Propulsion Alternatives for Suburban Rail Corridors: Viable Options to Extending Electrification

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Costs of railroad electrification have risen dramatically. Rail transit is denied Manhattan (and other) business district access unless it is electrified. Commuters want one-seat rides to work. Operators wish to avoid, where possible, costly locomotive changes en route. Moreover, growth in the suburbs continues, reflected in modest growth in commuter railroad passenger volumes. All this results in time-consuming inconveniences to a great number of passengers. All of these factors combine to build a strong case for exploring alternatives to electrification extensions. In the Tri-State Region (New York, New Jersey, and Connecticut), this issue is further complicated by the presence of four major carriers: New Jersey Transit Corporation, Metropolitan Transportation Authority, Connecticut Department of Transportation, and Long Island Railroad. All of these carriers have, or recently had, electrification or re-electrification proposals under consideration. The Tri-State Regional Planning Commission assembled this group to address the cost-effectiveness of electrification alternatives in a systemwide fashion. A technical feasibility study entitled Propulsion Alternatives for Suburban Rail Corridors resulted and has been completed recently. This study developed cost comparisons between selected propulsion options from technical and cost data obtained from a number of rail operators and rail equipment manufacturers. The analysis clearly illustrated that a number of candidate propulsion alternatives, especially dual-mode locomotive service, are more cost effective than traditional electrification. The implications are of national significance. Direct commuter-rail services to metropolitan centers can be provided without costly extension of electrification. Selective electrification can be programmed in affordable segments and the one-seat service areas can be significantly expanded.

An extensive commuter-rail system connects the Manhattan central business district (CBD) with the outlying suburban areas of the Tri-State Region (New York, New Jersey, and Connecticut). Since these tracks are underground in Manhattan, diesel trains, which have substantial ventilation requirements, are not allowed to operate into Manhattan CBD terminals.

Access, therefore, must be provided by electric trains. The inner portion of the commuter-rail system and several entire routes are currently electrified. However, only about half the total route mileage in the Tri-State Region is electrified. At present, for rail service beyond electrification, passengers change trains, or engines are changed, or there is dual-mode service. Changing engines or requiring passengers to change trains is inconvenient, time consuming, and requires additional equipment. This results in public pressure to extend electrification in order to eliminate transferring between trains or the delays of changing engines. It also results in the need to purchase, maintain, and operate additional equipment.

Moreover, the population is increasing in those areas beyond electrification and this is further increasing the pressure to extend electrification. However, sufficient funds are unavailable for many of these extensions, so that much of the commuter-rail system will remain nonelectrified.

The question, then, is, Are there feasible alternatives to electrification that will provide access to Manhattan? To address this question, the Tri-State Regional Planning Commission sponsored a technical feasibility study entitled Propulsion Alternatives for Suburban Rail Corridors. This study was funded by the Urban Mass Transportation Administration and performed in cooperation with the Metropolitan Transportation Authority (MTA), the New York State Department of Transportation, the New Jersey Transit Corporation, and the Connecticut Department of Transportation. The consultant was Alexander Kusko, Inc. This overview is a summary of the analysis and results of that study and recommendations that follow from it.

At a time when critical decisions are being made that concern several of the electrification extensions identified in Figure 1, this obviously timely project focuses on two specific areas. The first is the feasibility of several alternative propulsion options to extending electrification. The second is the quantification of all appropriate cost and technical factors for all electrified and nonelectrified options. These two evaluations should help key decisionmakers select the optimal propulsion for particular route segments in the Tri-State Region.

