CALIFORNIA DEPARTMENT OF TRANSPORTATION

FEASIBILITY STUDY FOR ELECTRIFYING THE CALTRAIN/PCS RAILROAD

FINAL REPORT

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MORRISON KNUDSEN CORPORATION

In Association With

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EXECUTIVE SUMMARY

A. INTRODUCTION

The CalTrain Electrification Feasibility Study was initiated by the California Department of Transportation (Caltrans) to examine the technical feasibility of electrifying the commuter rail service on the San Francisco Peninsula between San Francisco and San Jose, including the proposed extension of commuter rail service to Gilroy.

Electrification of the study lines offers the potential for faster train service coupled with reduced operating costs through savings in fuel, crew and vehicle maintenance costs. Reductions in noise and air pollution are also important benefits. These advantages, however, are gained only at the expense of major capital investment in the electrification facilities -- electrical substations, overhead contact wiring, electric locomotives, and related equipment. The purpose of this electrification study is to evaluate the technical and economic feasibility of electrification of the study lines.

The analysis is performed for three segments of the line: (1) electrification of commuter services within San Francisco between 4th & Townsend and 25th Street, (2) between San Francisco 25th Street and San Jose's Lick Maintenance Facility, and (3) extension of electrified service from Lick to Gilroy. Electrification of the downtown San Francisco Terminal extension was covered in that project's EIS report; there is therefore no duplication of costs within this study.

The objective of the study was to determine the service level scenario at which electrification would be economically justified, or if its economic feasibility is not indicated in the foreseeable future, to determine the economic "shortfall" or subsidy required to support the electrification investment. In economic terms, the evaluation of railroad electrification involves essentially a trade-off between the initial capital costs of the electrification installed equipment and motive power and the annual economic savings deriving from reduced fuel/energy costs, reduced vehicle maintenance costs, reduced pollution, and reduced travel time. While the initial costs are relatively independent of future traffic levels, the annual savings vary directly with the number of trains operating; hence there is a theoretical traffic threshold, or service level, at which electrification becomes economical.

To attempt to establish this optimum service level, the approach adopted for the electrification study was to determine costs of electric traction at three possible service levels. The first would correspond to the 66-train service level scenario. This would involve the replacement of diesels with electric motive power and equipment. The second alternative is a service level of 114 trains per day, and the third alternative is a service level of 158 trains per day, involving replacement of dual mode (capable of operating as diesel or electric locomotives) with electric locomotives.

For each of these cases, the economic analysis includes the electrification investments for each operating scenario. Annual cost savings are calculated for an extended operating period beyond the initial installation, for purposes of comparing costs and benefits. The costs and benefits are compared on a conventional discounted cash flow (DCF) basis, which determines the economic feasibility of either timing alternative, or indicates the economic shortfall in either case.

Figure 1 is a map of the CalTrain Corridor.

B. OPERATIONS

A Train Performance Simulation (TPS) program was used to simulate the operation of CalTrain in the diesel mode and the electric mode, with electric locomotives and with EMU cars. The existing EMD F40PH diesel locomotive with 3, 6, and 10 car trains was compared with the EMD AEM-7 electric locomotive with the same size trains, and with Metro North M-2/M-4 EMU cars. The trains were simulated with existing Southern Pacific Transportation Company timetable speed limits and restrictions, except that the maximum speed limit used was 79 MPH instead of the current 70, and the current 45 MPH speed restriction within the limits of Redwood City was eliminated. Only operation between the San Francisco 4th & Townsend Street terminal and the San Jose Cahill Station was simulated.

Figure E-2 provides a running time comparison for the proposed CalTrain service, using the simulated diesel case, the simulated electric case with an electric locomotive, and EMU cars.

Because of the performance of electrified equipment compared to diesel trains and the close spacing of stations on the Peninsula with 26 stations within the 46.9 miles between San Francisco and San Jose, the electrified CalTrain with three cars saved about 7 minutes in running time compared to the diesel case, around 9 minutes with 6 cars, and around 12 minutes with 10 cars. EMU cars compared to the diesel case saved about 5 minutes with 3 cars, 13 minutes with 6 cars, and 23 minutes with 10 cars.

The simulations showed that electric powered locomotive and EMU vehicles both offer a travel time savings over the present diesel operation for both local and express services. The simulations also showed that for electric locomotive hauled trains the amount of improvement over current running times is dependant primarily on the length of the train, with longer trains benefitting more from the improved acceleration characteristics of electric power.

C. RIDERSHIP

It should be noted that estimation of rail ridership, for either diesel or electrified service, is a complex process. There are a number of factors that contribute to the decision to use the Peninsula Commute Service (PCS). Paramount among these is train running time. Other factors include:

a) The number of PCS trains operated in peak and off-peak periods;
b) PCS train headways at each station served;

