TECHNICAL REPORT

THE COST OF CONVERTING LINE 204

TO TROLLEY COACH OPERATION

AUGUST 1985

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

425 SOUTH MAIN STREET

LOS ANGELES, CALIFORNIA 90013

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1.0 BACKGROUND

1.1 Purpose

On January 3, 1985, the Board of Directors of The Southern California Rapid Transit District requested that the cost of installing and operating a Trolley Coach (TC) System be analyzed for one of its major lines. This request is motivated by the desire to provide reliable bus service that is environmentally less obtrusive than the existing motor bus service in heavily traveled areas. Another motivating factor is the possibility that TC conversion could offer equivalent bus service at lower cost. The only existing technological alternative to the motor bus is the TC, whose viability in revenue service has been tested by decades of operating experience.

Line 204 along Vermont Avenue is among the most promising routes for demonstrating the cost and operating advantages of TC service. This paper approaches this analysis in three major phases. First, the cost of providing vehicles, fuel, vehicle maintenance, and revenue operation for the existing service on Line 204 is estimated. Second, the cost of replicating this service using the latest off-the-shelf TC technology is determined. This phase requires special attention to the cost of constructing the overhead wiring and power distrubution system both along the route and within an operating division. Finally, this cost information is used to estimate life cycle (annualized) costs so that a comparison can be made between the two technologies. It is hoped that this method could be extended to the analysis of other lines that exhibit TC conversion potential. This analysis is of a preliminary nature designed to ascertain the potential economies of TC operation. Such information will determine whether further, more refined analyses could promise to establish TC operation as a solution to the District's goal of providing transit service that strikes a balance between cost and environmental impact.

Highlights of the analysis are presented in the body of this paper while the technical and methodological details are reserved for the appendix.

1.2 History

The earliest TC was demonstrated in Berlin by Werner von Siemens in 1882. An eight-wheel "trolley" rode on top of two overhead wires to pick up electricity. It was pulled by the vehicle from a flexible cable. By 1901 Max Schiemann had developed a system whereby power is collected underneath the wire.

The U.S. experienced its first application of TC service in the Laurel Canyon area of the Hollywood Hills in 1910. This "trackless trolley" was used to feed riders from the steep slopes of "Bungalow Town" to the Pacific Electric Railway tracks below. This TC was capable of climbing grades that the primitive gasoline-powered motor buses of the day could not negotiate. Modern TCs still enjoy this advantage over today's diesel buses. The Laurel Canyon service lasted for only a short time, but the idea of being able to extend trolley service without bearing the expense of laying rails had taken root.

Despite its early appearance, the TC did not become a regular component of Los Angeles' transit network until 1947. At this time TCs replaced rail service along two routes -- one extending from 6th Street and Wilton Place through Downtown to 58th Street and Central Avenue, and the other along Brooklyn Avenue in East Los Angeles through Downtown to 51st Street and Ascot Avenue. By 1963 the Los Angeles Metropolitan Transit Authority had extended these lines to a total of 23 one-way route miles before abandoning their operation.

The reasons for discontinuing TC service appear to be two-fold. First, the demise of five rail lines in 1963 left these two TC lines as the sole users of a large, aging power distribution system that was becoming ever more expensive to maintain. Second, the patronage on these lines was declining. Thus the prospects for providing TC service at a reasonable cost looked dim for the immediate future. Permission to extend TC service along Alvarado Street was granted by the Public Utilities Commission in 1955, but never exercised.

Nationally, TCs flourished during World War II but declined during the 1950s. Only a handful of cities in the U.S. opted to keep part of their systems in operation. San Francisco, Seattle, and Dayton have systems centered in their Downtown areas. Philadelphia's and Boston's systems operate only in outlying areas. As service densities increased in other cities, new interest rose in TC technology as a means to reduce the life cycle costs of providing bus service and to avoid noise and air pollution on congested city streets.

1.3 Trolley Coach and Motor Coach Compared

This paper is a head-to-head comparison of TC and Motor Coach (MC) operation of current service on Line 204. The MC and TC are very similar in terms of appearance, driver operation, vehicle size and carrying capacity. These two modes differ, however, in operating characteristics and environmental impacts. The fundamental differences are their propulsion systems and means by which power is supplied to these systems. The MC is virtually self contained. Fuel is carried on board the vehicle and burned in the engine. The engine converts this fuel into traction energy, exhaust gases, sonic energy, and heat, all located where the vehicle and its riders happen to be at the time. In the case of diesel buses, some of these products of combustion are undesirable. Noise and exhaust are at best a nuisance, at worst a health hazard, in the immediate vicinity of the vehicle. Noise and vibration also adversely affect passenger comfort and perhaps even patronage volumes. Steep grades are difficult for diesel buses to negotiate due to the low torque delivered by diesel engines at low speeds.

Nevertheless, self contained operation has many advantages. Unscheduled, but all too frequent, traffic disruptions are easily avoided. Local and skip-stop runs may be readily mixed by virtue of MCs' passing capabilities. Routes can be quickly altered without the need to follow power distribution hardware. Short-lining can be scheduled without the need to construct additional overhead turnback wiring.

Trolley coaches require a fixed investment in power distribution along the route. These vehicles initially cost more than MCs, but their longer life reduces their life cycle capital outlay requirement. The operating costs of TCs are lower than MCs, however, further compensating for the capital cost of overhead wiring. Thus, TCs will be more cost effective where revenue service exhibits a high ratio of revenue vehicle miles to route miles.

While TCs are less flexible to operate than MCs, they exhibit many advantages. Having noise levels comparable to those of automobiles, they are quieter than MCs, improving the urban environment in which they operate as well as passenger comfort. Passenger comfort is also enhanced by the TC's lower engine vibration. The propulsion system is less likely to break down during revenue operation and upset service schedules.
The air quality impact of TCs is non-existent in the vicinity of the vehicle. On a mile by mile basis, diesel-fired turbine generators at the power plant are significantly cleaner than the diesel engines on board MCs. Asphalt road beds are exposed to less stress; TCs do not spill fuel on the roadway and their axle weight is lower than equivalent MCs. Visual impacts of TCs and MCs are hard to compare; the visual clutter of overhead wires is the price paid for eliminating the smoke emitted from MCs. Table 1.3.1 compares the environmental impacts of these two modes. The TC also has the edge in engine performance, giving it better acceleration and hill climbing abilities. Owl service pull-outs are unnecessary because base run vehicles need not pull in for refueling.

TABLE 1.3.1

TROLLEY COACH VS DIESEL COACH
ENVIRONMENTAL IMPACTS

	MOTOR COACH	TROLLEY COACH
Peak Exterior Noise*	92 dbA	83 dbA
Exhaust Emissions:		
Smoke	1.3 gr/mi	1.0 gr/mi
Carbon Monoxide	21.3 to 22.6 gr/mi	0.3 gr/mi**
Nitrous Oxides	21.5 to 24.3 gr/mi	10.3 gr/mi**
Hydrocarbons	4.0 to 4.7 gr/mi	0.2 gr/mi**

* Comparable automobile noise levels are in the mid-80's dbA. Differences greater than 3dBA are audibly apparent.