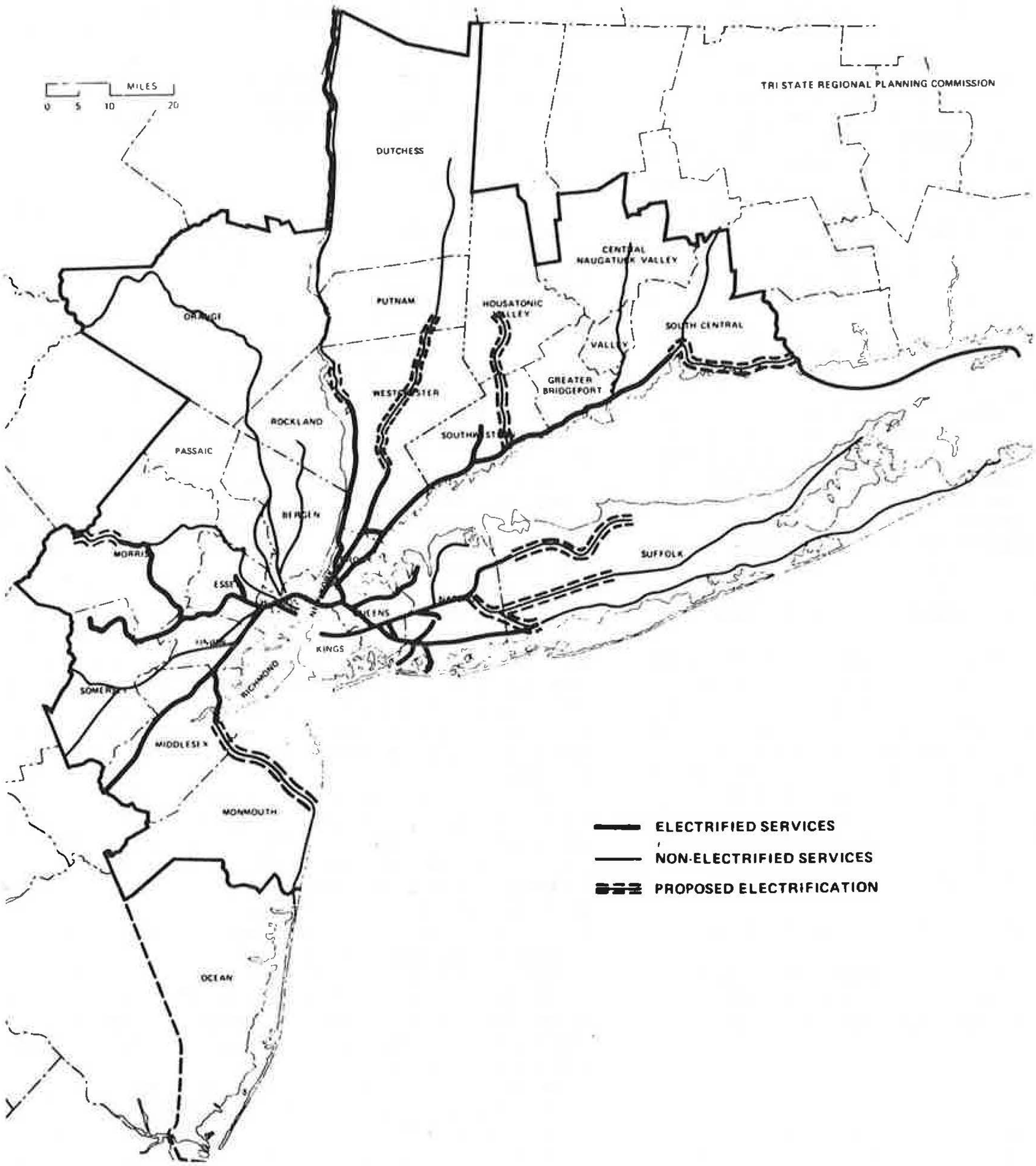
GENERAL CRITERIA AND ASSUMPTIONS

The technical study is for the most part generic; that is, it is primarily concerned with identifying and pricing general factors of various electric-propulsion systems and alternatives to electrification for typical rail corridors in the Tri-State Region. Comparisons of different types of systems are meant to represent typical situations. Analysis of a particular route in the Tri-State Region would use the generic data developed in the study and would apply them to the conditions for that particular corridor. As discussed in a later section, this was done for one selected route in the Tri-State Region as an example.

Some of the major criteria and assumptions used in this study are indicated below:

1. All data are assumed to apply to commuter-rail service to New York City (i.e., peak-period service to the Manhattan CBD).
2. All costs are in constant 1980 dollars. A capital recovery factor of 0.10 was applied to capital costs for direct comparison with developed annual costs.
3. The types of propulsion systems analyzed are limited to those that provide direct access (no change of equipment or transfer of passengers) to the CBD. All major types of alternatives have operated or are now operating in the Tri-State Region.
4. The typical rail corridor under analysis involves a 30-mile segment already electrified at the CBD end of the corridor and a 20-mile double-track extension that is proposed to be electrified. Eight different passenger volume levels are analyzed, which include the passenger levels estimated for the routes identified in Figure 1.
5. An average of five passenger cars is assumed per locomotive.
6. The 20-mile nonelectrified segment includes nine passenger stations, which results in an average station spacing of 2.2 miles.
7. About 80 percent of the daily ridership is assumed to ride in the 3-h peak period.
8. Shop margins (the number of vehicles out of service at any given time) are assumed to be 15 percent.
9. Single-level passenger vehicles are attributed a nominal seating capacity of 120.
10. As the study progressed, the option of a bilevel passenger car was indicated to be feasible

Figure 1. Electrification extensions proposed for Tri-State Region.



and was added as a suboption at a nominal seating capacity of 200.