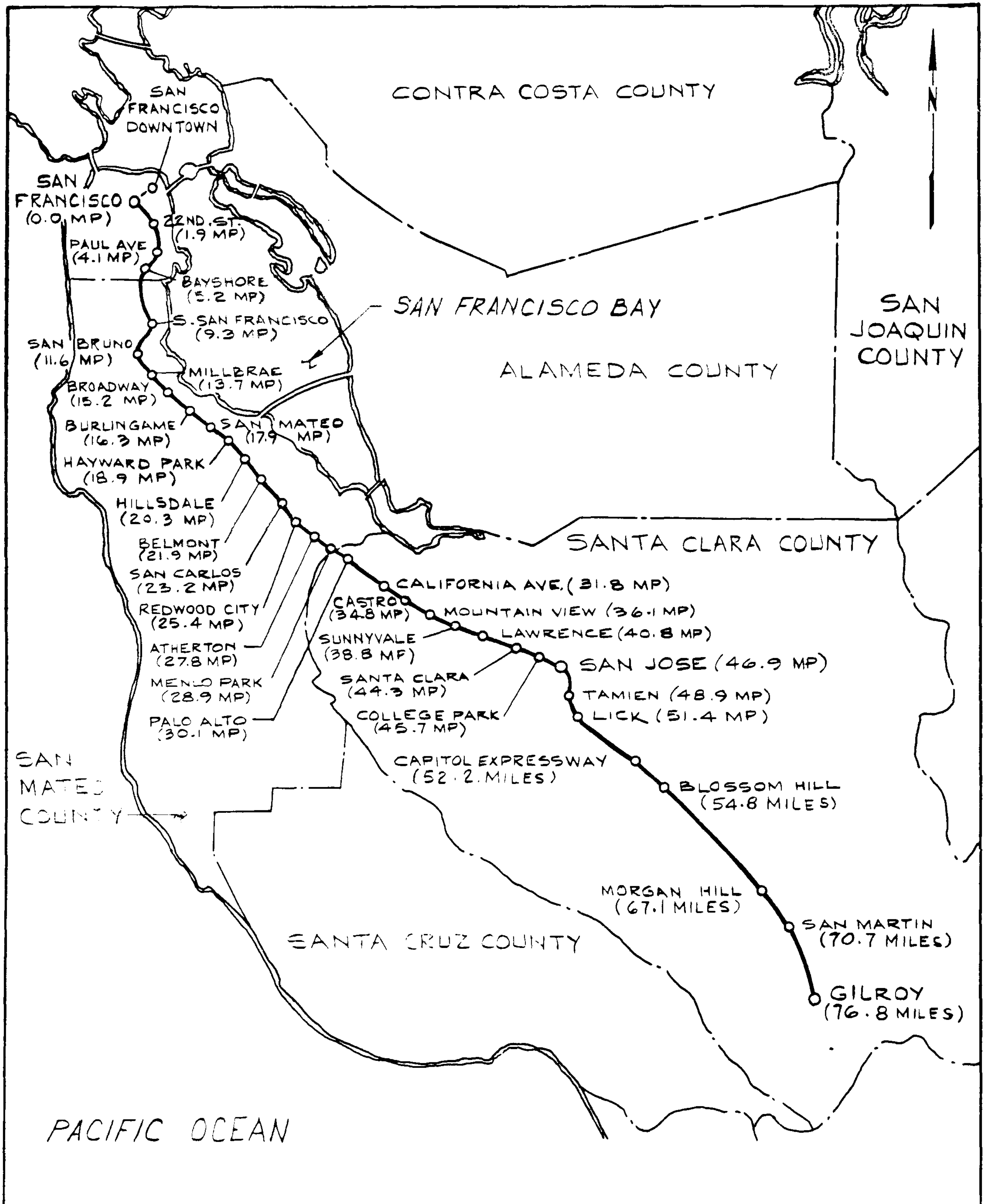


Figure 1

MAP OF CALTRAIN CORRIDOR

MORRISON-KNUDSEN ENGINEERS, INC.
180 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105

FIGURE E-2
COMPARISON OF TRAIN PERFORMANCE SIMULATION (TPS) RESULTS
ELECTRIC LOCOMOTIVE, DIESEL LOCOMOTIVE, AND EMU

Running Time Between Stations - Minutes

	3-Car-Simulation			6-Car-Simulation			10-Car-Simulation		
Station	Diesel	Electric	EMU	Diesel	Electric	EMU	Diesel	Electric	EMU
San Francisco									
22nd Street	5.2	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.2
Paul Avenue	3.5	3.4	3.4	3.7	3.6	3.4	4.1	3.8	3.4
Bayshore	2.2	2.1	2.2	2.5	2.2	2.2	2.9	2.5	2.2
So. San Francisco	5.3	5.1	5.1	5.5	5.3	5.1	5.9	5.5	5.1
San Bruno	3.4	3.2	3.4	3.8	3.4	3.4	4.2	3.7	3.4
Millbrae	3.1	2.8	2.7	3.5	3.1	2.8	3.9	3.4	2.8
Broadway	2.6	2.3	2.4	2.9	2.5	2.3	3.3	2.8	2.3
Burlingame	2.2	2.0	2.1	2.6	2.2	2.1	2.9	2.6	2.1
San Mateo	2.8	2.4	2.5	3.1	2.7	2.5	3.5	3.0	2.5
Hayward Park	2.1	1.9	2.0	2.4	2.1	2.0	2.7	2.4	2.0
Hillsdale	2.6	2.3	2.3	2.8	2.5	2.3	3.1	2.8	2.3
Belmont	2.8	2.4	2.5	3.1	2.7	2.5	3.5	2.9	2.5
San Carlos	2.5	2.2	2.2	2.7	2.3	2.2	3.1	2.7	2.2
Redwood City	3.1	2.8	2.9	3.7	3.1	2.9	4.0	3.4	2.9
Atherton	3.4	3.0	3.1	3.8	3.3	3.1	4.4	3.6	3.1
Menlo Park	2.3	2.0	2.1	2.5	2.3	2.1	3.0	2.7	2.1
Palo Alto	2.3	2.1	2.2	2.7	2.3	2.2	3.0	2.7	2.2
California Ave.	2.8	2.4	2.5	3.1	2.7	2.5	3.5	3.0	2.5
Castro	3.8	3.4	3.5	4.3	3.7	3.5	4.8	4.0	3.5
Mountain View	2.5	2.2	2.2	2.9	2.4	2.2	3.2	2.8	2.2
Sunnyvale	3.7	3.2	3.3	4.2	3.5	3.3	4.9	3.9	3.3
Lawrence	3.0	2.7	2.8	3.3	2.9	2.8	3.7	3.3	2.8
Santa Clara	4.4	4.1	4.2	4.9	4.3	4.2	5.4	4.6	4.2
College Park	2.6	2.4	2.4	2.8	2.6	2.4	3.1	2.9	2.4
San Jose	3.3	3.2	3.2	3.5	3.4	3.2	3.9	3.5	3.2
Total	**77.5**	**70.8**	**72.4**	**85.5**	**76.3**	**72.4**	**95.3**	**83.8**	**72.4**

c) Typical origin station wait times for PCS patrons;
d) PCS station access times;
e) Times required to reach each destination zone after the PCS train arrives at the destination station;
f) PCS transit fares;
g) Connecting feeder bus and/or MUNI Metro services;
h) Competing BART and express bus services; and
i) Traffic conditions on parallel highway routes.

Electrification of the Peninsula Commute Service trains would result in significant travel time savings for most major station-to-station pairs. The magnitude of time savings depends on the length of the trip, the number of station stops made, and the type of electric power source used. The decrease in travel times would be perceived as a benefit and attract new riders to the PCS service. Based on the decreases in travel times, new ridership estimates were projected for the PCS service with either the electric locomotive or EMU power source.

These travel time benefits would result in increased Caltrain ridership amounting to, depending on whether the electric locomotive or EMU power source is used, 1,800 to 5,000 trips per day for the 66-train schedule; 2,900 to 8,500 trips per day for the 114-train schedule; and, 6,300 to 13,500 trips per day for the 158-train schedule. Ridership forecasts are shown in Table E-1.

D. MOTIVE POWER

There are two possible types of electrified motive power: the electric locomotive and the electric multiple unit (EMU). Electric locomotives propel trains of non-powered trailer cars. On the other hand EMU's are self-propelled passenger power cars designed to operate alone or coupled in trains in any multiples up to ten or twelve cars.