** Assumes diesel turbine generation. These emissions occur at the site of the generator instead of at the site of the vehicle.

The energy consumption of TC operation is roughly the same as that of MCs on a mile by mile basis. While electricity generators can more efficiently convert fuel into energy than diesel bus motors, power losses in transmission lines to the TC reduce the ultimate fuel efficiency of these vehicles. The major energy advantage of TCs over MCs is the former's lack of dependence on petroleum fuels. TCs are ultimately powered by coal, natural gas, running water, or whatever energy source that is cost effective for the generation of electricity at any given time.

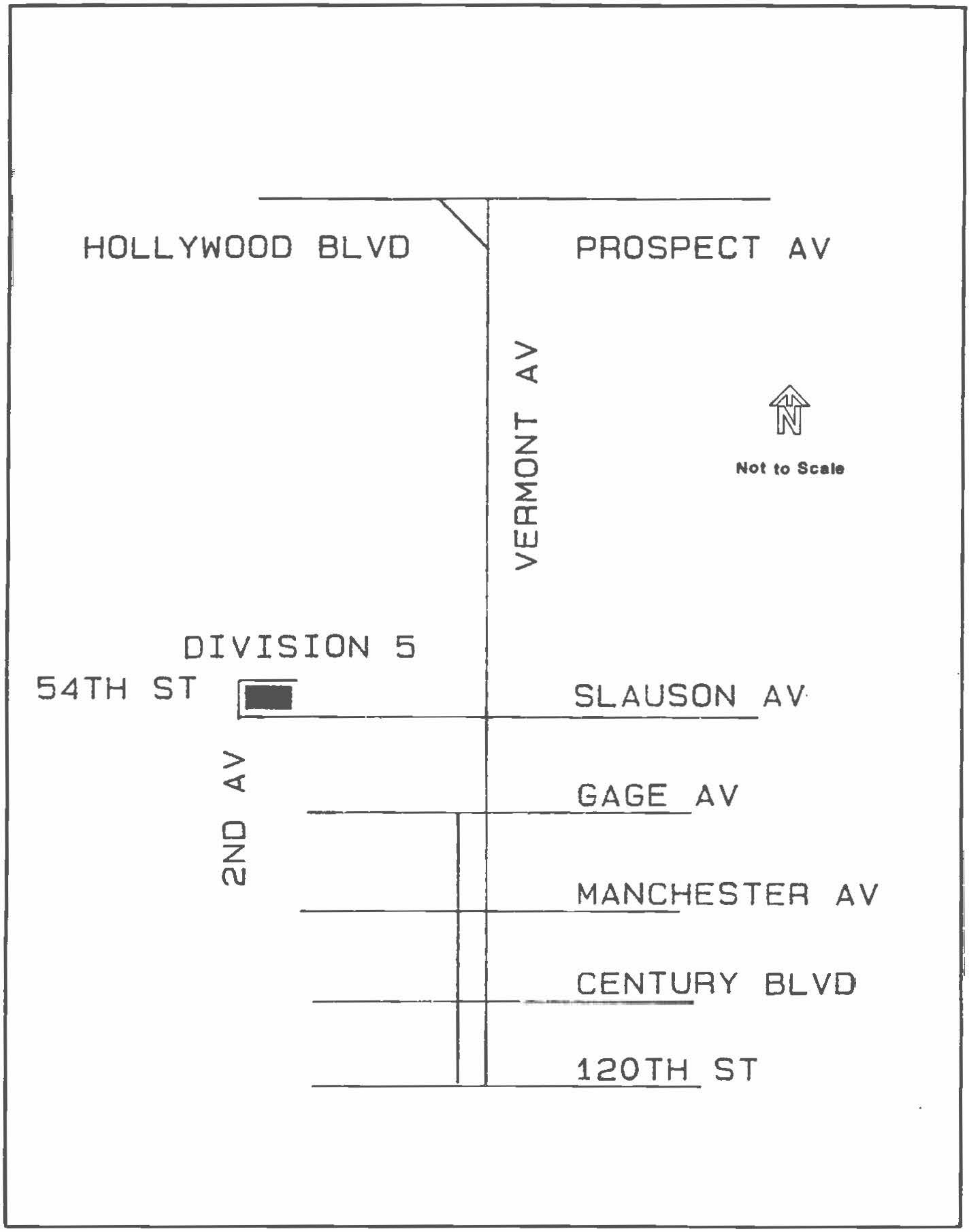
Comparing the operational and environmental characteristics of TCs and MCs brings to light the trade-offs offered by these two technologies. The essential purpose of these vehicles is to provide personal transportation capacity along fixed routes. The TC does so with less adverse effects on the environment than the MC. This report is devoted to estimating the cost of these environmental advantages along Line 204 - Vermont Avenue.

1.4 Line 204 - Vermont Avenue

Line 204 is a prime candidate for conversion to TC operations. The portion of interest along this route runs 12.5 miles from 122nd Street to the south to Hollywood Boulevard to the north (See Figure 1.4.1). The Griffith Park Observatory service is not included in this study because of its low use -- only an average of 30 revenue vehicle miles per route mile each day. Line 204 runs in a straight line, requiring few complicated and unsightly switches, curves, and crossings ("special work") to be constructed along its path. Both termini and all of its current short-line turnback loops were U-turns at one time. Such U-turns are relatively inexpensive to wire. Division 5 is less than two miles away, keeping deadhead wiring acceptably short. Finally, Vermont Avenue has a history of trolley rail service. Thus, utility lines are sufficiently high above the roadbed to allow ample clearance for TC wires. In fact, the trolley poles are still standing along portions of the route.

Bus traffic along Line 204 is heavy. During weekdays some 427 revenue vehicle miles are traveled for every mile of route. This is intensive use by any standard, even by those of other TC routes in the U. S.. Patronage has been increasing in recent years, reaching some 64,000 per day in 1983. As a result, short line trips have been replaced with trips that cover larger portions of the route. Thus, the need for constructing short-line turnback loops has decreased over time.

All of these geographical, historical, and demand factors point to Line 204 as a prime candidate for TC conversion. The only irony is that the Griffith Park service, whose steep grades could be more adequately climbed by TCs, has not the demand sufficient to justify the capital cost of wiring its path. Nevertheless, straight routes with heavy use with few overhead limitations are ideal conditions for conversion to TC operation. Line 204 has such a route.