11. Since the analysis was concerned with the incremental variable costs among options, crew requirements were not considered.

PROPULSION OPTIONS

All of the baselines and alternatives in this study are characterized as either locomotive-hauled passenger coaches or self-propelled passenger cars. Two or more self-propelled passenger cars can be operated in multiple-unit (MU) trains. Electric MU (EMU) trains are common in the Tri-State Region as are both electric and diesel-electric locomotives.

Eight major propulsion options were selected for detailed analysis, four of which contain additional suboptions for bilevel cars. The first three, the so-called baseline options, are three standard methods for extending existing electrification systems. The last five options are feasible alternatives to the baseline electrification extensions. Each of the eight options is described below in detail.

BASELINE OPTIONS

The three baseline options are representative of the three types of electrified systems programmed for the Tri-State Region.

Baseline 1 represents electrification at 25-kV, 60-Hz alternating current (ac) power. This is considered the worldwide state of the art for new commuter-rail electrification projects but is not yet used in the Tri-State Region. However, the Morris and Essex operation in New Jersey is currently being converted to this system from its current 3-kV direct current (dc) system. The Northeast Corridor and the North Jersey Coast Line, both now electrified at 11-kV, 60-Hz ac, were to be converted to 25-kV, 60-Hz ac as part of an extensive modernization program. (This program is now deferred due to funding and technical constraints.) The 60-Hz systems are compatible with the commercial power grid and so can tap power with relatively simple substations.

The ac power, supplied by substations spaced approximately 20 miles apart, is drawn directly from contact wires (supported by catenary) by pantographs located on top of each vehicle. The ac current is then converted on board to lower-voltage dc current for use by the dc traction motors. The vehicle used for this analysis, the JA-3, is based on the most recent purchase of Jersey Arrow EMUs.

Baseline 2 represents electrification at 12.5-kV, 60-Hz ac that is linked to 600-V dc operation. For this operation, the vehicle assumed, the M-2, is based on the most recent purchase of M-type dual-voltage EMUs, as currently used on the New Haven line in Connecticut and New York State. The vehicle draws ac power in ac electrified territory in the same manner as the baseline 1 vehicle (ac substations are spaced 10 miles apart in this scenario). When the vehicle operates in dc electrified territory, however, it draws dc power directly from the wayside third rail through collector shoes for use by the dc traction motors.

Baseline 3 represents 600-V dc third-rail electrification. It is currently used on the Long Island Railroad as well as the Harlem and Hudson lines that serve Westchester County in New York State.

Dc power (from substations spaced two miles apart in this scenario) is simply drawn directly from the third rail by collector shoes on the vehicle. The vehicle assumed for this operation, the M-1, is based on the most recent purchase of M-type single-voltage EMUs. For this option, a baseline 3A, which assumes a single-track route, was also analyzed.

The advantage of all three baseline options is high performance; their relative disadvantage, however, is their high implementation costs. In summary, the baseline options are as follows:

1. Baseline 1--EMU (Jersey Arrow, JA-3)--25-kV, 60-Hz ac, catenary;
2. Baseline 2--EMU (Cosmopolitan, M-2)--12.5-kV, 60-Hz ac/600-V dc, catenary and third rail; and
3. Baseline 3--EMU (Metropolitan, M-1)--600-V dc third rail.

ALTERNATIVE OPTIONS

There are five alternatives to the baseline options evaluated in the study. These are described in detail below.

Alternative 1 is a dual-mode locomotive (DML) that hauls trailer cars at a ratio of five cars per locomotive. A conventional diesel-electric locomotive uses a diesel engine that drives a generator to supply dc electric power to the dc traction motors. A diesel-electric/electric (DE/E) DML operates as a conventional diesel-electric locomotive in nonelectrified territory as well as an electric locomotive in electrified territory.

The particular locomotive analyzed for such operation is based on the F40PH design of the Electro Motive Division of General Motors Company. This F40PH is the standard high-horsepower locomotive used today for commuter and intercity passenger service. (A lower-power version, the FL-9 DML, currently operates on the Hudson, Harlem, and New Haven lines. Built more than 20 years ago, some are currently being rebuilt.)

