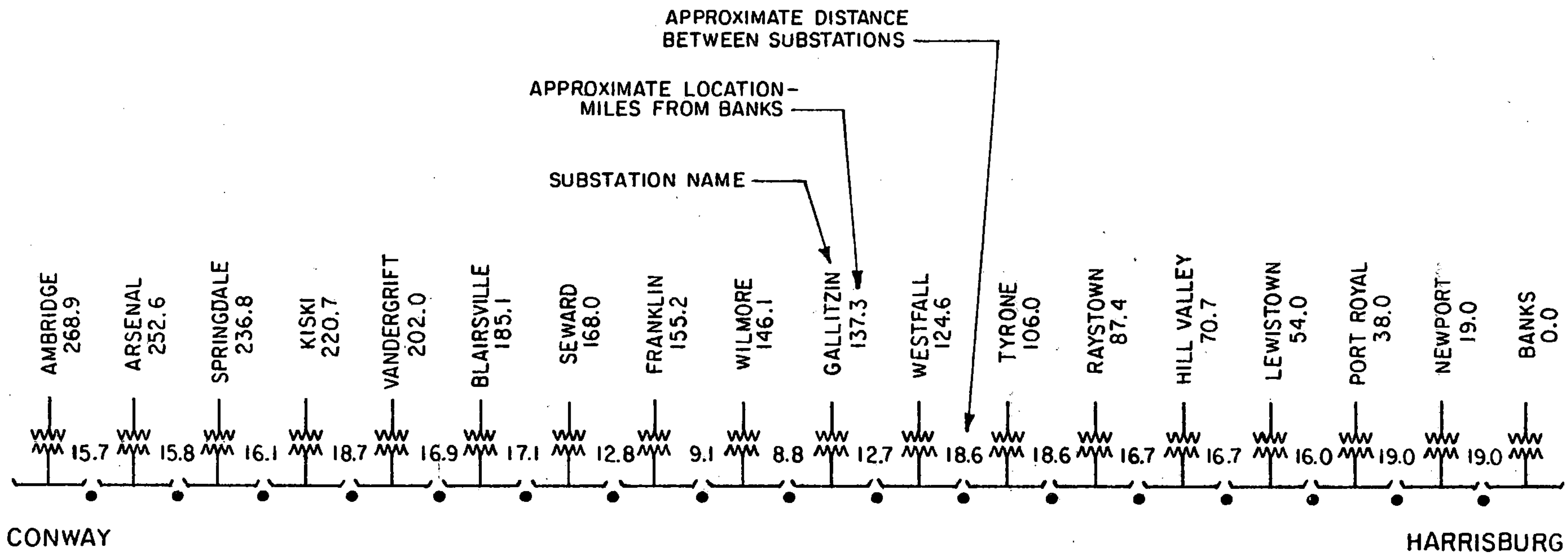
The system includes transmission supply, frequency and voltage selection, location and sizing of substations, and catenary electrical characteristic requirements. This is work done prior to specification of catenary and substation design details.

6.1 Design and Operational Strategy

After considering systems operating at 12 kV, 60 Hz; 25 kV, 60 Hz; 25 kV, 25 Hz; 50 kV, 25 Hz, and 50 kV, 60 Hz, G&H recommended a 25 kV, 60 Hz system for all trackage west of Harrisburg. This power supply system would consist of 18 substations along the 268 mile route, as shown in Figure 6.1. Two transformers were specified for each substation, such that either one could meet normal train power requirements. Each substation would be fed by a single utility transmission line operating at one of these standard voltages: 69, 115, 138 or 230 kV.

The catenary system design is a center feed system, where each substation supplies power to the center of a catenary section on the order of 15 miles in length. Catenary switching stations are located at the junctures of adjacent catenary sections. These switching stations, which normally have all switches open, permit near-normal operation on all tracks even if one substation is out of service. In this case the catenary section normally powered by the inoperative substation will be supplied with power at each end from the adjacent catenary sections via their substations. The G&H study also concluded that power factor correction equipment installed in each substation would be beneficial, and recommended including capacitor banks in the design for this purpose.

G&H discussed the cost of supplying electric power with four utilities which would provide service in the areas west of Harrisburg, as described in Section 4, "Traction Energy Costs". None of these utilities had provided service to electrified railroads, so that rate schedules set up for such service were not available. G&H subsequently based their cost projections on calculated energy and demand requirements at each substation using standard industrial rate schedules. Composite energy and demand charges were determined for the territory west of Harrisburg using weighted average techniques based upon each utility's generating mix and its contribution to total energy requirements.



● PHASE BREAK AND CATENARY SECTIONALIZING STATION-LOCATED AT APPROXIMATE MIDPOINT BETWEEN SUBSTATIONS.

FIGURE 6.1 25KV 60HZ CENTER FEED ELECTRIFICATION SYSTEM FOR WEST OF HARRISBURG.

The following system configurations were examined and evaluated.

- 25 kV, 25 Hz with centralized 60 to 25 Hz converter stations, a 230 kV, 25 Hz transmission line, and parallel feed to the catenary.

- 25 kV, 25 Hz with converter stations at each substation, parallel feed to catenary.

- 25 kV, 60 Hz center feed distribution with phase breaks.

- 25 kV, 60 Hz, 3-wire autotransformer, center feed distribution.

Two basic locomotive types were used in the electrical computations; a 5100 rhp thyristor unit similar to the General Electric Model E60C and a modular group of thyrister locomotives rated at 1500 hp per axle.

Contingency operation at near normal capacity is to be maintained with loss of a transmission line source to one or more (not adjacent) substations and loss of a substation. Loss of one transformer has little effect, as they are sized so a single transformer can handle near normal peak loads.

Computation of substation demand was done for the peak load expected in the year 2010 High Growth Traffic Scenarios. This represents operation of 75% track capacity. Using the train schedule for this day, the daily substation load profiles were calculated using the Alternating Current Railroad (ACRR) program which uses TPC and Train Dispatching Simulator program inputs. Criteria required catenary voltages to remain within 25 kV ± 10% for normal and a minimum of 17.5 kV for reduced performance.