In selecting suitable motive power for an electric CalTrain service, the prime concern operationally is to be able to match service needs with a minimum call to reconfigure trains on a short term (e.g., daily) basis. Today's schedule has 3, 4, 5, and 6 bi-level gallery car consists operating on a strict basis; trains are made up to suit a specific train duty and substitutions are not easy to arrange. One solution is to consider the adoption of a train formation utilizing new power cars hauling the existing trailer (non powered) cars. If one power car could haul a trailer car or a cab control car, 2, 4, 6, 8 and possibly 10 car trains could be programmed. Such an approach appears attractive operationally as it will provide for flexible train formations, ease of maintenance and comparable capital cost. This concept is known as electric motor trailer (EMT) combinations.

EMTs would consist of a motor power car (MPC) pulling an existing CalTrain gallery car. Each MPC would have all the same controls as the cab control car. In addition, it would be equipped with a roof-mounted pantograph for collecting electric power from the overhead catenary system. The lower level passenger compartment would be reduced in size to provide space for the required traction power equipment and other auxiliary apparatus. MPCs, however, are not

Table E-1

RIDERSHIP FORECASTS WITH ELECTRIFICATION
Caltrain Electrification Ridership Analysis

Schedule	Base (Diesel)		Forecasted Daily One-Way Trips			
			Electrification		Electrical Multiple Units	
			Low	High	Low	High
66-Train	25,620	Increase	1,780	3,480	2,580	5,080
		Total	27,400	29,100	28,200	30,700
114-Train	43,200	Increase	2,900	5,800	4,300	8,500
		Total	46,100	49,000	47,500	51,700
158-Train	68,000	Increase	6,300	7,900	6,700	13,500
		Total	74,300	75,900	74,700	81,500

Sources: BART San Francisco Airport Extension/Caltrain Upgrade Alternatives Analysis/DEIS, MTC, 1990.
San Francisco Caltrain Terminal Relocation EIR, MTC, 1989.

Wilbur Smith Associates; May 1992.

currently used in the United States.

With locomotives, the simplest solution is direct replacement of all diesel locomotives with electric locomotives, using standard production off-the-shelf models, such as the 6000 hp AEM-7 or ALP-44, which are used in commuter service by New Jersey Transit, SEPTA in Philadelphia, and MARC in Maryland.

Motive power is only one aspect of the overall study of electrifying the CalTrain service, albeit an important one. From that perspective, some important conclusions can be drawn.

Electric motive power is superior to diesel power in the following ways:

1. For a vehicle with comparable horsepower, the electric vehicle has greater acceleration capabilities because it can draw on a nearly unlimited source of power from the traction power supply system on a short time basis, while a diesel vehicle is limited to the power which can be produced by the diesel engine and generator on board the vehicle. This results in the electrically powered train having a shorter over-the-road running time.

2. The cost of energy to operate the electrically powered train is considerably less than the cost of fuel oil for a diesel powered train. In addition, the diesel locomotive requires a large sump of lubricating oil and a large supply of treated cooling water for the diesel engine.

3. The diesel locomotives require a refuelling facility. Refuelling is an extra operation to be completed each day.

4. The diesel locomotive with its engine, assorted pumps, and radiators is a much more complicated machine to maintain than an electric locomotive or EMU car, which contains mostly static type equipment with some blowers for cooling. Diesel locomotives in passenger service require a major overhaul about every ten years, whereas electrically powered rolling stock requires much less maintenance over its life. Diesel locomotives in passenger service have a life expectancy of 25 years versus 35 years for electric locomotives.

5. Environmentally the electrically powered train is superior to the diesel powered train for the following reasons:

    - No pollution since there is no fuel burned on board the train.

    - Less noise, since the diesel engine which must operate at full throttle position (approximately 1000 rpm) on the road to generate head end power is replaced by mostly static components with some motor-driven blowers.

- The leaking of diesel fuel/lubricating oil along the railroad right-of-way is eliminated.

6. The existing fleet of CalTrain gallery cars can continue to be used either by directly replacing the diesel locomotives with electric locomotives, or by replacing the locomotives and expanding the capacity of the fleet at the same time by procuring new California Car cab control cars built as electric power cars.

In comparing locomotives and EMU cars, EMUs can provide more flexibility of operations, in that they can more easily be made up into trains of varying size, including operation as single-car trains for off-peak hours. However, each EMU must be maintained as frequently as a locomotive under current federal regulations. The increased flexibility of operations may be offset by the increased maintenance cost of an EMU fleet.

Replacement of the existing fleet of gallery cars with brand new EMU cars is probably not practical, considering the economic implications of the manner in which the existing fleet was purchased and then resold by Caltrans under Safe Harbor Leasing. In addition, maintenance of a fleet of EMU cars could be more costly than maintaining a fleet of no more than one half powered vehicles and the rest trailer cars.

The estimated cost of an electric locomotive is approximately $4.5 million versus $3.5 million for a California Car manufactured as an MPC; nearly twice as many MPCs would be required compared to electric locomotives for the 158 train scenario, because an MPC would have the performance capability of handling only one gallery car. Considering the difference in capital costs and maintenance costs for the entire fleet, it is recommended that the motive power for an electrified CalTrain be electric locomotives.

E. SELECTION OF ELECTRIFICATION TRACTION SYSTEM

Although a variety of options for traction voltage, both alternating current (AC) and direct current (DC) do exist, budgetary economic analysis shows that 25 kV AC will be the most cost effective standard system for the Peninsula Corridor as described below. Table E-2 presents cost comparisons for standard electrification systems for a typical 50 mile double track corridor.

Compared to the DC schemes, the 25-kV system will have a lower number of electric traction power supply substations along the route with a minimum number of connections to the utility network, the smallest overhead contact system conductor sizes and the use of well-proven standard electrical equipment. A 25-kV AC system will have the lowest initial costs and annual maintenance costs and will not cause electrolytic corrosion of underground utilities (e.g. pipes and steel pilings, etc). However, this system may cause electromagnetic interference in trackside signaling and communications circuits, and adjacent telephone circuits, which will require mitigation. In the case of this commuter corridor, with many existing fibre optic communications circuits, and a signalling system due for renewal anyway, the costs of mitigation