Both an ac and a dc version of the DML were analyzed. The ac DML would draw power from overhead catenary in electrified territory in the same manner as the baseline 1 vehicle. The dc DML would draw power from third rail in electrified territory in the same manner as the baseline 3 vehicle.

Each version was also analyzed hauling both single-level and bilevel passenger coaches. The single-level coach analyzed is based on a recent purchase of the lightweight Jersey Comet (model PP3). The bilevel coach under consideration for use in the Tri-State Region is based on a preliminary design of a low-profile vehicle for use in the restricted New York tunnels.

Alternative 2 is a gas-turbine/electric (GT/E) dual-mode vehicle. It is essentially an MU car, nearly identical to a conventional M-1 EMU, except that it carries its own on-board power supply for use in nonelectrified areas.

In electrified territory, it acts as a conventional dc EMU that draws power from the third rail. In nonelectrified territory, a lightweight, compact gas turbine drives an electric generator to operate the dc traction motors.

Typically, this equipment resembles the eight GT/E vehicles demonstrated in the 1970s by the MTA on the Long Island Railroad in New York State. These vehicles evolved from a series of demonstrations (in which the Tri-State Regional Planning Commission cooperated) and design developments in the late 1960s and early 1970s.

Alternative 3 is an ac electric locomotive that hauls trailer cars at a ratio of five cars per locomotive. Such an operation is common to current New Jersey services. This option involves locomotive propulsion supplied by overhead-catenary wires; as such, extension of ac electrification is necessary for this operation. This alternative is analyzed as hauling both single-level and bilevel coaches.

The specific locomotive analyzed is the high-horsepower AEM-7, which is currently assigned to Northeast Corridor National Railroad Passenger Corporation (Amtrak) operations. Since this option is evaluated with a trailer-to-locomotive ratio of 5 to 1 as with the DML option, operating experience has shown that this combination produces an extremely high-performance train.

Alternative 4 is a dc electric locomotive that hauls trailer cars at a ratio of five cars per locomotive. Such an option requires extension of dc electrification and is analyzed for both single-level and bilevel coaches.

Dc electric locomotives once operated extensively in the Tri-State Region. Typical examples were New York Central "T" or "S" class locomotives involved in access to Grand Central Terminal in New York City and DD-1 locomotives involved in the original design of Pennsylvania Station in New York City.

Today, the electric mode of the FL-9 locomotives uses third-rail dc power for operation into Grand Central. Moreover, dc electric locomotives were recently purchased and placed in service as switchers at Grand Central.

Alternative 5 is a battery/electric dual-mode vehicle. It is essentially a dc EMU with a substantial battery pack for operation in nonelectrified territory.

This equipment concept is based on the successful, but limited, intercity service currently used in Germany. Moreover, tripower locomotives (gas, electric, and battery) were once in service both in third-rail and overhead-catenary territories in the Tri-State Region.

While the battery/electric vehicle avoids the necessity of extending electrification, it does require a supplemental power supply at the end of the route and substantial electric operation for battery recharging. This option, for the purposes of this study, also includes a flywheel-regenerative

Table 1. Technical and cost data.

Equipment (per unit)	Costs (1980 dollars) Capital (000s)	Maintenance[a] Electrified Territory	Maintenance[a] Nonelectrified Territory	Vehicle Weight[b] (lb 000s)	Vehicle Horsepower Rating	Vehicle Power Requirements: Kilowatt Hours per Car Mile	Vehicle Power Requirements: Gallons per Car Mile	Sample Trip Time[c] (min)
Ac electric car (baseline 1)	1000	0.80	–	113	700	9.37	–	26.9
Ac/dc electric car (baseline 2)	1100	0.88	–	125	650	10.06	–	27.3
Dc electric car (baseline 3)	950	0.80	–	92	560	7.16	–	27.0
Ac DML (alternative 1)	1442	0.40	1.84	275	3000	5.51/8.06[d]	0.52/0.77[d]	27.8
Dc DML (alternative 1)	1085	0.40	1.84	265	3000	5.44/7.99[d]	0.52/0.76[d]	27.8
GT/E car (alternative 2)	1330	0.80	1.47	100	560	7.57	1.23	27.1
Ac electric locomotive (alternative 3)	2430	0.36	–	200	7000	4.95	–	25.3
Dc electric locomotive (alternative 4)	1300	0.36	–	200	3000	7.50	–	27.3
Battery/electric car (alternative 5)	1171	0.80	2.35	130	560	6.26/10.43[e]	–	27.0
Single-level trailer coach	750	0.87	0.87	74	–	–	–	–
Bilevel trailer coach	1300	0.87	0.87	130	–	–	–	–
Conventional diesel locomotive[f]	920	–	1.67	260	2000/3000[g]	–	2.70	29.2
Self-propelled diesel car[f]	1100	–	1.79	120	400	–	0.47	–