The 25 kV, 60 Hz center fed system was selected as technically feasible and cost-effective. The 25 kV, 60 Hz, 3-wire autotransformer system, while it has the capability of maintaining better catenary voltage regulation, was much more expensive. The two 25 Hz configurations were also rejected on a cost basis.

50 kV catenary was also considered. While this saved $12,500,000 in substation costs for Harrisburg to Conway and Trent to Oak Island, the additional costs of three-voltage locomotives ($22,000,000) and civil construction to achieve the needed additional clearances ($23,000,000) greatly offset the savings. 50 kV was rejected on the basis of economics.

Power factor correction was found to be economically practical and most cost-effective when capacitors are located in the substations.

6.2 Summary of Costs and Units

Total estimated installed costs for each candidate electrification system were:

- 25 kV, 25 Hz with central converters (initial costs only)	$139,900,000
- 25 kV, 25 Hz with individual converter substations (initial costs only)	$ 91,400,000
- 25 kV, 60 Hz, center feed, including power factor correcting capacitors	$ 53,400,000
- Autotransformer station for 25 kV, 60 Hz, 3-wire additional to center feed system	$ 30,000,000

The total number of substations required from Harrisburg to Conway are 18 with a maximum spacing of 19 miles, a minimum spacing of 8.8 miles, and an average spacing of 15.78 miles. Maximum peak 15-minute demand was 27.8 MW, average was 21.6 MW. Maximum 60-minute demand was 17.9 MW, average was 13.8 MW. The highest short-term peak is 37.5 MVA.

The major power supply system components are substations and switching stations. Figure 6.1 shows the location of substations and switching stations for the line segment from Harrisburg to Conway. Table 6.1 provides technical and cost data for substations; Table 6.2 has similar but abbreviated data for switching stations, since there are only three types.

Power factor correction to 0.95 at the substations would result in a total energy and penalty savings at 1982 present worth of $3.9 million and cost $633,000 for installed capacitors. Correcting power factor to 0.9 would save $916,000 and cost $216,000.

Power factor correction to 0.9 on the locomotives would cost over $5.6 million and provide an additional present worth savings in catenary losses of $1.25 million. Even with this additional savings, on-board power factor correction does not approach cost-effectiveness.

6.3 Generalization of Results

Although the G&H study concluded that electrification at 25 kV, 60 Hz was optimal for the Harrisburg-Pittsburgh line, a system designed for 50 kV, 60 Hz may be more cost-effective in relatively open country. In fact, the study indicated that the power supply system cost of $53.4 million could be reduced by $12.5 million (23%) if 50 kV were used instead of 25 kV. The higher voltage was not selected because of the extra costs associated with modifying locomotives to take 50 kV (as well as the standard 12 and 25 kV system voltage elsewhere) and additional civil

TABLE 6.1

SUBSTATION DATA: G&H RECOMMENDED 25 kV, 60 Hz SYSTEM

Name	Peak Hourly Demand (MW)	Substation Rating* (MVA)	Number of Tracks	Distance to Next Substation (Miles)	Cost ($ millions)
(HARRISBURG) BANKS	10.1	20	3	0	2.626
NEWPORT	17.3	30	3	19.0	2.672
PORT ROYAL	14.5	20	3	19.0	2.626
LEWISTOWN	15.2	40	3	16.0	2.717
HILL VALLEY	17.9	30	3	16.7	2.518
RAYSTOWN	14.2	20	3	16.7	2.626
TYRONE	15.8	30	3	18.6	2.518
WESTFALL	14.9	30	4	18.6	2.765
GALLITZIN	12.1	20	4	12.7	2.720
WILMORE	8.6	20	4	8.8	2.873
FRANKLIN	11.6	30	4	9.1	2.765
SEWARD	13.8	40	4	12.8	2.964
BLAIRSVILLE	15.1	20	2	17.1	2.226
VANDERGRIFT	16.3	30	2	16.9	2.271
KISKI	13.5	20	2	18.7	2.226
SPRINGDALE	11.0	20	2	16.1	2.226
(PITTSBURGH) ARSENAL	15.2	20	2	15.8	2.226
AMBRIDGE	10.8	20	2	15.7	2.188
			SUBTOTALS:	268.3	45.753
	ADDITIONAL ITEM:	REAL ESTATE FOR SUBSTATIONS			.623
			TOTAL COST:		46.376

*This is the total substation capacity, supplied by two transformers in each substation. Either one could handle the peak load in a satisfactory manner, due to the high overload capacity of each transformer (up to 300% for short periods).

TABLE 6.2

SWITCHING STATION DATA

Station Switching Capability (number of Tracks)	Quantity Required	Cost per Unit ($ thousands)	Total Cost ($ millions)
2	5	182	.91
3	7	234	1.64
4	6	286	1.72
			4.27

engineering costs. These two costs totalled approximately $45 million. However, the locomotive modification costs would not apply for locomotives designed primarily for 50 kV, and civil engineering charges could be much less in open country.

The substation costs are about $60 per kVA at normal maximum rating. This cost is significantly higher than other recent estimates of substation cost. The reasons for this difference will be discussed in Section 7, Substations, since that is where a detailed breakdown of substation components and cost is presented.

The use of a load simulation program such as ACRR is a sophisticated and optimum method for handling the substation load problem. Where simpler traffic patterns have been encountered, manual calculation using TPC inputs has been found cost-effective.

The study of economics of power factor correction should be applicable to other studies. If power factor correction is cost-effective, and it generally is on the basis of reduced demand charges and power factor penalties, substation located capacitors should be more economical than on-board capacitors. Consideration should also be given, however, to the cost-effectiveness of normally high power factor propulsion systems such as rectifier-chopper and asynchronous variable frequency controls.