TABLE E-2
BUDGETARY DIRECT COST COMPARISON OF STANDARD ELECTRIFICATION SYSTEMS FOR TYPICAL 50 MILES OF 2-TRACK ROUTE

Standard System Configuration	25kV AC Overhead	1500 VDC Overhead	600 VDC Overhead	600 VDC Ground Level
Distribution System	Lightweight Conductors	Heavy Conductors	Heavy Conductors	Third Rail
Current Capacity (typical)	600A	1500A	1800A	1800A
Substations (S/S) Size (typical)	20 MVA	1 MW	1 MW	1 MW
Primary Supply Spacing (typical)	115 kV	34.5 kV	34.5 kV	34.5 kV
Spacing (typical)	20 miles	3 miles	1 mile	1 mile
Qty S/S in 50 miles of route	3	16	50	50
S/S Cost Each	$2.2M	$0.8M	$0.5M	$0.5M
S/S Cost Total (a)	$6.6M	$12.8M	$25M	$25M
STM in 50 miles of route	105	105	105	-
Cost of OCS per mile	$400k	$450k	$500k	-
Cost of OCS Total (b)	$42M	$47.2M	$52.5M	-
STM in 50 miles of route	-	-	-	105
Cost of Third Rail per mile	-	-	-	$600k
Cost of Third Rail Total (b)	-	-	-	$63M
Total cost for 50m of route (a+b)	$48.6M	$60M	$77.5M	$88M
Civil Modifications Allowance	$10M +∅	$10M +∅	$10M +∅	$10M *∅
Electrical Installation Direct Cost(a+b+c)	$58.6M∅∅	$70 ∅∅	$87.5M	88M$
Cost Ratio	1.0 (base)	1.2	1.5	1.5

Legend:

- STM — Single track miles, including crossovers and sidings
- * — Essential fencing allowance for public safety. Actual costs may be much more.
- ∅ — Excludes tunnel work to accommodate double stack freight
- \+ — Overhead clearance attainment for catenary, and provision of safety barriers on bridges.
- ∅∅ — Excluding motive power, signalling, communications and maintenance facility, design, construction protection, construction management, inflation, contingency and financing, and all owner costs.

are expected to be small compared to the overall cost of electrification.

With the level of service proposed for CalTrain, 25-kV substations would be typically spaced 15 to 30 miles apart depending upon the type of 25-kV system selected. This spacing allows for one substation to be out of service between two operating substations with no impact on train operations. The incoming primary power is readily obtained by taking supply from electric utilities at 34, 69 or 115 kV 3 phase and by means of transformers producing 25-kV single phase in CalTrain's own substations. These substations would have all the various protection isolation and monitoring features typical in traction power supply substations. PG & E has indicated that a cursory review of the proposed traction power system discloses that power could probably be supplied to the proposed substations without major alteration to their existing facilities, except to construct an approximately one mile long transmission line as a feeder near Redwood City.

F. ENVIRONMENTAL EFFECTS

Table E-3 presents a summary of environmental changes related to conversion of CalTrain from a diesel powered commute service to an electrified service.

One of the most significant impacts resulting from electrification of CalTrain would be the overall improvement in regional air quality, by eliminating the fumes and smoke from diesel locomotives (particularly nitrogen oxides - NOx) and attracting patrons to the service, thereby decreasing auto trips. The most substantial improvement would be the 1% decrease in regional NOx. Although seemingly small, this decrease is a significant air quality improvement because it results from the implementation of a single project. Air quality policies often stress the usefulness of many "one percent solutions" to attain air quality and replacing diesel locomotives with electrified rolling stock on CalTrain can effect just such an improvement. Locally, however, pollutant emissions around CalTrain stations would increase minimally as a result of more auto trips to station parking lots. Conversely, while autos will be forced to wait at grade crossings more often with the increase in the amount of trains operating, thus creating pollutant "hot spots", electrified trains with their faster acceleration will reduce the amount of time motorists are forced to wait while crossing gates are down compared to diesel powered trains.

Another significant impact is the reduction in noise from locomotives. The sound level of a diesel locomotive averages 87 dBA 100 feet from the locomotive versus 69 dBA for an electric locomotive. There will be some noise from substations - 40-50 dBA at 100 feet, but this can be mitigated by sound walls, or by placement of the substations in areas where there are no sensitive receptors.

An improvement in energy usage would result from electrifying CalTrain. Diesel locomotives are dependent entirely on fossil fuels. The operation of an electrified CalTrain will result in the conservation of between 550 and 1,318 million BTU of energy per day from #2 diesel oil. The significance of this savings lies in the fact that only a small amount of #2 diesel fuel can be refined from any given barrel of crude oil, a non-renewable source, and ultimately limited in supply. In contrast, electricity for CalTrain can be obtained from hydropower, solar, wind,

TABLE E-3
SUMMARY OF ENVIRONMENTAL CHANGES
DIESEL TO ELECTRIC

	Potential Change from Diesel to Electric[1]	Reason for Change	Able to Mitigate Potential- Change
Air Quality	+ + +	Diesel fuel to electric; auto trips switching to train trips.	
Noise			
Engine (noisiest system source)	+ +	Electric quieter than diesel.	
Substations (in immediate vicinity)	-	Minor new noise sources.	Yes; if required, sound barriers at sensitive receptors or locate in less sensitive area.
Visual Effects	-	Introduction of new visual elements to corridor	Yes; screening, simple/ uncluttered catenary system and well designed support poles and substations.
Electromagnetic Field Hazard/Interference			
Hardwire Utility Interference (EMI)	-	Introduction of additional electromagnetic field.	Yes; mitigate with standard design techniques
Appliance Interference	-	Introduction of additional electromagnetic field.	Yes; mitigate with standard design techniques
Heightened Public Concern	-	Introduction of additional electromagnetic field	Yes; public information Campaign
Health Hazards	?	Introduction of additional electromagnetic field	Unknown
Energy			
Non-Renewable Resource Depletion	+ + +	Ability to use non-fossil fuel energy source at electric generating station	

TABLE E-3 (Continued)

SUMMARY OF ENVIRONMENTAL CHANGES
DIESEL TO ELECTRIC

	Potential Change from Diesel to Electric[1]	Reason for Change	Able to Mitigate Potential - Change
Energy Use Efficiency	+	Single point, larger generating facilities at electric sources	
Public Safety Concerns	-	Introduction of new electrical elements	Yes; "ground" metallic apparatus, design and emergency safety standards that limit public exposure to electrified sources
Passenger Comfort Concerns	+	Less noise, no fumes	
Circulation			
Grade Crossings	+	Slightly faster train speeds, less traffic wait time at crossings	
Station (negligible-spread over 26 stations)	0	Increased train ridership, more autos to stations	
Construction (temporary)	-	Introduction of construction activities and equipment	Yes; dust control, acceptable/appropriate work hours.

(1) Electric includes both EMUs and electric locomotives.