[a] In dollars per mile traveled.
[b] Empty-vehicle weight; for purposes of performance measurement, an average weight of 150 lb/seated passenger was used.
[c] Based on traveling a 20-mile segment with nine passenger station stops.
[d] First value represents operation with single-level coaches, the second with bilevel coaches.
[e] First value represents electric operation, the second battery operation.
[f] Included for comparison.
[g] First value represents current diesel operation, the second programmed diesel operation.

braking system. While all options could benefit from such equipment, it was deemed essential for this option to provide good performance in the battery mode.

For comparison, two typical types of standard diesel-electric services were also evaluated: a train of five rail diesel cars (RDCs) and a conventional diesel-electric locomotive that hauls trailer cars in the ratio of five cars per locomotive. However, such options would require costly increases in the ventilation system capacity in the tunnels and are therefore not considered beyond their furnishing of comparative costs.

In summary, the alternatives are as follows:

1. Alternative 1--a DE/E DML,
2. Alternative 2--a GT/E dual-mode MU,
3. Alternative 3--an ac electric locomotive,
4. Alternative 4--a dc electric locomotive, and
5. Alternative 5--a battery/electric dual-mode MU.

DATA

The key technical and cost data used in the study are summarized in Table 1. The table illustrates, for each type of equipment, the following:

1. Capital cost in 1980 dollars,
2. Annual maintenance costs, and
3. Vehicle power requirements in kilowatt hours per car mile for electrified operation and gallons per car mile for nonelectrified operation.

For the electrification scenarios, the table below gives the capital costs and maintenance costs (in dollars per year):

Wayside (per route mile)	Cost (1980 dollars) Capital (000s)	Maintenance
Ac electrification	1570	3 625
Ac/dc electrification	1789	3 625
Dc electrification	3603	20 150
Dc electrification (single track)	2160	14 150

These data were developed from information supplied by various national rail equipment manufacturers as well as rail operators in the Tri-State Region.

OUTLINE OF OPTION COMPARISONS

The data shown in Table 1 were applied to the three baseline options and five alternative options to compare costs and performance for various passenger levels.

Figure 2 compares the relative costs per seat of the three baseline options. (Although one would expect to extend the same type of electrification over the nonelectrified territory, this does not preclude one baseline from being a viable alternative to another baseline option.) Figures 3, 4, and 5 show the costs per seat of each of the three baseline options, versus the appropriate alternatives, for various passenger levels.

For the four comparisons, only single-level coach options are used. In addition, although the 2000-20 000 range of passenger levels is used, most of the proposed electrification extensions in the Tri-State Region fall into the narrower 4000-8000 range.

Figure 2 directly compares baselines 1, 2, and 3. As such, it compares

1. Extending 25-kV ac electrification and using ac electric MU cars (baseline 1),
2. Extending 12.5-kV ac electrification and using ac/dc electric MU cars (baseline 2), and
3. Extending 600-V dc electrification and using dc electric MU cars (baseline 3).

Figure 3 compares baseline 1 with alternatives 1, 2, and 3. Thus, it compares

1. Extending 25-kV ac electrification and using ac electric MU cars (baseline 1),
2. Not extending electrification and using either ac or dc DMLs to haul trailer cars (alternative 1),
3. Not extending electrification and using GT/E (alternative 2), and
4. Extending 25-kV ac electrification and using ac electric locomotives to haul trailer cars (alternative 3).

Figure 4 compares baseline 2 with alternatives 1 and 2. As such, it compares

1. Extending 12.5-kV ac electrification and using ac/dc electric MU cars (baseline 2),

Figure 2. Cost comparison of three baseline electrified options.