7.0 SUBSTATIONS (G&H Section 2.2)

The objectives of this work were to develop conceptual designs for substations and associated apparatus to a level of detail required to estimate the capital costs of substations and switching stations.

7.1 Design and Operational Strategy

A simplified one-line diagram of a typical 3-track substation and a switching station are shown in Figure 7.1. The major components of the substation are power transformers, metering transformers, circuit breakers, switches and lightning arresters. The switching station consists primarily of switches. Power transformers are standard two-winding types with off-load tap changers and provision for the future addition of cooling fans and oil circulating equipment. All substation power transformers were specified to meet one of three standardized power ratings, namely 10, 15 or 20 MVA.* This requirement improves the interchangeability of transformers among substations in the event of transformer failures.

Primary disconnect switches were specified to be outdoor, air-break, motor-operated units with three-ganged poles for the utility incoming power supply line switches and two-ganged poles for the transformer isolating switches. The high-speed grounding switches were specified to be single-pole units with spring or propellant-actuated closing mechanisms suitable for outdoor application.

Transformer secondary (25 kV) circuit breakers require two poles, but feeder and bus-tie breakers would be single-pole units. All breakers were specified to be outdoor type 46-kV class units with motor-charged, spring-operated closing mechanisms and maximum interrupting capability of 20 kA.

Each power supply substation described by G&H also included a switchboard, a control house and provision for complete remote operation.

Switches in the sectionalizing/switching stations were 46 kV-class manually-operated single-pole units capable of interrupting 600 A loads and closing into 1200 A loads.

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*These are self-cooled ratings, sometimes indicated by the letters OA after the numerical MVA rating. OA symbolizes oil/air cooling, where naturally circulating oil transfers heat to cooling fins located outside the transformer and subject to natural atmospheric airflow. FO signifies forced oil cooling and FA indicates forced air cooling (fans used to increase airflow over the cooling fins). The combined use of forced oil and air cooling is signified by FOA. These conventions are discussed here because it is common to see a transformer specified by three values, e.g., 20/27/33 corresponding to OA/FA/FOA.

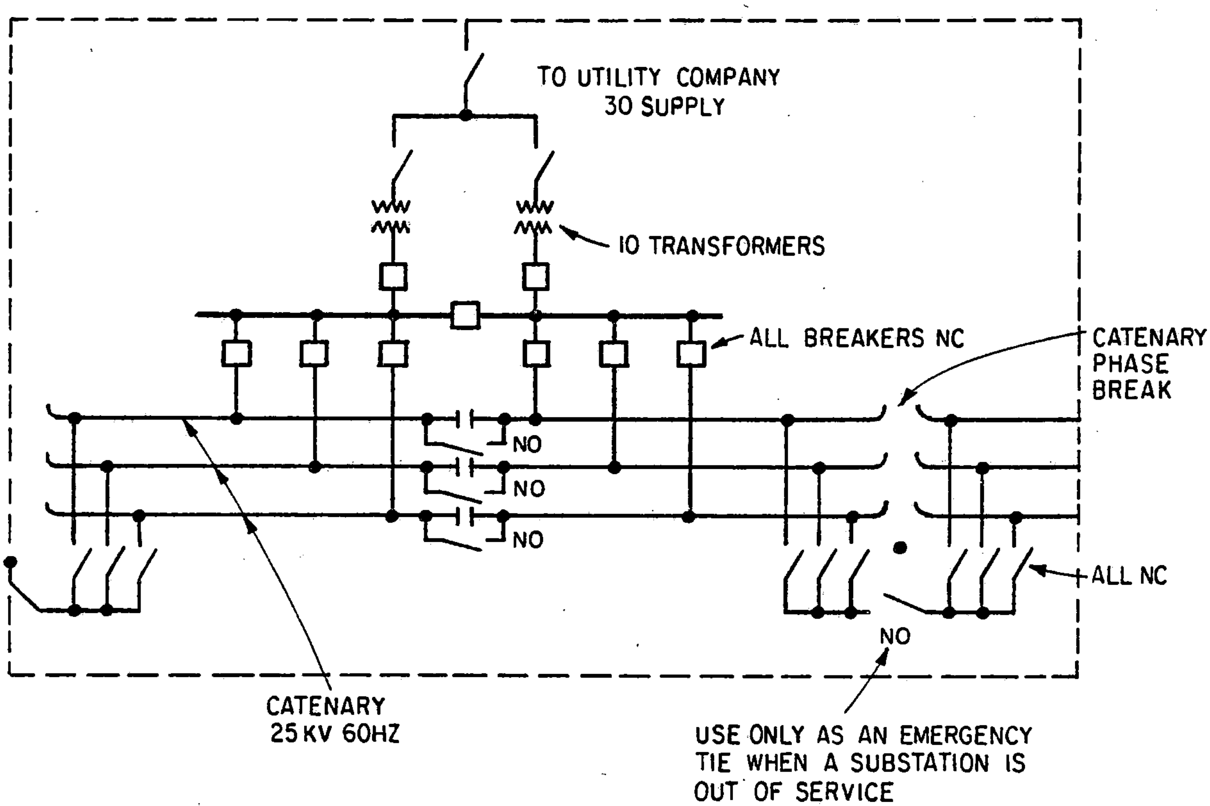

FIGURE 7.1 TYPICAL TRACTION SUBSTATION
TWO TRANSFORMER - THREE TRACK

7.2 Summary of Costs and Units

Table 4.1* summarizes the major components and costs of a typical power substation designed to supply three tracks. G&H used this particular substation as a "base case", and modified its design and components to develop the cost of all other substations.