Notes:

+ Potential positive change
- Potential negative change
0 No change/negligible
? Unknown change; likely to be nominal when added to existing sources

geothermal, and nuclear fission sources as will as fossil fuels, such as coal or heavier petroleum fuels. In addition, generation of electricity in a central location and distributed to users is considered a more efficient utilization of energy.

Electrification may have modest negative impacts also. The catenary system associated with an 25-kV electrification system may be perceived as resulting in visual clutter, depending on the complexity of the network of wiring needed for the overhead catenary system, and the obtrusiveness of the catenary support poles and the substations. It is difficult to mitigate for the visual effects created by these wires. One possibility is to place trees and other vegetation at the edge of the right-of-way to screen the catenary wires from view, but only if this could be accomplished without interfering with train operations and maintenance.

The use of aesthetically pleasing support poles could help minimize their visual obtrusiveness. Although the prime concern in designing poles is making them strong enough to support the catenary wiring, a variety of different types of poles have been used in rail systems.

The traction power substation would typically be of a size approximately 60 feet by 80 feet to 100 by 150 feet depending on the supply voltage from the utility and be surrounded by a wall or fence 9 feet high. Some substation hardware can be placed into steel or brick buildings to conceal it. Substations can be completely hidden behind walls and trees, if so required.

25-kV AC electrical systems generate electromagnetic fields in the vicinity of all equipment carrying an electric current. Electromagnetic fields create electrical interference in communication and railroad signal cables that run parallel. This phenomenon is commonly known by its acronym, EMI (electromagnetic interference). There is also concern with potential interference with the operation of private appliances, such as TVs and radios. Some public concern recently has been focused on the suspected public health effects of these electromagnetic fields.

The strength of an electromagnetic field diminishes rapidly with increasing distance from the 25-kV source be it catenary or substation. Therefore, the extent of effects mentioned in this section will depend mainly on the distance of the affected person or cable from the equipment generating the field, in other words, those people and utilities within the near vicinity of the rail system - within the PCS right-of-way. It is also possible that electromagnetic fields produced by an electrified rail system could affect electrical communications equipment outside the right-of-way.

EMI can be mitigated by the shielding of cables or by other proven techniques.

During the construction of facilities for use in the electrical operation of CalTrain, construction would occur at various sites along the CalTrain corridor. The required construction will include building up to four electric substations, placement of support poles (60-70 per mile) and the wiring of 120 miles of catenary; construction should take approximately 2 years. However, it should be noted that the length of time of actual construction activities at any one location would be of a shorter duration.

During the construction period the following impacts may occur:

- Air pollutants may be emitted by construction equipment (assumed to be diesel), causing short-term degradation of air quality; possible mitigation measures are the use of electric construction equipment where feasible.

- Air-borne dust may be released at construction sites; dust could be minimized by frequent watering down exposed dirt or construction of temporary wind breaks.

- Short-term noise impacts may occur in the vicinity of construction sites; noise impacts can be minimized by limiting the hours of construction activity so as to affect the least number of people.

- Motor vehicle travel may be interrupted; this may be minimized by providing detours or publishing alternate travel routes in advance of construction beginning.

G. MAINTENANCE

In comparing the maintenance requirements of diesel powered and electric powered systems, for the purposes of this study, only the items of locomotive/MPC and gallery servicing, and maintenance of the electrification system need to be considered for costing. Other railroad maintenance requirements, such as permanent way maintenance, and signal/communications system maintenance, would be the same for diesel or electric traction, and are not included in this section of the study.

Less maintenance is required on electrified motive power than on a diesel locomotive. This is because much of the equipment on an electric locomotive or MPC, such as the transformer, rectifiers, inverters, etc. are static components compared to the diesel engine/alternator combination, fuel and lube oil pumps, etc. on a diesel locomotive. FRA regulations do require, however, the same level of periodic inspection for either type of vehicle.

Other commuter rail systems have found electrified rolling stock to provide more reliable operation, with a higher availability compared to diesel locomotives, particularly because there are fewer components to malfunction and because they do not have to be removed from service for fueling or to add engine cooling water.

An electrification system, however, with its overhead catenary system, substations, and supervisory control system, does entail an additional maintenance item not found on a diesel system. On the other hand an electrified service will not require a facility for diesel fuel storage and pumping equipment, lube oil tanks and the special safety requirements attendant to such facilities.

H. ECONOMICS

Capital costs for each alternative were determined in a line item fashion. The unit cost, number of units and total cost for each cost item was determined. Engineering, design and contingency costs were also calculated by using a percentage of facility and equipment capital costs. Capital facilities and equipment needed for both dual mode and electric operations can be categorized as either vehicles, or alignment facilities.

An evaluation of capital costs for the two alternative electric modes indicates that electric locomotive capital costs are considerably less than EMT (using MPCs) costs. At a 66 train schedule, electric locomotive costs are approximately $53 million less. The cost difference is $89 million at the 114 train schedule and $62 million at the 158 train schedule. The cost difference at the 158 train schedule is less, for the EMT fleet requirement is assumed to be the same at both the 114 and 158 train schedules because equipment utilization is increased with the more frequent schedules. A comparison of EMT and electric locomotive capital cost projections is presented in Tables E-4 and E-5.

Operating and maintenance (O&M) costs were also determined in a line item fashion. The analysis of O&M costs is based on spreadsheet cost models which calculate staffing requirements, labor costs and non-labor costs for the projected quantity of service supplied (e.g., peak vehicles, revenue vehicle-miles) and the physical size of the system (e.g., route-miles, number of stations). Separate cost models were developed for diesel/dual mode and electric operations.

Cost estimates for the 66-train schedules (diesel operations only) are based on the cost model developed from the Peninsula Corridor Joint Powers Board's (JPB) proposals for a 60-train schedule. Dual mode cost estimates are based on a modified version of this cost model. The introduction of electric operations is anticipated to increase costs in three cost categories: Maintenance of Rail Lines; Maintenance of Service Equipment; and Power Costs.

Annual O&M costs for electric operations were estimated by developing a second cost model. This model is also a variation of the diesel cost model built from the JPB cost proposals, with modifications to account for electric operations. It differs from the dual mode cost model in that there are no costs associated with diesel operations.

Table E-6 presents a comparison of O&M costs for the alternative modes.

While estimated capital costs and O&M costs have been identified, a complete comparison of diesel/dual mode and electric costs cannot be made until potential farebox revenue is considered.