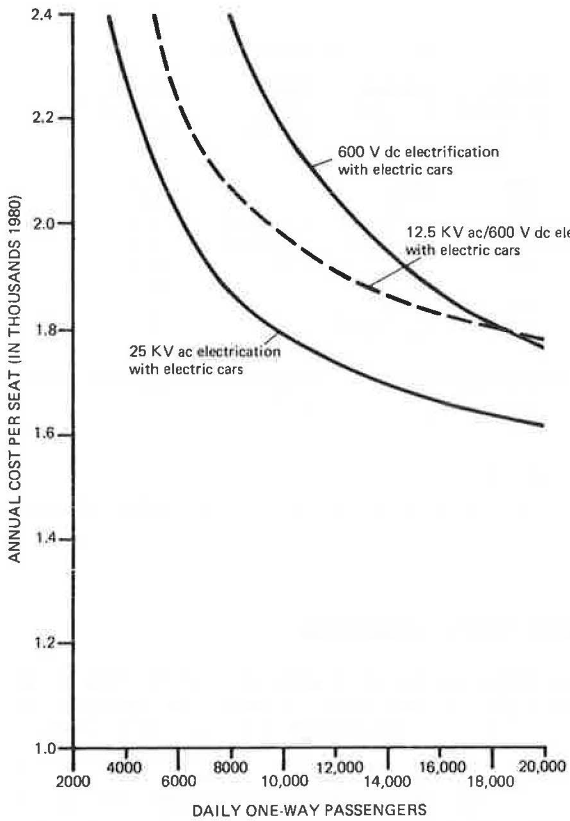


Figure 4. Cost comparison of 12.5-kV ac/600-V dc electrification with selected alternatives.

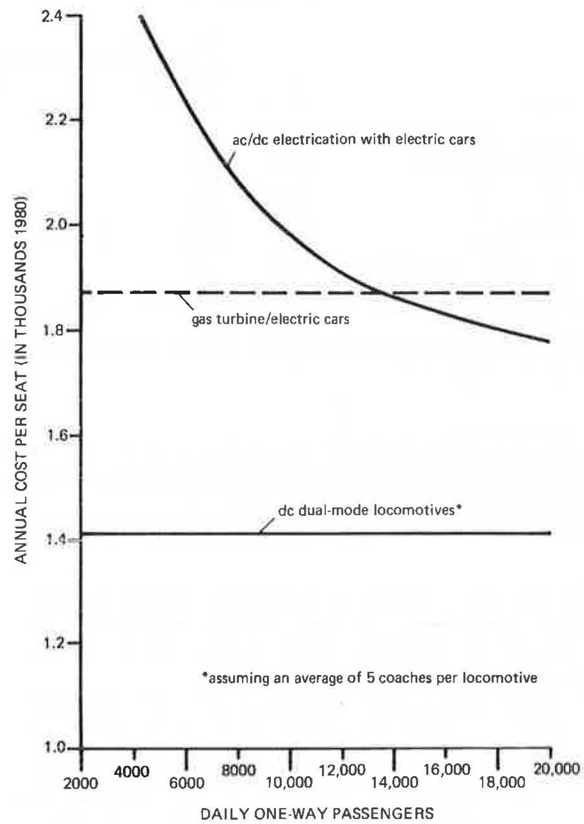


Figure 3. Cost comparison of 25-kV ac electrification with selected alternatives.