TABLE 4.1

BASE CASE SUBSTATION COST

(Lewistown Substation)

Unit Pricing Element	Unit Cost ($)	Quantity	Total Cost ($)
a. Incoming line (230 kV)	169,000	1	169,000
b. High-voltage bus (230 kV)	208,000	1	208,000
c. Main transformer (230 kV/25 kV, single-phase, 20 MVA)	282,750	2	565,500
d. Two-pole isolating breaker (25 kV)	136,500	2	273,000
e. Potential transformer (25 kV/120 V)	26,000	2	52,000
f. Auxiliary transformer (25 kV/120-240 V, 167 kVA)	26,000	2	52,000
g. Bus tie breaker (25 kV)	175,500	1	175,500
h. Feeder breaker (25 kV)	110,500	6	663,000
i. Relaying, control, and supervisory control	357,500	1	357,500
j. Site preparation	100,750	2	201,500
Total Estimated Cost of Basic Substation			2,717,000

A comparative estimate** escalated into 1979 dollars gives a cost of $1,200,000. This substation design uses fewer switching devices and circuit breakers. Its application is adapted more to the outlying regions where fault currents are not as severe and transmission networks less complex. This substation does not include separate incoming line isolation, separate transformer circuit breakers, or metering and relaying beyond that necessary for billing and basic protection. The costs do not include supervisory control or remote annunication. The design is more akin to an industrial transformer setting than a fully equipped utility substation.

*This table is identical to Table 2.2-1 of the G&H report.

**Reference 1, Figures 3.3.2 and 3.3.3.

Table 4.2 provides similar cost data for a switching station. This is a "base case" design, also configured for two-track operation.

TABLE 4.2

BASE CASE TWO-TRACK CATENARY SECTIONALIZING STATION COST

Unit Pricing Element	Unit Cost ($)	Quantity	Total Cost ($)
Basic structure consisting of poles, frames, and tie switch	78,000	1	78,000
Catenary isolating switches	26,000	4	104,000
Total Estimated Cost of Basic Catenary Sectionalizing Station			182,000

A comparative estimate* escalated to 1979 dollars indicates a cost of $111,000. An oil circuit breaker sectionalizing station is similarly estimated to cost $221,000. Both of these sectionalizing station designs are of simpler design, with provisions to tie across each phase break, but not parallel adjacent catenaries. Costs of remote supervisory control and annunication have not been included in the Reference 1 estimates.

7.3 Generalization of Results

The designs of substations and switching station proposed by G&H for a 25 kV, 60 Hz power supply appear to be satisfactory and complete for their intended uses. As such, these designs for 2, 3 and 4 track substations and switching stations can be used as general designs for other electrification studies in high density areas of the U.S.

There is some question as to whether the designs and costs estimated by G&H for these stations are in the range of what may be called typical or nominal for wider application. Referring to a study** of engineering cost data performed for DOT in 1976 and escalating those costs to 1980, it is suggested that a typical two-track substation would cost about $35 per kVA of capacity at present. The 1981 cost of a two-track substation, according to the G&H study, is approximately $56 per kVA; reduced by 12% to approximate 1980 cost, this is about $49 per kVA. Therefore, in order to use the G&H cost data for general estimating purposes in more outlying regions, it may be appropriate to reduce these costs by roughly 30%.

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*Reference 1, Figure 3.3.5.

**Reference 1.

8.0 CATENARY (G&H Section 2.3)

The objective of this work was to develop a conceptual design for a catenary system to a level of detail required to estimate the system capital cost.

8.1 Design and Operational Strategy

G&H considered a number of catenary system designs before selecting a tangent-chord, fixed-termination design supported by transversely guyed wood poles. Figure 8.1 is an illustration of this system. Although a two track installation is shown, the basic design would also be used for three- and four-track applications. Certain route segments require special structural arrangements, such as self-supporting steel poles, but most of the trackage west of Harrisburg can be served using guyed poles.

A number of criteria were established for the catenary system, of which a few basic items are listed below:

- Maximum train speed of 70 mph.
- Maximum wind loading of 65 mph on bare conductors.
- Structure loading to meet ANSI Heavy Loading District specifications at a minimum or current Conrail specification.
- Electrical clearances to meet current ANSI specifications and the Report of AREA Committee 33, Part 2.1.

At phase breaks (the locations where on 15-mile segment of catenary ends and another begins) a more complex catenary design, the constant-tension system, is recommended by G&H. Mechanical loading considerations led to this choice, rather than variations in contact wire height. All catenary systems would be protected by ground wires.

The contact, messenger and ground wire specifications are summarized briefly below.

Contact Wire:	336.4 kcmil hard-drawn, grooved 55% conductivity bronze, "Figure 9" deep section.
Messenger Wire:	19 strand composite copperweld-copper conductor, Type E, with a copper-equivalent conductivity of 250 kcmil.
Ground Wire:	336.4 kcmil, 30/7 ACSR