Passenger revenue has been projected by applying an average fare/passenger to the ridership projections for each alternative train schedule. The current average fare collected per passenger is $1.56. For purposes of this analysis, it has been assumed that the average trip length will

TABLE E-4
CAPITAL COST ESTIMATES FOR ELECTRIC EMT OPERATIONS (In $1,000s) – WITH ELECTRIFICATION TO GILROY

Cost Item	Unit Cost	Unit	66 Train Schedule Units	66 Train Schedule Cost ($1,000s)	114 Train Schedule Units	114 Train Schedule Cost ($1,000s)	158 Train Schedule Units	158 Train Schedule Cost ($1,000s)
Alignment Costs								
4th to 25th St.								(1,2)
Catenary System	$400	Track Mile	3.8	$1,520	0.0	$0	0.0	$0
Bridge Fencing	$100	Bridge	3	$300	0	$0	0	$0
Subtotal				$1,820		$0		$0
25th St. to Lick								
Substations	$2,200	Substat.	3	$6,600	3	$6,600	3	$6,600
Catenary System	$400	Track Mile	99.0	$39,600	99.0	$39,600	99.0	$39,600
Bridge Fencing	$100	Bridge	35	$3,500	35	$3,500	35	$3,500
Bridge Supports	$60	Bridge	1	$60	1	$60	1	$60
Subtotal				$49,760		$49,760		$49,760
Lick to Gilroy								
Substations	$2,200	Substat.			1	$2,200	1	$2,200
Catenary System	$400	Track Mile			25.4	$10,160	25.4	$10,160
Bridge Fencing	$100	Bridge			2	$200	2	$200
Subtotal						$12,560		$12,560
Add-On Costs								
Engineering/Design	15.0%	Const. Cost		$7,740		$9,350		$9,350
Contingency	40.0%	Total Cost		$23,730		$28,670		$28,670
Right-of-Way	n/a	n/a		$0		$0		$0 (3)
Total Alignment Costs				$83,050		$100,340		$100,340
Vehicles								
EMT's	$3,500	Vehicle	46	$161,000	61	$213,500	61	$213,500
TOTAL COST:				**$244,050**		**$313,840**		**$313,840**
Credits								
Locomotive Resales	($1,500)	Vehicle	20	($30,000)	20	($30,000)	20	($30,000)
Pass. Car Resales	($1,000)	Vehicle	27	($27,000)	12	($12,000)	12	($12,000)
Subtotal				($57,000)		($42,000)		($42,000)
NET COST:				**$187,050**		**$271,840**		**$271,840**

NOTES:

(1) Capital costs associated with the extension to 2nd/Market are not included.
(2) For 66 train schedule, costs reflect 4th/Townsend to 25th Street and no Gilroy service.
(3) Substations and other improvements are assumed to be located on JPB right-of-way.
(4) Costs are in 1993 dollars.

TABLE E-5
CAPITAL COST ESTIMATES FOR ELECTRIC LOCOMOTIVE OPERATIONS (In $1,000s) – WITH ELECTRIFICATION TO GILROY

Cost Item	Unit Cost	Unit	66 Train Schedule Units	66 Train Schedule Cost ($1,000s)	114 Train Schedule Units	114 Train Schedule Cost ($1,000s)	158 Train Schedule Units	158 Train Schedule Cost ($1,000s)	
Alignment Costs									
4th to 25th St.									(1,2)
Catenary System	$400	Track Mile	3.8	$1,520	0.0	$0	0.0	$0	
Bridge Fencing	$100	Bridge	3	$300	0	$0	0	$0	
Subtotal				$1,820		$0		$0	
25th St. to Lick									
Substations	$2,200	Substat.	3	$6,600	3	$6,600	3	$6,600	
Catenary System	$400	Track Mile	99.0	$39,600	99.0	$39,600	99.0	$39,600	
Bridge Fencing	$100	Bridge	35	$3,500	35	$3,500	35	$3,500	
Bridge Supports	$60	Bridge	1	$60	1	$60	1	$60	
Subtotal				$49,760		$49,760		$49,760	
Lick to Gilroy									
Substations	$2,200	Substat.			1	$2,200	1	$2,200	
Catenary System	$400	Track Mile			25.4	$10,160	25.4	$10,160	
Bridge Fencing	$100	Bridge			2	$200	2	$200	
Subtotal						$12,560		$12,560	
Add-On Costs									
Engineering/Design	15.0%	Const. Cost		$7,740		$9,350		$9,350	
Contingency	40.0%	Total Cost		$23,730		$28,670		$28,670	
Right-of-Way	n/a	n/a		$0		$0		$0	(3)
Total Alignment Costs				$83,050		$100,340		$100,340	
Vehicles									
Locomotives	$4,500	Vehicle	18	$81,000	25	$112,500	31	$139,500	
TOTAL COST:				**$164,050**		**$212,840**		**$239,840**	
Credits									
Locomotive Resales	($1,500)	Vehicle	20	($30,000)	20	($30,000)	20	($30,000)	
NET COST:				**$134,000**		**$182,840**		**$209,840**	

NOTES:

(1) Capital costs associated with the extension to 2nd/Market are not included.
(2) For 66 train schedule, costs reflect 4th/Townsend to 25th Street and no Gilroy service.
(3) Substations and other improvements are assumed to be located on JPB right-of-way.
(4) Costs are in 1993 dollars.

TABLE E-6
COMPARISON OF ANNUAL O&M COSTS
FOR ALTERNATIVE MODES

Train Schedule	Operation Mode	Cost ($1,000s)	Cost Tr. Hour	Cost Pass.
66	Diesel	$41,533	$1,353	$5.07
	Electric to Tamien	$42,157	$1,373	$4.66
114	Dual Mode	$67,101	$1,190	$4.86
	Electric to Gilroy	$64,392	$1,142	$4.23
	Electric to Tamien	$64,839	$1,150	$4.26
158	Dual Mode	$92,273	$1,189	$4.24
	Electric to Gilroy	$86,389	$1,113	$3.60
	Electric to Tamien	$86,847	$1,119	$3.61

Notes:
(1) All costs in 1993 dollars.

remain similar to today's average trip length, thus resulting in the current average fare per passenger.

Ridership under electric operations is anticipated to be slightly higher than ridership under diesel operations due to slightly improved travel times. When applied to the average fare per passenger, annual passenger revenue projections are as follows:

Train Schedule	Diesel/Dual Mode Ridership	Electric Ridership	Diesel/Dual Mode Revenue	Electric Revenue
66	8,200,000	9,040,000	$12,792,000	$14,102,000
114	13,820,000	15,220,000	$21,559,000	$23,743,000
158	21,760,000	24,030,000	$33,946,000	$37,487,000

It is important to note that the above revenue projections assume the same annual ridership for both electric operating scenarios (Gilroy versus Lick electrification).