RTD

ROUTE OF PROPOSED TROLLEY COACH OPERATION ON LINE 204

FIGURE 1.4.1

2.0 COST ELEMENTS FOR EXISTING MOTOR COACH SERVICE

In order to address the question of conversion and operating cost of TC service it is necessary to compute the marginal cost of existing service, i.e., the savings that would be gained by shutting down current MC service on Line 204. These costs include vehicle acquisition, maintenance, and operations. Operations costs are subdivided into two categories: fuel (including lubricants) and revenue operation (driver labor, line superintendent labor and taxes). These cost elements are derived from the District's Section 15 report for 1984 to maintain consistency with established cost analyses of MC and TC systems. Detailed derivations are presented in the appendix.

Throughout this paper, "Line 204" refers to all service on Vermont Avenue except trips to Griffith Park Observatory. All costs are expressed in constant 1984 dollars. Table 2.0.1 summarizes the estimates of capital and operating costs for the existing MC service on Line 204.

2.1 Vehicle Acquisition

The maximum number of vehicles required on Line 204 at any given time is 44 for the weekday evening peak period. Using a 15% spare ratio, 51 MCs must be purchased to provide the services scheduled for Line 204 as of September 9, 1984. These vehicles are assumed to be equipped with air conditioning and wheelchair lifts. Such a fleet costs $8.7 million constant 1984 dollars. These buses are assumed to last 12 years.

2.2 Fuel and Lubricants

Fuel consumption is calculated by the hour instead of by the mile. This approach is adopted to account for the higher fuel consumption per mile experienced by vehicles that travel local routes at low speeds. Details concerning the derivation of the $3.54 per vehicle hour fuel and lubrication costs are in the appendix. At this rate it costs $642,000 to fuel and lubricate vehicles that operate on Line 204 during 1984.

2.3 Vehicle Maintenance

Vehicle maintenance costs are also measured on a vehicle hour basis. Buses that operate at slow speeds require more maintenance per mile than those that travel at higher speeds. Estimating maintenance on an hourly basis is an attempt to overcome this bias. At a cost of $14.36 per vehicle hour, maintaining the vehicles for Line 204 comes to $2.61 million.

TABLE 2.0.1

Estimated Costs Of Motor Coach

Service For Line 204

(thousands of constant 1984 dollars)

Capital Costs:	
Vehicle Acquisition	$8,721
Operating Costs:	
Fuel and Lubricants	$ 642/YEAR
Vehicle Maintenance	2,608/YEAR
Revenue Operations	4,618/YEAR
TOTAL OPERATING COST	$7,868/YEAR

2.4 Revenue Operation

Revenue operation is the cost of guiding vehicles along their scheduled routes. Driver labor is the most expensive component of this cost. Also included are line superintendent labor and license fees. These cost items are assumed to remain the same per vehicle hour for both MC and TC operation. At $25.43 per vehicle hour, these components amount to $4.6 million per year. This is by far the largest element of operating cost and is not expected to differ by a significant amount if the vehicles were regular 40-foot TCs rather than regular 40-foot MCs. These costs may differ if articulated TCs are employed.

3.Ø TROLLEY COACH SYSTEM CAPITAL COSTS

The cost structure of TC systems is more capital intensive than that of MC systems. The overhead wiring and power distribution equipment along the route are up-front capital expenditures that are recovered to some extent by savings in operating costs. For this reason TC service can only be cost effective along heavily traveled routes. This chapter addresses the capital needs of TC operation on Line 2Ø4 and estimates their costs. The findings are summarized in Table 3.Ø.1. These costs take into account only cost components that may vary from those of MC operation.

3.1 Vehicle Acquisition

Suppliers of TCs are fewer in number than for MCs, especially in North America. Current vehicle acquisition cost data are scarce due to the relatively infrequent purchases of these vehicles. Few vehicles have been purchased with the combination of features used in this analysis. These features are:

1) Air Conditioning
2) Wheelchair Lifts
3) Chopper Control
4) Emergency Battery Pack

The first two features meet the same level of passenger comfort and service accessibility as the MCs described in Chapter 2. The third feature reduces the energy needs of the vehicle by 1Ø% to 25%. Chopper control is a relatively new technology that is now proving its worth in revenue service. The emergency battery pack allows limited off-wire excursions by the vehicle. Such capabilities both enhance the operating flexibility of the vehicle and reduce the capital investments otherwise needed for installing emergency turnback loops and some complicated special work in the yard. Details of these and alternate features are discussed in the appendix.

Figures 3.1.1 and 3.1.2 illustrate both standard 4Ø-foot and articulated TC models. The standard model 4Ø-foot is used in this analysis in order to preserve the equivalence of the modeled TC system and the existing MC system in terms of line capacity, headways and dwell times.

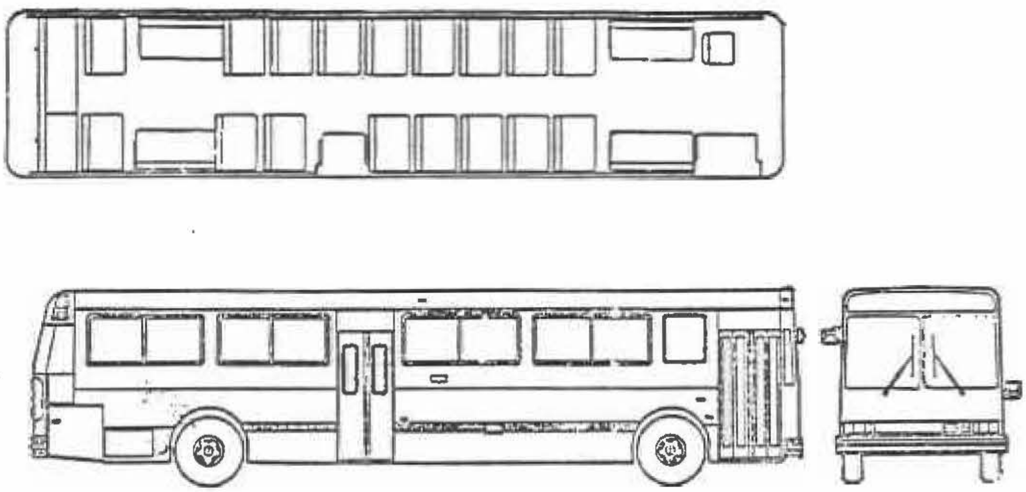
The TCs used in this analysis are estimated to cost $227,ØØØ each. While this purchase price is 3Ø% higher than that of a comparable MC its serviceable life is 25 years. This results in TCs having a lower annualized acquisition cost than MCs. A fleet of 51 such vehicles costs $11.6 million, the largest capital cost component of the system.