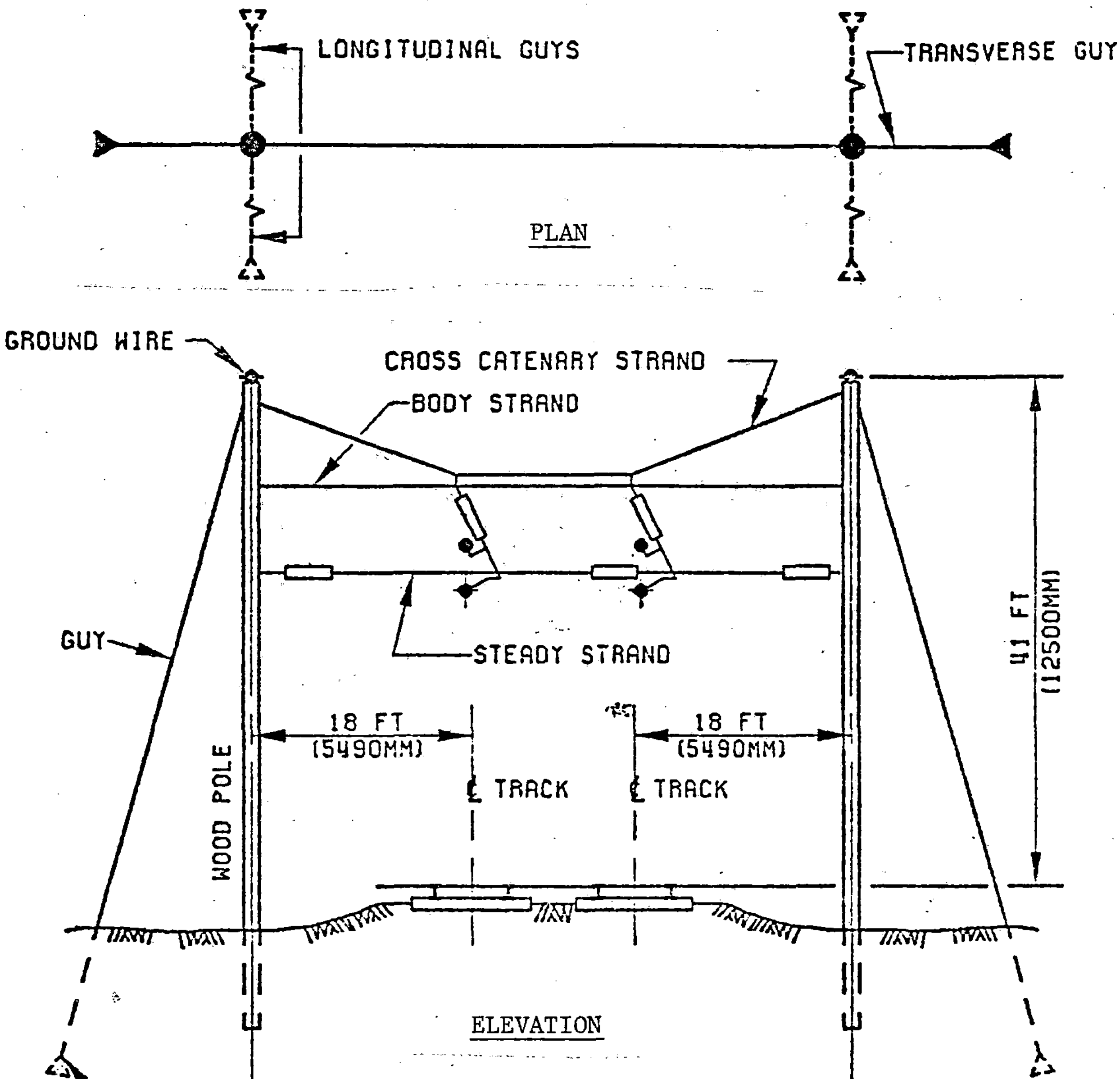

FIGURE 8.1

BASIC CATENARY STRUCTURE

NOTES

1. Poles would be Class II. Southern Yellow Pine.

2. Poles would be embedded directly in soil or rock in augered holes backfilled with crushed stones or other suitable material.

3. Screw type anchors would be used in normal soil. Where rock is encountered, rock anchors would be substituted.

4. For longitudinal structural stability, longitudinal guys would be provided at approximately every 8th structure.

Source: This is G&H Figure 2.3-1

In open country, the nonimal minimum distance from railtops to contact wire would be 24'0". Structure spacing would vary from a maximum of 240' on tangent track to a minimum of 135' on curved track. A catenary segment of 15 miles (nominal) would be made up of individual sections 7,500' in length, called "tension lengths".

Air gap section "breaks" would be constructed at specific locations within a catenary segment to permit electrical isolation of individual lengths of catenary for maintenance and repair. The entire 25-kV system would be insulated to 46-kV class standards.

The guy wires and cross-catenary wires of wood poles would be bonded to the overhead ground wires, for the purpose of minimizing pole fires due to leakage current across insulators. Similar bonding would also be employed on the steel poles used in special situations. The overhead ground wires themselves would be connected to the rails through impedance bonds to limit the difference in potential between rails and the steel structures.

8.2 Summary of Costs and Units

G&H examined tubular and wide-flange steel support structures as well as aluminum, precast concrete and wood poles before selecting wood poles on the basis of minimum cost per catenary support structure. Table 8.1 presents the results of a cost comparison between the two competitive support structures, transversely-guyed wood poles and wide-flange steel "poles". Table 8.2 contains per-unit data for several types of wood support structures recommended by G&H.

Total capital cost for the complete catenary system west of Harrisburg is estimated to be $98,520,000, of which the support structures represent approximately $37,000,000.

8.3 Generalization of Results

G&H selected a fixed-termination catenary design primarily because Conrail has specified a 70 mph speed limit for the route west of Harrisburg. The disadvantage of this design, namely relatively small variations in the height and profile of the contact wire, was overmatched by the higher cost of a constant-tension system and the fact that modern lightweight pantograph collectors could accommodate the expected contact wire variations at speeds less than 70 mph. It is probable that trains operating in excess of 70 mph would require the more stable but constant-tension catenary system.

Generalizing about the usefulness of cost data developed by G&H for other electrification projects is very difficult because catenary system costs were not broken down into categories, e.g., two-track tangent, three-track light curves, etc. Since the total cost of catenary structures

TABLE 8.1

COSTS OF STEEL AND WOOD CATENARY SUPPORT STRUCTURES

Track Section	No. of Tracks	Route Miles	No of Struct's	Construction Costs: Wood Pole Construction	Construction Costs: Steel Pole Construction
TANGENT	1	11	250	508 800	645 100
	2	117	2 616	10 045 600	13 472 500
	3	63	1 393	5 760 200	7 383 000
	4	55	1 219	5 540 700	6 887 500
LIGHT CURVE	1	3	87	177 000	254 900
	2	29	815	2 848 100	4 726 800
	3	46	1 278	5 284 200	7 667 800
	4	19	520	2 048 800	3 198 000
HEAVY CURVE	1	3	134	272 600	459 600
	2	16	650	2 206 800	4 420 100
	3	5	180	638 100	1 278 000
	4	10	408	1 607 200	3 057 700
TOTAL				36 938 100	53 451 000
SALVAGE					1 069 000
NET TOTAL COST				36 938 100	52 382 000
DIFFERENTIAL NET TOTAL COST				15 443 900	

NOTES

1. The cost comparison includes mainline routes and route segments designated for electrification.

2. The costs include material, labor and equipment for structural components only, i.e., foundations, guys, anchors, and cross-strands and excludes items common to both wood and steel poles such as hardware, insulation, grounding, ground wires and associated materials.