The cost effectiveness of electric operations was measured by evaluating the net cost associated with each alternative train schedule and mode of operation. Annual operating costs were added to annualized capital costs to arrive at total annualized costs. Passenger revenue was then subtracted from the total cost to arrive at the net cost. This methodology is used by the Federal Transit Administration (FTA) as a measure of cost-effectiveness in Alternative Analyses and other planning reports. Because capital funding is more obtainable than operating subsidies, net costs were also calculated without annualized capital costs. Table E-7 presents the annualized net cost associated with each alternative.

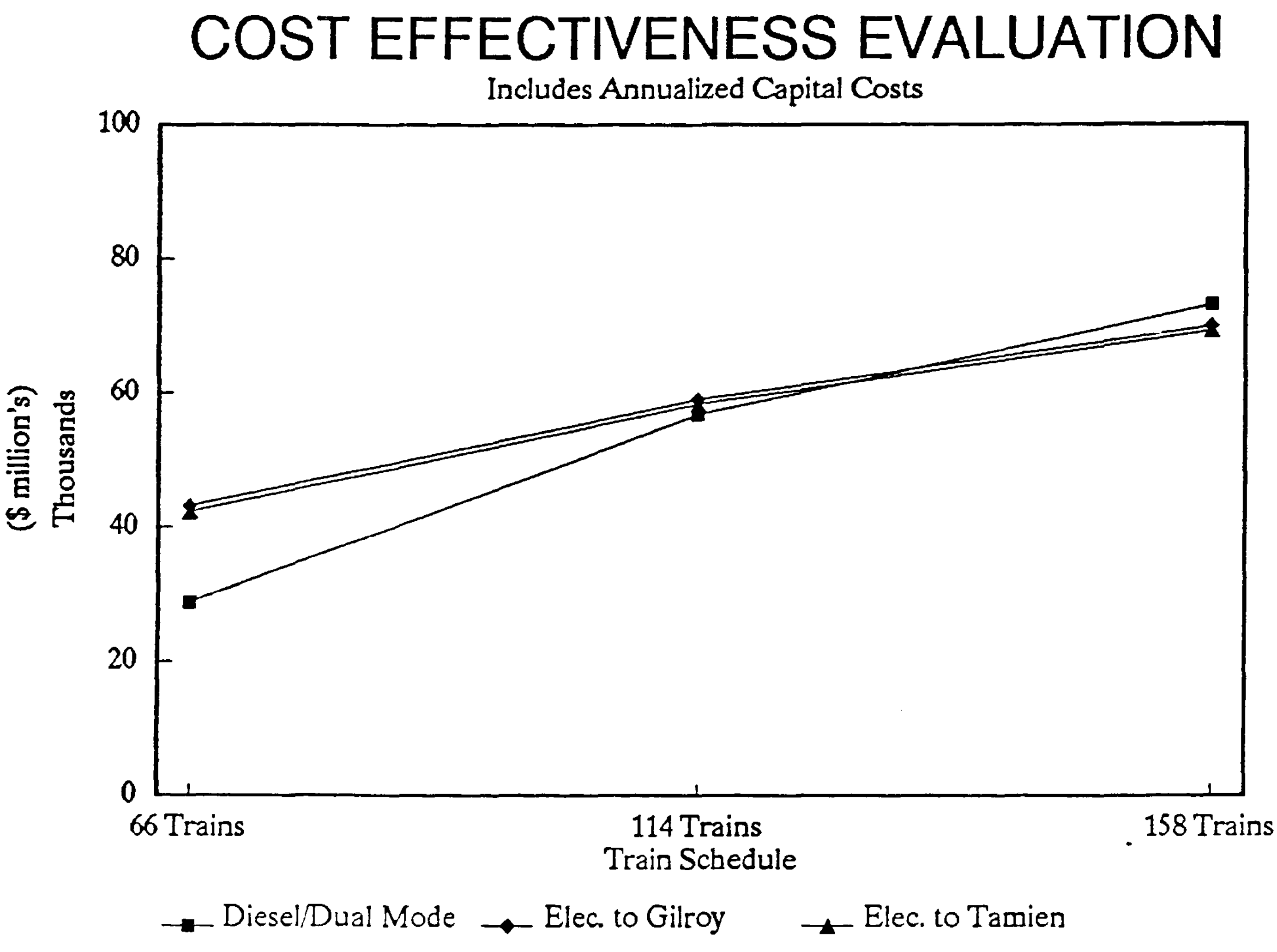
Costs associated with the 66 train schedule under electrified operations are anticipated to be $13.6 to $14.4 million higher than costs associated with diesel operations, depending on the electrification scenario. The difference in costs for the 114 train schedule ranges from $1.6 to $2.3 million, depending on the electrification scenario. At the 158 train schedule, annualized costs for electric operations are $3.1 to $3.8 million less than costs for dual mode operations. A comparison of net costs for each train schedule and mode of operation is illustrated in Figure E-3. This figure illustrates two important findings: a) at the 114 train schedule, the net cost for all three operating scenarios is within $2.5 million); and b) total costs for track electrification to Lick is slightly less than total costs for electrification to Gilroy (approximately $750,000).

The cost effectiveness evaluation is significantly different when annualized capital costs are not included. At the 66 train level of service, diesel operations are $0.7 to $1.0 million **more** than costs for either electrification scenario. The cost savings at the 114 train level are $4.5 to $4.9 million, depending on the electrification scenario. The cost savings at the 158 train level are $9.0 to $9.4 million. Figure E-4 illustrates the cost savings obtained by electrification, should capital costs not be included as an annualized cost. Over 80 percent of the O&M cost savings

TABLE E-7
NET COSTS FOR DIESEL (DUAL MODE) AND ELECTRIC OPERATIONS
(In $1,000s)