TABLE 3.0.1

Estimated Costs of Trolley Coach
Service for Line 204
(thousands of constant 1984 dollars)

Capital Costs:	
Vehicle Acquisition	$11,577
Overhead Wiring	7,890
Power Distribution	4,025
Other Capital Equipment	490
Total Capital Costs	$23,982
Operating Costs:	
Energy	$ 376/year
Vehicle Maintenance	2,007/year
Revenue Operations	4,618/year
Overhead & Power Maintenance	347/year
Total Operating Costs	$ 7,348/year

Figure 3.1.1 FLYER TWO AXLE TROLLEY COACH



BUILDER: FLYER

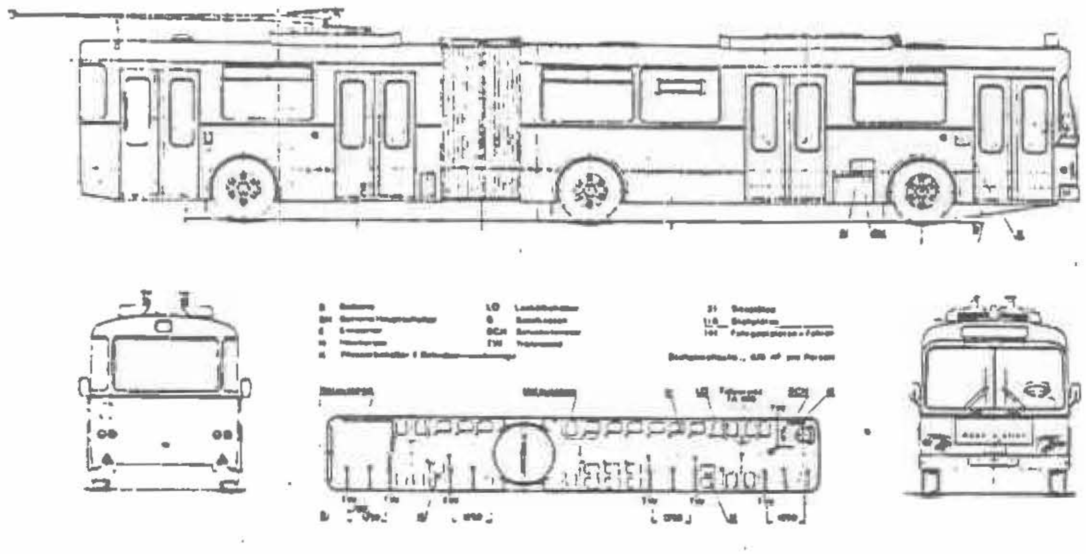
ELECTRICAL EQUIPMENT SUPPLIER: GENERAL ELECTRIC (2)

MODEL NO. E900-10240 (1)

DIMENSIONS (ft/mm)	
Length - overall	40/12192
Width - overall	8.5/2590
Height - overall	10.2/3109 (3)
Wheel Base	23.7/7224
Floor Height	2.9/884
Door Openings (between handrails)	2.5/762 (4)
Minimum Turning Radius	37.2/11339
WEIGHT EMPTY (lbs/kg)	23000/10431
CAPACITY (seats/standees)	51
PROPULSION AND PERFORMANCE	
Motor	GE 1213 Compound 600 Volt DC
Rating of Motor (hp/kw)	155/116
Motor Control	Cam control switched resistor (5)
Top Speed (mph/kmph)	40/67
Acceleration (mphps/mpsps)	3.5/1.6
AUXILIARY POWER	
Top Speed (mph/kmph)	Not included
STATUS	Production Model

(Source: Wilkins et. al, 1979)

Figure 3.1.2 M.A.N. ARTICULATED TROLLEY COACH



BUILDER: M.A.N. (GRAF & STIFT)
ELECTRICAL EQUIPMENT SUPPLIER: KIEPE ELECTRIC

MODEL NO. GE-110/54/57 A

DIMENSIONS (ft/mm)	
Length - overall	54.1/16500 (1)
Width - overall	8.2/2500
Height - overall	11.3/3460 (2)
Wheel Base	18.8-17.9/5745-5450
Floor Height	2.8/855
Door Openings (between handrails)	4.1/1250
Minimum Turning Radius	34.1/10400
WEIGHT EMPTY (lbs/kg)	28665/13000
CAPACITY (seats/standees)	31/100 (3)
PROPULSION AND PERFORMANCE	
Motor	Keipe, Compound 600 Volt DC
Rating of Motor (hp/kw)	N/A
Motor Control	Contactor (other types available)
Top Speed (mph/kmph)	37/60
Acceleration (mphps/mpsps)	N/A
AUXILIARY POWER	
Top Speed (mph/kmph)	Not included
STATUS	Production Model

(Source: Wilkins, et. al, 1979)

3.2 Overhead Wiring

Overhead wiring is the most obvious evidence of the presence of TC service. It is also a TC system's major cost handicap. Unlike electric rail vehicles whose steel wheels conduct electric current to ground, TCs must maintain both "hot" and "neutral" contact with overhead wires. This requires the suspension of two wires for TCs where rail requires only one. This also requires insulated crossings to be installed wherever two opposing TC wires meet (See Figure 3.2.1). Both of these requirements lead to a cluttered aerial appearance of the conductors at curves and intersections where much special work (crossings, switches, etc.) are located. Fortunately, Line 204 requires relatively little special work along its route, reducing both the cost of the overhead work and its visual impact.

Figure 1.4.1 illustrates the route for Line 204 to be used for costing purposes. The revenue portion of the route is essentially the same as the existing one, running along Vermont Avenue from 122nd Street to Hollywod Boulevard. Turnback loops are to be constructed at the line termini as well as at 106th Street and 90th Street for scheduled short-lining at Century Boulevard and Manchester Avenue, respectively. Layover zones near these turnbacks are those now in use with the exception of the 90th Street loop. Here the layover zone used prior to November 19, 1984 is adopted in order to reduce overhead wiring costs and to avoid TC traffic along residential side streets. No emergency turnback loops are provided. The selection of TCs with emergency off-wire capability is made in lieu of constructing permanent wiring for non-scheduled vehicle movements.

Slauson Avenue is selected as the deadhead route to Vermont Avenue from Division 5. While 54th Street was considered (wiring 54th Street would be less expensive), Slauson is a wider thoroughfare, offering better possibilities to bypass obstructions to normal traffic. The more commercial land use along Slauson Avenue would be less adversely affected by TC operation than residential 54th Street. Special work along this deadhead route includes three double wire 90-degree turns and a tee junction at Vermont Avenue.

Other special work occurs south of Gage Avenue to negotiate Vermont Avenue's expansion from a 70-foot right-of-way to a 150-foot right-of-way. Additionally, a traffic signal is to be installed at the northern terminus to facilitate a U-turn about a traffic island bordered by Vermont Avenue, Prospect Avenue, and Hollywood Boulevard.