3. The salvage value for steel poles is estimated to be 2%. This represents the retrievable value of steel after the projected life of project (30 years) less the cost of retrieving, projected in today's dollars.

Source: G&H Table 2.3-1.

TABLE 8.2

COST OF GUYED WOOD POLE CATENARY STRUCTURES

Type of Track	Number of Tracks	Cost Per Structure
Tangent	1	$2,040
	2	3,840
	3	4,140
	4	4,550
Light Curve	1	$2,030
	2	3,490
	3	4,130
	4	3,940
Heavy Curve	1	$2,030
	2	3,400
	3	3,550
	4	3,940

Source: G&H Table 2.3-1.

is about 38% of the total catenary system west of Harrisburg, one may infer that the non-structural catenary components represent 62% of the cost. With an estimated 1019 track miles of catenary, the estimated unit cost of catenary is about $97,000 per mile. Another study* of railroad electrification costs estimated that the cost of a double-track constant-tension catenary system would be in the range of $66,000 to $153,000 per track mile (1980 dollars). The G&H figures compare well with these estimates considering that the terrain is variable from easy to moderately difficult.

*"Engineering Cost Data Analysis for Railroad Electrification", DOT-TSC-1156, 1976.

9.0 CIVIL RECONSTRUCTION (G&H Section 2.5)

While clearances for various new railroad line segments have been recently established by regulation; this has not generally been made retroactive. Clearances have been increased on a selective basis in many cases as traffic demands required them. The addition of an overhead catenary system, required for most heavy freight line-haul electrified operations, either further reduces this clearance, or requires the increase of limiting clearances. As reduced limiting clearances are usually not acceptable from either operational or safety aspects, bridge heights must be increased, tunnels rebuilt, signal bridges raised or redesigned, and, in many cases, tracks lowered below clearance limiting structures. The cost of this civil reconstruction can be, and usually is, a major capital investment factor in an electrification program. As expected, it is a major cost element in the prospective electrification of the Conrail line from Harrisburg to Pittsburgh.

9.1 Design and Operational Strategy

The G&H study considered two alternate routes: Harrisburg to Pittsburgh via Kiski Junction, known as the Conemaugh line and the Harrisburg to Pittsburgh mainline.

The basic reference was the American Railway Engineering Association (AREA) Committee 33 Clearance Diagram. This diagram sets desired and minimum clearances for catenary of various voltages. The clearances for 25 kV and 50 kV catenary were considered in this case.

The existing vertical clearance of each structure was compared with the clearance required for the two catenary voltages considered. Sources of information were Conrail's computerized bridge tabulations, Conrail's clearance diagrams and track charts, supplementary field measurements by Conrail regional engineering offices, and a site survey of Harrisburg to Pittsburgh line segments. Existing load gauge data source was the 1977 edition of Annual Railway Line Clearance Manual. Major structures requiring significant reconstruction were specifically identified.

Major affected sites were analyzed to determine whether removal or raising of the structure or lowering track or a combination would be most practical. In general, track lowering was most cost-effective and practical.

The basic formula for computing the required clearance is as follows:

$$H = Y + C + C_1 + D$$

where:

H = Minimum distance from top of rail to underside of structure.

Y = Load gauge (maximum height of car plus load).

C = Static electrical clearance between the overtrack structure and the supporting messenger wire.

C_1 = Static electrical clearance between the contact wire and the car, including allowances for upward displacement of vehicle, downward catenary drift, and construction tolerance.

D = Depth of catenary, assumed to be 6 inches.

In addition, an allowance of 12 inches for track rise has been included to account for future maintenance considerations.

Using the electrical clearance requirements published by the AREA Committee 33 modified to suit fixed-termination variable-tension catenary, the following criteria was established:

	25 kV	50 kV
C = Static electrical clearance, overtrack structure to messenger wire (absolute minimum), inches	8	16
C_1 = Static electrical clearance, contact wire to car, inches	13	26
D = Assumed depth of catenary, inches	6	6
T = Track rise allowance, inches	12	12

The reconstruction sites were classified into four major categories:

a. Rail traffic under highway or railroad bridges
b. Rail traffic under minor structures
c. Rail traffic through tunnels
d. Rail traffic on through-truss bridges

Where track lowering was selected, particular attention was paid to the technical and cost impacts of drainage, stability of adjacent retaining structures, and interferences with utilities and foundations.

The present railroad has a loading gauge less than the 21 feet specified for new construction. Where structure raising or track lowering was indicated, only that additional clearance required for the catenary plus a 12-inch track use anticipated with future maintenance. Where structures must be replaced, they would provide the full 21-foot loading gauge. For structures which were already scheduled for replacement, their replacement cost would not be charged to electrification.

Protective barriers and shields are specified. Aluminum protection barriers would be installed along the parapets of overhead bridges and along the top of retaining walls at deep cuts. These are to deter accidental contact with the catenary as well as vandalism. Concrete bridges would additionally have continuous steel plate shields above the catenary to protect the reinforcing steel from electric power arcs.

It was found that primary distribution lines crossed the railroad ROW at nearly every public grade crossing and practically nowhere else. No secondary distribution lines crossed the ROW. No crossings met the recommended 45-foot minimum above the rail, and all would have to be raised. A sample of about 3/4ths of the line's crossings was obtained from the serving utilities, and this ratio was applied to the remainder. An allowance of one telephone cable or line crossing for every two primary distribution line crossing was made. One major telephone crossing was costed separately.

Transmission line crossings were few, and those had adequate clearance, so it was determined that existing clearances were adequate. Generally, transmission lines crossing railroads and similar construction have clearances which allow for primary distribution line crossings, and the catenary falls in the same general height and clearance category.