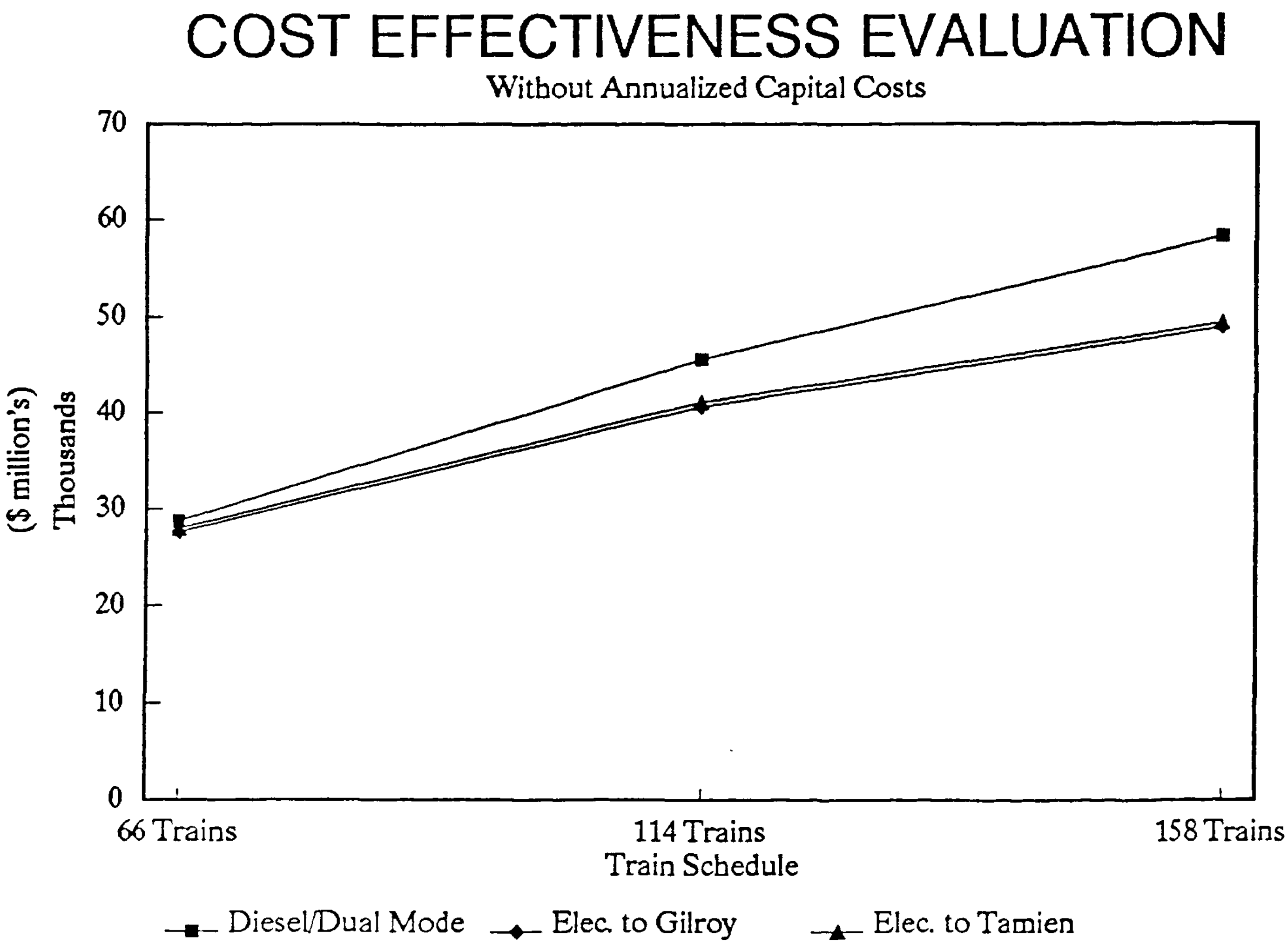
Train Schedule	Operation Mode	Annual O&M Costs	Annual Capital Costs	Total Costs	Pass. Revenue	Net Cost incl. Annl. Cap. Cost	Net Cost w/o Annl. Cap. Cost
66	Diesel	$41,533	$0	$41,533	$12,792	$28,741	$28,741
	Electric to Lick	$42,157	$14,250	$56,407	$14,102	$42,305	$28,055
114	Dual Mode	$67,101	$11,210	$78,311	$21,559	$56,752	$45,542
	Electric to Gilroy	$64,392	$18,370	$82,762	$23,743	$59,019	$40,649
	Electric to Lick	$64,839	$17,210	$82,049	$23,743	$58,306	$41,096
158	Dual Mode	$92,273	$14,840	$107,113	$33,946	$73,167	$58,327
	Electric to Gilroy	$86,389	$21,160	$107,549	$37,487	$70,062	$48,902
	Electric to Lick	$86,847	$20,000	$106,847	$37,487	$69,360	$49,360

FIGURE E-3



COST EFFECTIVENESS EVALUATION
Includes Annualized Capital Costs
100
80
60
40
20
0
($ million's)
Thousands
66 Trains
114 Trains
158 Trains
Train Schedule
Diesel/Dual Mode
Elec. to Gilroy
Elec. to Tamien

FIGURE E-4


COST EFFECTIVENESS EVALUATION
Without Annualized Capital Costs
70
60
50
40
30
20
10
0
($ million's)
Thousands
66 Trains
114 Trains
158 Trains
Train Schedule
Diesel/Dual Mode
Elec. to Gilroy
Elec. to Tamien

is in reduced power costs and maintenance of service equipment costs.

The most significant cost savings provided by electrification is in O&M costs. Over 80 percent of the O&M cost savings is in reduced power costs and maintenance of service equipment costs.

There are also environmental benefits associated with electrification. If these benefits were financially quantified, electrification could also be determined to be more cost-effective than dual mode costs at the a lower train service level, possibly with the 114 train schedule. At this level of analysis, however, it is not possible to quantify environmental benefits in monetary terms.

I. CONCLUSIONS

To summarize, the analysis provided in this report has evaluated the cost-effectiveness of electrified CalTrain service at three alternative levels of service and two alternative electrification scenarios (electrification to Gilroy versus the San Jose area. Key findings in this evaluation are as follows:

- Electrification of CalTrain would be based on a 25 kV AC system with catenary, utilizing electric locomotives and the existing fleet of gallery cars (plus an expanded fleet of locomotive-hauled cars)

- The environmental benefits of an electrified CalTrain outweigh negative environmental impacts.

- Capital and operating costs for EMT operations would be significantly higher than capital and operating costs for electric locomotive service, at all levels of service that were analyzed. Therefore, only costs for electric locomotives were compared to diesel/dual mode costs.

- At all three train schedules, capital and O&M costs for electrifying the line to Lick in the San Jose area (with diesel locomotive service from Tamien to Gilroy) is anticipated to be slightly lower than costs for electrification of the entire line to Gilroy, judged strictly on economic terms (that is, without environmental benefits).

- With the assumptions utilized in this report, when annualized capital costs are included in the calculations, electric service is anticipated to be more cost-effective than dual mode locomotive service somewhere between the 114 and the 158 train service level. At the 114 train schedule, however, the difference in costs is less than $2.5 million. It is possible that electric locomotive service to Gilroy could also be more cost-effective than dual mode service at the 114 train schedule, once environmental benefits were financially quantified. The level of analysis provided in this study, however, does not allow for the financial quantification of these benefits.

  If annualized capital costs are not included in the cost-effectiveness calculations, electric operation is more cost-effective than diesel operation at the 66 train level of service, with increasing operating cost savings as more trains are operated per day.