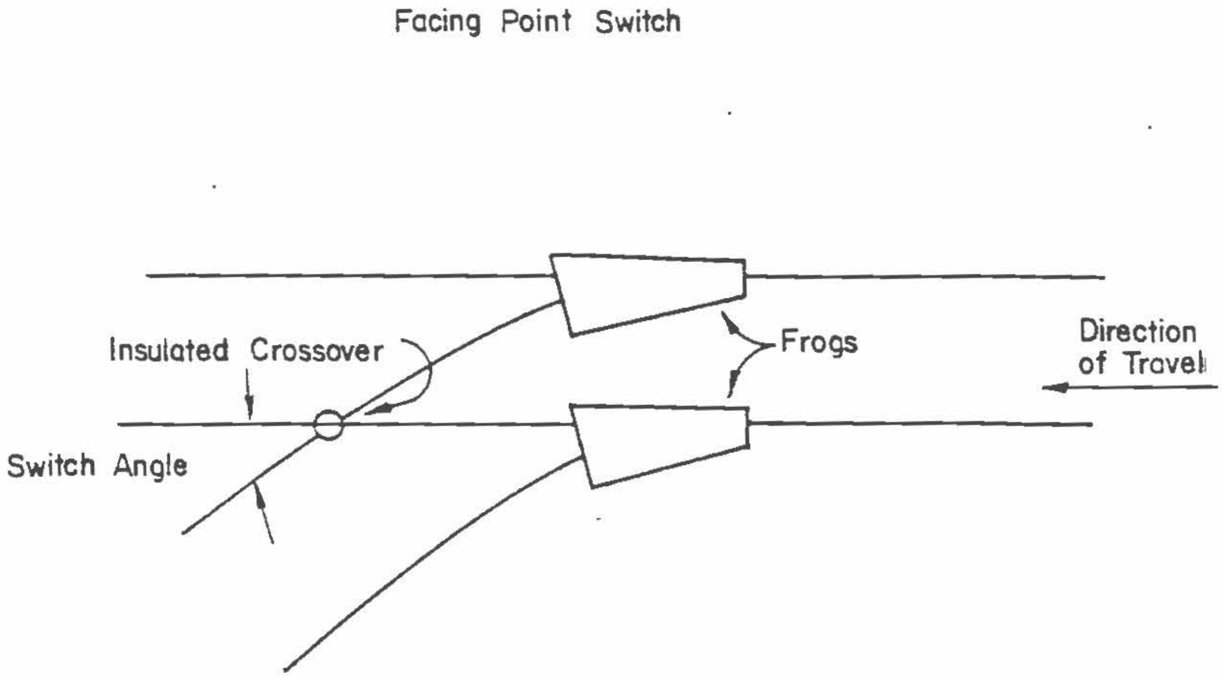
Utility relocation along both Vermont Avenue and the deadhead route is minimal. Inspection of these routes only identified some existing wiring that parallels the Santa Fe Railroad right-of-way at Vermont and Slauson Avenues and Slauson between Western and Denker Avenues as necessary for relocation. Relocation here means increasing their height above 20 feet over the road bed. No other utility relocation is accounted for in this analysis, but preliminary engineering may identify where more relocation would be necessary.

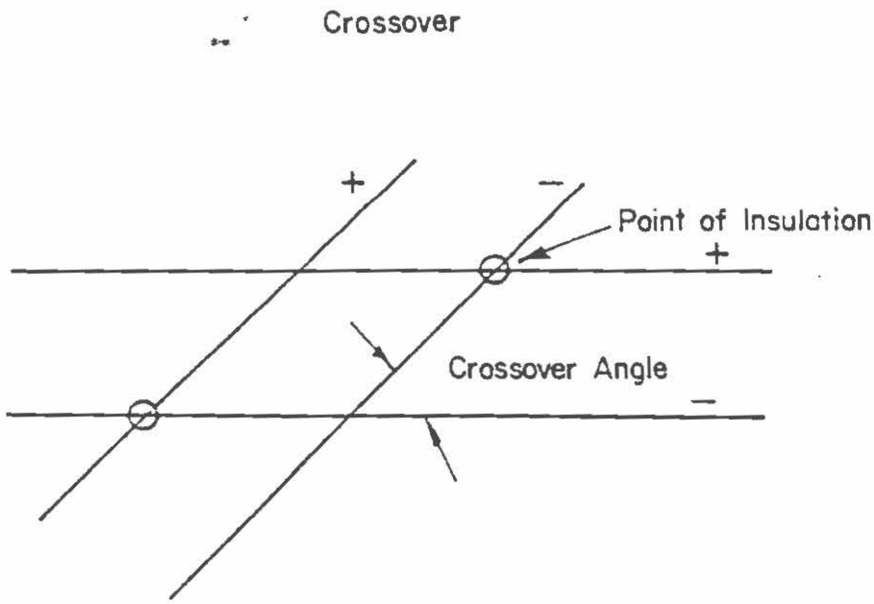
Figure 3.2.2 illustrates how tangent wire is installed along "straightaways." One-way wire (one hot plus one neutral) is suspended from a pole and bracket. This technique is used for one-way sections of the route and along streets that are too wide for span suspension. Span suspension is used where possible along two-way sections of a route. Overhead wire is suspended below the spans between two opposing poles. Both methods of wire suspension are used in this analysis. The deadhead route and Vermont Avenue north of Gage Avenue are primarily double wire suspended from spans. Vermont Avenue, south of Gage Avenue, is too wide to accommodate spans, so brackets suspend single wire throughout much of this portion of the route. Both methods are used inside Division 5.

Figure 3.2.3 illustrates how special work (i.e., switches, curves, and crossings) is hung. The poles used for these installations are heavier and more expensive than those used for running straight tangent wire in order to withstand the stress of anchor guys that maintain proper wire angles. For the purposes of this analysis, curves will use the more economical curve segment construction rather than the elaborate backbone method. All overhead costs are subdivided into two categories. The first category includes line materials. These components (wire, switches, crossings, etc.) have an expected life of 30 years. Poles, brackets, spans, road bed alterations, and utility relocations make up the second category and have an expected life of 50 years. Table 3.2.1 summarizes the cost estimates of overhead wire for both categories along Line 204. Together they total $7.89 million. A conservative 25% is included in this cost for engineering and contingencies