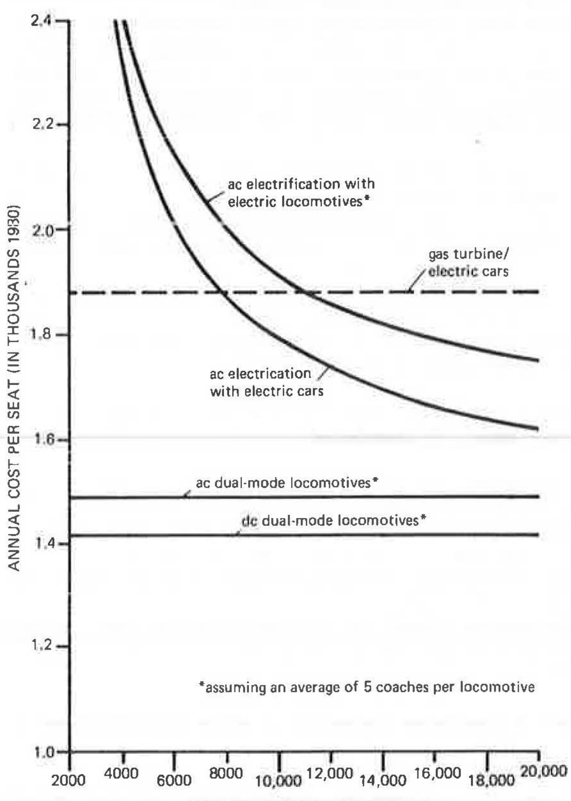
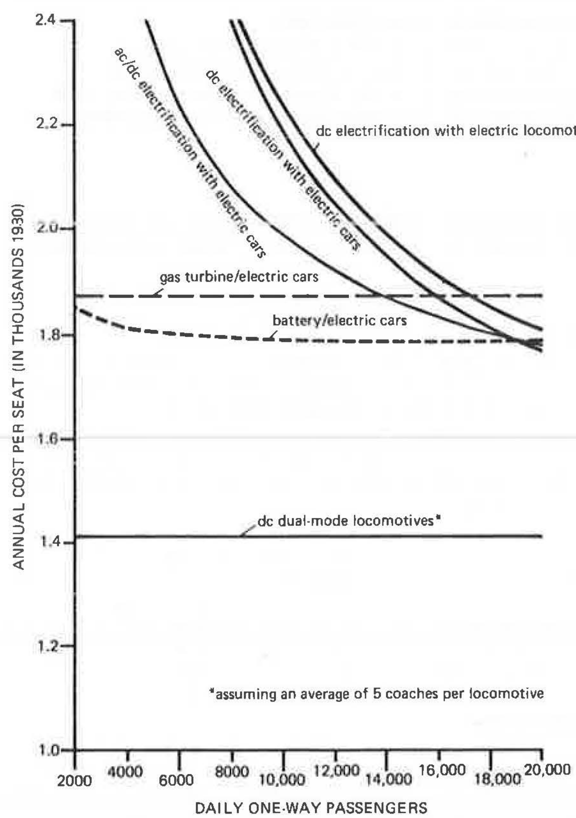


Figure 5. Cost comparison of 600-V dc electrification with selected alternatives.



2. Not extending electrification and using dc DMLs to haul trailer cars (alternative 1), and
3. Not extending electrification and using GT/E MU cars (alternative 2).

Figure 5 compares baseline 3 with alternatives 1, 2, 4, and 5, as well as with baseline 2. Thus, it compares

1. Extending dc electrification and using dc electric MU cars (baseline 3),
2. Not extending electrification and using dc DMLs to haul trailer cars (alternative 1),
3. Not extending electrification and using GT/E MU cars (alternative 2),
4. Extending electrification and using dc electric locomotives to haul trailer cars (alternative 4),
5. Not extending electrification and using battery/electric MU cars (alternative 5), and
6. Extending 12.5-kV ac electrification from the dc electrification and using ac/dc electric MU cars (baseline 2); this option is viable due to the relatively lower costs of the ac electrification.

Table 1 also estimates the relative performance of each of the options. The estimates are for operation over the assumed 20-mile nonelectrified segment; performance is expressed as travel time over the route in minutes.

RESULTS OF OPTION COMPARISONS

The implications of the comparison of options are clear. The extension of electrification is generally not cost effective at relatively modest passenger levels. Operation of dual-mode locomotives is the most cost-effective alternative to extending electrification.

Both the GT/E option and battery/electric option provide substantial cost savings relative to electrification at modest passenger levels. However, both are still more costly than the DML option at all passenger levels. As ridership increases, electrification becomes competitive with the battery/electric and GT/E options.

When electrification is considered for implementation, dc third-rail electrification is shown to be typically the most costly, ac/dc electrification second, and ac overhead-catenary electrification least costly. However, as passenger levels increase, dc electrification becomes competitive with ac/dc electrification. In addition, electrification with electric locomotives is seen to be somewhat more costly than electrification with the corresponding electric MU cars. The cost of the bilevel coach suboption for each alternative is somewhat lower than that of the corresponding single-level coach suboption.

The above observations are based on the assumed 50-mile route, the inner 30 miles of which are electrified. However, a number of other factors affect both the absolute and relative costs of the options. Such factors include train length and electrification length.

A cursory analysis of the cost impact of train length (i.e., the number of cars in the train) was performed in the study. As expected, all locomotive options maintained their relative positions to each other; similarly, all MU options maintained their relative positions.

However, other comparisons were significant. For dc electrification, the electric locomotive-hauled train becomes competitive with EMUs for train lengths of more than six cars. The DML is such a cost-effective option that only at small train lengths (one- or two-car trains) do other alternatives (such as GT/E and battery/electric) become competitive.