9.2 Summary of Costs and Units

For the Enola to Conway segment, via Conemaugh line the following statistics were developed for overhead clearance reconstruction, including six tunnels:

Route miles	283
Structures reviewed	276
Structures requiring modification (25 kV)	72
Modified structures/mile (25 kV)	0.25
Structures requiring modification (50 kV)	2.54
Modified structures/mile (50 kV)	0.90

Detailed breakdowns of unit costs are not given but the following useful figures for bridge rebuilding for 25 kV are available as calculatable:

Overhead bridge obstruction rebuilding cost	$ 11,333,000
Average cost per structure	171,712
Average cost per route-mile	40,000

Cost of increasing clearance in tunnels:

Total cost for six tunnels	$ 2,588,000
Cost per tunnel	431,000

The following figures are available for protective barriers:

Total cost of protective barriers	$ 2,952,000
Number of bridges requiring barriers	90
Average cost barriered bridge	32,800
Lineal feet of barrier	22,080
Average cost per foot of barrier	134
Average cost per route-mile	10,431

The following figures were presented for utility line reconstruction:

Total utility line reconstruction cost	$ 1,873,000
Cost per typical primary line crossing	9,400
Cost per typical telephone crossing	600
Average cost per route-mile	6,618

Undergrounding a major 500 pair telephone cable was estimated at $88,000.

9.3 Generalization of Results

The G&H study is site-specific, an approach which has been most effective in estimating the costs for thorough railroad electrification studies. By determining the required clearances and desired loading gauge, examining all potentially limiting overhead structures, and then estimating the method and cost of modification of each of the interfering structures, a reasonably accurate total civil reconstruction cost can be predicted.

The estimated cost for increasing bridge clearances for these line segments is substantially lower than a recent site-specific estimate* for loading gauge increase of 21.5 miles of the Boston and Main railroad from Boston to Lowell. This is a double-track mainline running through urban and rural terrain; conditions which appear to be comparable. Seventeen structures, approximately 0.8 structures per mile, require

*Sverdrup and Parcel and Associates engineering evaluation.

reconstruction; fifteen of them are to be corrected by track lowering. The cost is estimated in the range of $400,000 per structure. While the details are not available, the G&H costing appears to agree reasonably with Figures 3.4.1 and 3.4.2 of Reference 1. These differences point out the importance of developing accurate estimates for the reconstruction of each site on a structure-by-structure basis. Tunnels are particularly site-specific.

Other unit costs are probably more generally applicable. The unit costs of barriers expressed in 1980 dollars.

Barrier per lineal foot	$ 176/foot
Primary distribution line crossing	$12,400 each
Telephone line crossing, when joint with distribution line	$ 800 each

10.0 FINANCIAL ANALYSIS (G&H Section 1.2)

The objective of this work was to evaluate the economic and financial consequences of electrification for the Harrisburg-to-Pittsburgh line segment. It was determined that only the Conemaugh line route would be electrified.

10.1 Design and Operational Strategy

G&H determined the cost of all items required to electrify and operate the route, the cost of operating the two, each alternative using either electric or diesel locomotives, estimated rail traffic, and determined several traditional measures of financial performance based upon incremental cost differences. Table 10.1 summarizes the analysis of railroad electrification from Harrisburg-to-Pittsburgh. Although results are shown using constant dollars and current dollars, all costs and savings are expressed in current dollars in the report unless noted otherwise.

The G&H financial analysis is based entirely upon costs; revenues were excluded since it was assumed that they would be identical for diesel or electric locomotive use. The operations forecast needed for the determination of operating requirements in the years 1982-2010 was derived from the base-case traffic forecast. Two other traffic forecasts were examined, corresponding to low and high growth scenarios.

Straight-line depreciation was used to determine salvage values, but the report does not state explicitly what depreciation schedule (e.g., sum-of-years digits) was used to determine annual operating expenses for tax purposes.

G&H used separate inflation rates in the analysis for the following cost items, but the report does not specify what these rates were in their Section 4. The following line items were included:

- Construction cost (for all fixed plant investment);
- Diesel locomotive price;
- Electric locomotive price;
- Maintenance of Way labor;
- Maintenance of Equipment labor;
- Transportation - Train Crews;
- Transportation - Other;
- Materials Costs;

- Diesel Fuel Cost;
- Electric Energy Consumption (kWh) Cost; and
- Electric Peak Demand (kWh) Cost.

Income tax shields and credits were factored into the G&H analysis, consisting primarily of investment tax credits (exact details not in report), loss carry-forwards based on losses in previous years, investment tax credit carry-forwards and taxes on recapture (of assets) from sales of assets. In implementing these tax considerations, G&H assumed that Conrail would be profitable in 1982, and that previous losses and tax credits would make income effectively exempt from federal taxes for nine years after that*.

Table 10.2 is a summary of the investments required to electrify the Conrail mainline west of Harrisburg, and also the investments required for diesel operation. The breakdown for locomotive purchases is shown in Table 10.3.

G&H has estimated aggregate operating costs savings in current dollars and constant dollars; these results appear in Table 10.4. The report states that operating cost savings are small in the initial years of operation, but increase rapidly as inflation drives up the cost of diesel fuel and maintenance; however, there are no specific examples given of yearly costs.

Finally, G&H performed a number of sensitivity analyses to determine the effects of changes in traffic, fuel costs, capital costs and other parameters on the internal rate of return. The parameters varied and consequent results are shown in Table 10.5

10.3 Generalization of Results

The results of this financial analysis are not applicable to other railroads, of course, because Conrail is in a unique tax position due to its large previous losses. Nevertheless, the methodology used to develop internal rates of return, net present values and payback periods appears logical and appropriate. It is questionable whether the format of some results presented conveys useful information, for example; alternatively, levelized** operating costs of each option (electric or diesel operation) would be easier to compare with present annual operating cost estimates.

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*The consequence of this assumption will be discussed in Subsection 10.3.