Figure 3.2.1

Trolley Coach Overhead Wire Configurations



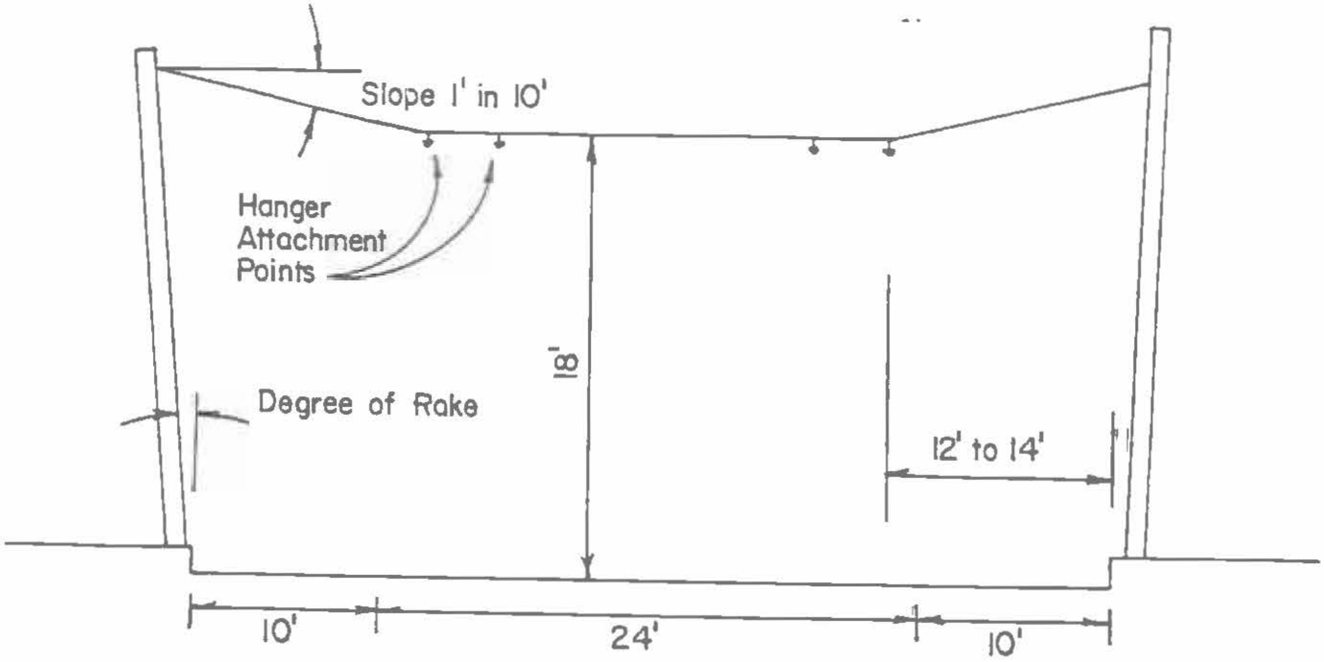


(Source: Wilkins, et al, 1979)