The cost impact of electrification length was also evaluated. For those options that do not require electrification (such as the DML, the GT/E MU car, and the battery/electric MU car), costs are independent of the length of the proposed electrification extension.

At fairly long extension lengths (40 miles), electrification options are costly relative to the nonelectrified options. As the length of the proposed extension decreases, the electrification options become more competitive. At more modest extension lengths (10-20 miles), electrification is as cost effective as some alternatives, such as GT/E and battery/electric.

Another factor to be considered is option performance. One measure of this is trip time for the passenger. Table 1 presents a simple comparison of total travel times estimated for each option for operation over the assumed 20-mile segment with nine intermediate stations.

As expected, electrification options with their associated high-performance vehicles (especially the ac electric locomotive) produce the fastest trip times. However, alternative options are still somewhat competitive (if optimal performance by each vehicle is assumed). As previously noted, these comparisons are largely the consequence of the assumptions made and unit costs developed in this study.

SAMPLE ROUTE ANALYSIS

One specific commuter route was used for a sample analysis of the generic data and methodology developed in the study. The route selected was the Raritan Valley corridor, which currently provides conventional diesel service only to Newark, New Jersey. For this study, it was assumed to be providing direct access from Raritan, New Jersey, to Pennsylvania Station, New York City. The results of the evaluation were generally similar for three passenger-level scenarios.

Extending electrification was not cost effective. A number of alternative options, especially the DML, are quite attractive. While the DML option is slightly more costly than the current diesel services to Newark, it provides direct access to Manhattan without passenger transfer, thus providing slightly reduced travel times and greater convenience.

While not specifically tested, perhaps an attractive service would be standard, full-time DML operation to Pennsylvania Station, with supplementary, peak-period-only service to Newark.

ADDITIONAL CONSIDERATIONS

A number of other factors not previously discussed here must also be considered in any detailed evaluation. Such factors were well beyond the scope of the original study.

One factor would be the substantial quantity of existing locomotive-hauled rolling stock not yet ready for retirement. The availability of such vehicles could significantly alter cost trade-offs in favor of locomotive options.

The implementation of direct service, either through electrification or dual-mode options, induces an increase in ridership by the elimination of time-consuming and inconvenient transfers. Such additional passenger volumes naturally increase vehicle requirements, but the extent of such additional loadings is dependent on the type of service provided.

Fleet compatibility is another real-world concern. Choice of propulsion option, while estimated to be cost effective through the methodology outlined, must consider the impact on overall operational flexibility and fleetwide maintenance requirements.

Modal split is also a factor in such evaluations. In addition, choice of option can affect economic development through property-value reinforcement. Obviously, a detailed sensitivity analysis is necessary in the evaluation of propulsion options for a specific commuter route.

ENVIRONMENTAL ISSUES

The study did evaluate general environmental issues as they related to the options under analysis. Noise pollution is generally below established regulatory U.S. Environmental Protection Agency (EPA) standards; transgressions are exceptions and only slightly above acceptable levels when they do occur. The quantity of atmospheric pollution produced by rail vehicles is relatively insignificant in comparison with the primary pollution source--the motor vehicle. Also, new diesel and gas-turbine rail vehicles produce lower emissions than older models.

The use of hazardous materials is a concern for all vehicle options. For electrified options, this involves carrying polychlorinated biphenyl (PCB) on MUs. However, this does not seem to pose problems when careful containment is assumed. For options that involve tanks that contain liquid fuel, the FL-9 experience is instructive; over the years, it has not presented unreasonable hazards.

CONCLUSIONS AND RECOMMENDATIONS

Providing direct access to a CBD, such as the Manhattan CBD, from outer suburban rail lines is an important and praiseworthy objective. There is a natural tendency to extend the baseline electrification systems. However, this study has demonstrated that this is a very costly approach and that there are feasible and less-costly alternatives that can also provide direct access. In particular, the DML option is especially cost effective.

Since U.S. metropolitan planning organizations (MPOs), such as the Tri-State Regional Planning Commission (the sponsor of this generic study), support provision of direct access to metropolitan CBDs for all suburban rail lines, they should also support detailed studies by the implementing agencies of alternatives that provide direct service for each suburban rail line beyond the current limits of electrification. These subsequent studies should extend and build on the results of this generic study. Conclusions from these route-specific studies should be acceptable to the MPOs before projects to extend baseline electrification are added to capital-improvement programs.

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