**A levelized annual cost is calculated by determining the present worth of all annual costs, and converting this total to an equivalent, constant annual cost.

TABLE 10.1

SUMMARY OF FINANCIAL ANALYSIS

A. RESULTS USING A CURRENT-DOLLAR METHODOLOGY

Net Investment	$ 410.5 million
Operating Savings and Working Capital Changes	$6,025.4 million
Internal Rate of Return	18.1%
Payback Period	9.6 years
Net Present Value (at 10% discount rate)	$ 629.0 million

B. RESULTS USING A CONSTANT-DOLLAR METHODOLOGY

Net Investment	$ 226.9 million
Operating Savings and Working Capital Changes	$1,118.9 million
Internal Rate of Return	8.8%
Payback Period	11.7 years

SOURCE: G&H Table 1.

TABLE 10.2

INVESTMENT COSTS, 1980 - 2010

($, millions)

Fixed Plant Investment	Electric Case	Diesel Case	Net Investment
Catenary	$105.1	-	105.1
Substations	56.9	-	56.9
Communications	33.6	-	33.6
Signal Systems	64.1	34.9	29.2
Civil Reconstruction	19.2	-	19.2
Design and Engineering	25.4	3.6	21.8
Construction Management	11.8	2.9	8.9
Other	42.4	10.1	32.3
Total Fixed Plant Investment	358.5	51.6	306.9
Rolling Stock Investment			
Electric Locomotives	536.6	-	536.6
Diesel Locomotives	603.3	2,364.4	-1,761.1[3]
Credits[1]	364.9	922.0	557.1[4]
Total Rolling Stock Investment	775.0	1,422.4	- 667.4[3]
Terminal Value of Investments at December 31, 2010[2]	629.5	1,400.6	771.1[4]

[1]Credits from retirement of existing locomotives (at December 31, 1981), salvage values of purchased locomotives at retirement, and rental value of locomotive purchased for eventual use on this route but used elsewhere until needed.

[2]Book value of assets (net of accumulated depreciation) at the end of the project life.

[3]Net savings in investment.

[4]Net loss in terminal value or credits.

SOURCE: G&H Table 7.

TABLE 10.3

LOCOMOTIVE PURCHASES BY PERIOD

($, millions)

Current Dollars	Electric Case	Diesel Case	Net Investment
1982-1990	390.2	207.6	182.6
1991-2000	401.7	593.0	- 191.3
2001-2010	348.0	1,563.8	-1,215.8
Total	1,139.9	2,364.4	-1,224.5
Constant Dollars			
1982-1990	302.5	95.3	207.2
1991-2000	101.7	158.6	- 56.9
2001-2010	28.6	135.7	- 107.1
Total	432.8	389.7	43.2

SOURCE: G&H Table 8.

TABLE 10.4

TOTAL OPERATING COSTS, 1982 - 2010

($, millions)

Cost Category	Electric Case	Diesel Case	Savings
Current Dollars			
Energy	$2,972.9	7,563.7	4,590.9
Locomotive Maintenance	857.4	2,636.5	1,779.2
Transportation	3,281.0	2,931.4	- 349.6
Maintenance of Way	357.2	326.2	- 31.0
Other	187.9	192.4	4.5
Total Operating Costs	7,656.3	13,650.2	5,993.9
Constant Dollars			
Energy	889.1	1,387.1	498.0
Locomotive Maintenance	356.6	1,109.4	752.9
Transportation	1,356.1	1,223.5	- 132.6
Maintenance of Way	151.5	137.3	- 14.2
Other	80.8	89.2	8.4
Total Operating Costs	2,834.1	3,946.6	1,112.5

SOURCE: G&H Table 9.

TABLE 10.5

SENSITIVITY ANALYSES: VARIATION IN INTERNAL RATE OF RETURN (IRR) AS A FUNCTION OF SELECTED COST CHANGES

	BASE		LOWER TEST			UPPER TEST		
PARAMETER TESTED	VALUE	IRR	VALUE	% CHANGE	IRR	VALUE	% CHANGE	IRR
Traffic Level (Million Gross Ton-Miles)	904.3	18.1	761.7	-16	17.2	1,036.9	+15	20.4
Fixed Plant Investment ($, Millions)	358.5	18.1	286.1	-20	20.9	430.8	+20	16.8
Diesel Fuel Cost ($/Gallon)	0.83	18.1	0.66	-20	16.2	1.00	+20	20.7
Energy Inflation (Percent)								
Diesel Fuel	9.0		7.2			10.8		
Electric Energy Consumption	6.6	18.1	5.3	-20	17.1	7.9	+20	20.2
Electric Demand	3.5		2.8			4.1		
Electric Locomotive Maintenance Unit Costs ($/Thousand Gross Ton-Miles)	0.318	18.1	0.229	-28	18.1	0.424	+33	17.9

SOURCE: G&H Table 11.

Certain kinds of cost data, such as locomotive purchase and operating costs, were presented in terms of current dollars and constant dollars. G&H frequently stated that the constant dollar costs were presented to demonstrate the effects of inflation, and this purpose is accomplished. However, it is suggested that use of constant-dollar data for financial analysis criteria such as internal rate of return and payback period calculations is of limited value. The results are difficult to compare with traditional discounted cash flow calculations based upon current dollars. Output should also show annual cash flow by line item and total annual and accumulated cash flows. No mention of construction schedules was noted, and this can have a marked effect upon internal return on investment, present value, and particularly, payback period.

We have found it more effective to treat rate of inflation as a separate variable, developing all cost factors in constant dollars standardized at start of project. Appropriate inflation rate variables can be assigned to various line items where price escalations may differ from the average inflation rate. Diesel fuel and electricity are typical line items where this occurs. Using this approach, it is easy to explore the effects of various inflation and cost escalation rates by sensitivity analysis.

In conclusion, subsequent railroad electrification studies which may use the methodologies presented in Chapter 4 for financial analysis would need to use more current estimates of the discount rate for present value calculations and the inflation rate.