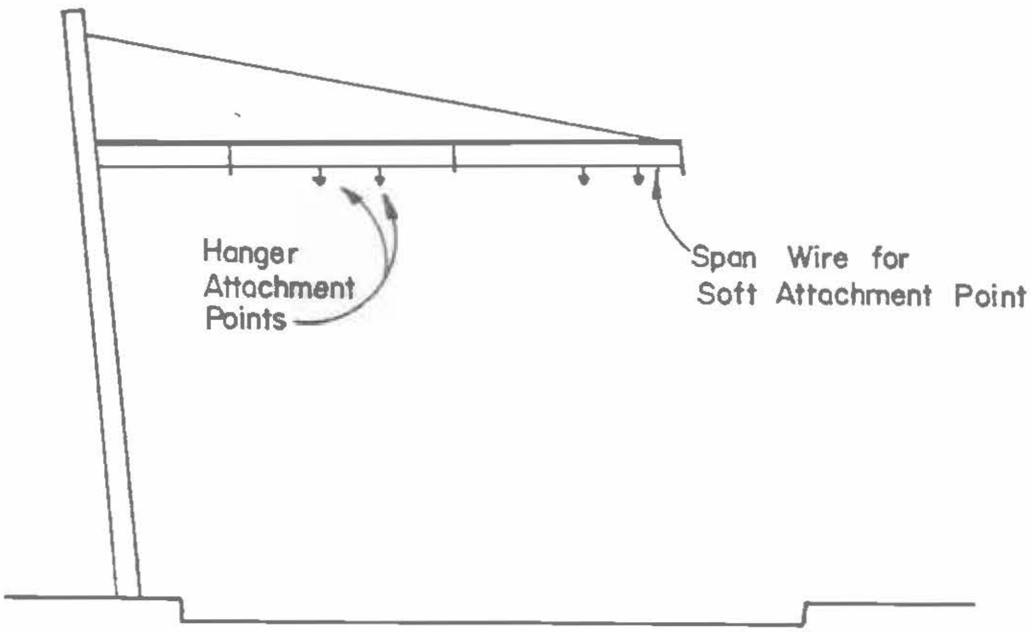
Figure 3.2.2

Typical Tangent Wire Installations

Tangent Section



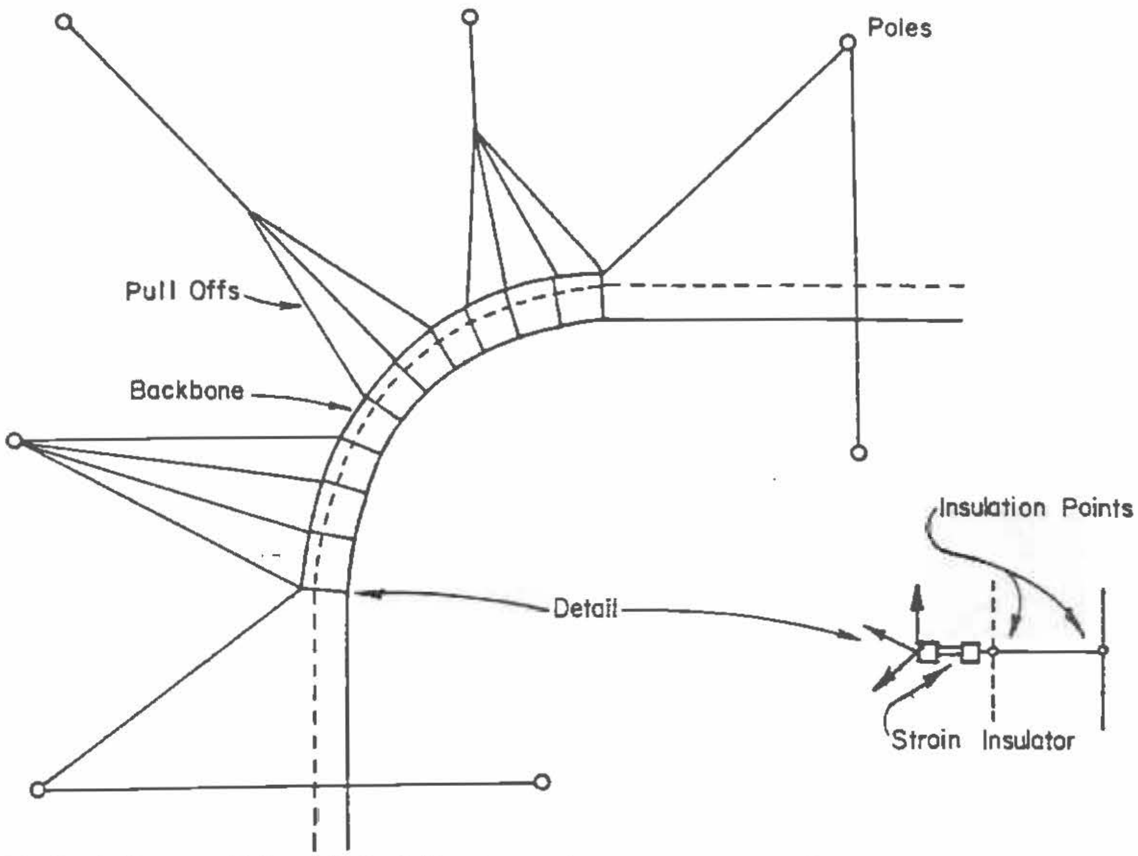
Tangent Section - Bracket Arm



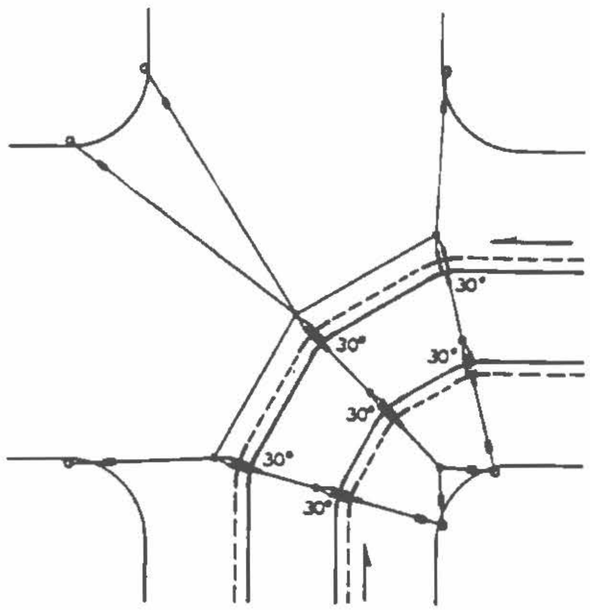
(Source: Wilkins, et. al, 1979)

Figure 3.2.3

Curve Alignments



Typical Curve Using Pull Offs, Strain Insulators and a Backbone



Typical Curve Using Curve Segments

(Source: Wilkins et. al,]979)

TABLE 3.2.1

Overhead Wire Capital Requirements
(thousands of constant 1984 dollars)

	30-Year Life	50-Year Life
Tangent Wire:		
Hollywood Bl. to Gage Ave.	$449	$2,564
Gage Av. to 122nd St.	211	1,360
Division 5 to Vermont Av.	100	573
Subtotals	$760	$4,497
Special Work:		
Hollywood Bl. Turnback & Layover Zone	$ 91.3	$ 67.0
Slauson Av. Tee Junction	75.9	67.8
Gage Av. "S" Curve	6.0	10.0
88th St. Layover Zone	13.8	5.2
90th St. Turnback	31.8	34.7
Century Bl. Layover Zone	14.3	12.5
106th St. Turnback	16.8	34.7

Table 3.2.1 (Continued)
Overhead Wire Capital Requirements
(thousands of constant 1984 dollars)

	30-Year Life	50-Year Life
120th St. Layover Zone	$ 15.8	$ 20.0
122nd St. Turnback	18.0	27.2
Division 5 to Vermont Av.	45.0	61.0
Division 5 Yard	180.2	206.2
Subtotals	$ 508.9	$ 546.3
Total Estimate	$1,269	$5,043
25% Engineering & Contingencies	317	1,260
Grand Totals	$1,586	$6,304

3.3 Power Distribution

The power distribution technology adopted for this analysis is the use of 500 kw, 600 volt feederless substations. Such substations are the product of modern solid state technology that allows small substations to be built at a cost per kilowatt of capacity comparable to larger substations with feeders. There are two major advantages to this system. First, costly and unsightly feeder wires will not have to be installed in order to distribute power from a few large substations to several miles of route. Instead, many feederless stations are distributed along the route in intervals close enough for the overhead wiring to serve the feeder function. Second, the reliability of the power system is greater with many small stations than a few large ones; should one small station fail, there are many others available to provide electricity to the stricken route segment.

The TC system modeled here requires 14 feederless stations: one at Division 5, one along the deadhead route, and one per mile along Vermont Avenue. At an equipment and installation cost of $250,000 each, a capital outlay of $4 million (including a 15% mark-up for engineering and contingencies) is required. A serviceable life of 30 years is assumed for this equipment.

3.4 Other TC System Capital

Some maintenance equipment designed for MCs are not compatible for TC use. Other equipment for maintaining overhead wires needs to be purchased as well. These capital items apply to modifications required at Division 5.

Hybrid bus washers are available for use in yards that service both MCs and TCs. The washer at Division 5 is not compatible for TC use; its side brushes wrap around the rear of the vehicle and another brush washes the roof. The poles on the roof of the TC and guys at the rear cannot be cleaned in this manner. This analysis assumes the construction of a TC washer parallel to the existing bus washer. Such an installation will cost $160,000 for equipment and $240,000 for the shelter and installation. A 30-year seviceable life is assumed.

Service and inspection stalls must also be provided with 600 volt electrical service. This may be provided either with overhead wires in the shop or with umbilicals that can be plugged into the vehicle. At a cost of $30,000 per bay, three bays could be electrified for $90,000. The serviceable life of this equipment is the same for 30 years as that used for overhead wiring.

4.0 TROLLEY COACH OPERATING COSTS

Many cost elements of TC operations correspond to those of MC operation - energy, maintenance, and revenue operation. In addition to these costs, the overhead wiring and power distribution system must be maintained. The first two items are generally lower in cost for TCs than for MCs. Revenue operation costs are much the same. Maintaining overhead wires, however, often costs as much as the energy and maintenance economies save.

4.1 Energy

The cost of electricity has three major components: capacity provided to the substations, the energy delivered to the vehicles, and an energy adjustment that is pegged to the cost of oil.

The Department of Water and Power charges 30 cents per kilowatt capacity per month based upon the highest maximum power demand recorded during the previous 12 months. The capacity required for each station is determined by the average consumption of vehicles within that substation's power segment. The capacity charges for all 14 substations are estimated to be $18,100 per year. Both the energy charge and the energy adjustment charge are based upon the consumption of electricity in kilowatt-hours. The energy adjustment charge is independent of the time of day the electricity is consumed. The energy charge, however, is 4.8 cents per kilowatt-hour during the peak period (11:00 a.m. to 7:00 p.m. on weekdays only) and 2 cents per kilowatt-hour during the remaining off-peak hours. The energy adjustment charge is currently 2.5 cents per kilowatt-hour all day. The combined charges for electricity consumption are estimated to be $164,000 per year for peak power and $194,000 per year for off-peak power.

The entire energy bill totals $376,000 per year, yielding a savings of $266,000 per year compared to MC operation. Southbound trips south of Manchester Avenue are in Southern California Edison's service area. This portion of Line 204 will be subject to a different energy billing structure which may cause minor alterations in these energy cost estimates.

4.2 Vehicle Maintenance

The cost of maintaining TCs is considerably less than that for MCs. The d.c. motors used in TCs require no transmission assemblies or other complicated components found on MCs. The TC's low vibration also reduces maintenance needs. Dynamic braking, whereby the energy of the vehicle's momentum is burned during deceleration, extends the life of mechanical brake components. Owl service vehicles need not pull in for refueling. In all, this results in an MC to TC maintenance ratio of 1.3. This translates into a maintenance cost per vehicle hour of $11.05 for TCs, a 23% reduction. The cost of maintaining TCs for the 182 thousand annual vehicle hours demanded by Line 204 amounts to $2 million per year. This saves some $600,000 per year in operating costs for Line 204.

4.3 Revenue Operation

Trolley coaches have some operating advantages over their MC counterparts. Quicker acceleration under proper conditions may result in higher average speeds. Owl service vehicles need not deadhead back to Division to refuel. Improved grade climbing abilities cannot only increase average speeds but increase savings in vehicle maintenance as well. In the case of Line 204, however, topographic and traffic conditions are not likely to allow these advantages to appear. The cost of deadheading four owl service vehicles is small compared to the total cost of revenue operation. For these reasons the cost of revenue operation is assumed to be the same for both TCs and MCs along Line 204. Revenue operations account for 60% of the operating cost of MCs on Line 204. Thus all savings in operating costs to be gained from conversion to TC service are restricted to cost components that account for less than half of the total operating cost of MC service.

4.4 Overhead and Power Distribution Maintenance

Many operators of TC systems have contracts with local power suppliers to maintain overhead wires, power substations, and feeders. Line 204's location within two electric utility service areas may impede the creation of such arrangements. For this reason this analysis estimates the cost of overhead and power distribution maintenance as if it were provided by the District. As such, it serves as an upper limit on such costs.

These maintenance costs are divided into labor, equipment, and materials. Eight full-time equivalent employees are assumed to man round-the-clock maintenance capabilities at a cost of $303,000 annually. Materials are expected to cost $29,000 per year ($2,000 per route mile). Equipment includes a cherry picker and a service van at a purchase, maintenance, and operating cost of $15,000 per year. All told, this additional $347,000 annual cost for overhead maintenance is larger than the savings in energy that such a network provides.

5.0 SYSTEM COST COMPARISON

The costs of both TC and MC service along Line 204 can now be compared. Table 5.0.1 lists capital and operating costs for the two systems. The comparison yields no surprises; the TC system exhibits higher capital costs but lower operating costs than the MC system. This raises the question of what the trade-off is between expenses incurred on a pay-as-you-go basis (operations) and expenses incurred up front (capital).

To deal with this problem, capital costs are annualized to an equivalent pay-as-you-go expense. These annualized costs are equivalent to payment schedules that must be met to service loans (e.g., pay back bonds) made for the purchase of the capital assets. Such a payment schedule expressed in today's purchasing power is affected by three factors: the rate of inflation, the discount rate, and the length of time during which the payments must be made, the so-called term of the payments.

The longer the term, the lower are the annualized costs. Thus, it is desirable to extend the term for as long a period as possible. A true measure of capital's annualized cost requires that the term of the payments equal the serviceable life of the asset. For this reason, payments for MCs are assumed to last for 12 years, TCs for 25 years, overhead wiring and electrical equipment for 30 years, and poles, spans, and brackets for 50 years.

The higher the rate of discount, the higher are the annual costs. The rate of discount measures the value of money one year from now compared to money available today. It is expressed in percentage terms. For example, a discount rate of 10% implies that an up front capital expense of $1 is equivalent to an operating expense of $1.10 one year in the future. At this rate, each dollar's worth of capital outlay is cost effective only if it saves $1.10 or more in operating cost a year from now. The discount rate is determined by the rate of inflation, the risk of future incomes (or savings) not materializing, and the rate of return on alternative uses of money. Among these alternatives are financial transactions in the money market (stocks, bonds, bank accounts), where the rate of interest serves as the critical discount rate for its participants; those having higher discount rates borrow, those having lower discount rates save.

This analysis uses three key discount rates. The lowest discount rate used here is 7%. This rate is the long term historical average interest rate when the rate of inflation is at its present level of 4% per year. Thus, 7% is the best long-term estimate of the rate of discount for investments having a term of 25 years or longer. The 10% rate is the current yield on tax-free revenue bonds backed by such funding sources as TDA or Proposition A sales taxes. It is, coincidentally, also the rate which UMTA uses for annualizing transit investments. The 12% rate is the current cost of money to low risk borrowers. This reflects the opportunity cost of money in today's economy as a whole, though it is likely to overestimate this cost for terms of ten years or longer.

The rate of inflation affects the value of future payments in terms of the buying power of money at the time it is paid. This analysis assumes a flat rate of inflation of 4% annually. At this rate, a dollar spent 18 years in the future will only purchase what 50 cents buys today. Annualized capital costs are deflated at this 4% rate in order to yield dollar amounts in terms of their buying power in 1984 prices. This is consistent with the estimation of operating and capital costs using 1984 data for prices and quantities.

TABLE 5.Ø.1

A Comparison of Capital and Operating Costs
for Motor Coach and Trolley Coach Systems
(thousands of constant 1984 dollars)

	Motor Coach	Trolley Coach	Savings or (Additional Costs)
Capital Costs:			
Vehicle Acquisition	$8,721	$11,577	$ (2,856)
Overhead, Wires, Power Distribution, Div. 5 Conversion		12,5Ø5	(12,5Ø5)
Total Capital Costs	$8,721	$23,982	$ (15,361)
Operating Costs:			
Vehicle Maintenance	$2,6Ø8/year	$2,ØØ7/year	$ 6Ø1/year
Energy	642/year	376/year	266/year
Revenue Operation	4,618/year	4,618/year	Ø
Overhead & Power Maintenance		347/year	(347)/year
Total Operating Cost	$7,868/year	$7,348/year	$ 52Ø/year

5.1 Annualized Motor Coach Costs

The only capital item to be annualized for the existing MC service for Line 2Ø4 is the cost of vehicle acquisition. The 12-year term and 4% inflation rate are applied to the three rates of discount discussed above to MC acquisition costs. The results are presented in Table 5.1.1. The bottom line for each discount rate indicates how much money must be paid each year to provide Line 2Ø4 with MC vehicles and operate them at current service levels. These results will be compared to those for an equivalent TC system.

5.2 Annualized Trolley Coach Costs

Trolley coaches require not only a larger capital outlay but a more diverse one as well. Various capital items have their own useful lives which, in turn, affect their annualized cost. Table 5.2.1 presents a summary of annualized costs for TC service along Line 2Ø4. Vehicle acquisition is the largest component among all cost elements, consuming more than half the payments for capital under all three discount rate scenarios. Revenue operation accounts for better than half of the total costs itemized here.

One observation worth noting is the small role played by energy costs in TC operation. Despite claims made by researchers and manufacturers for the energy savings that will be made possible by the vehicles of the future, the overall impact of such improvements in the total cost structure of TC operation is small. A 2Ø% reduction in energy consumption by means of flywheel storage, "regenerative" braking and other budding technologies would save the same amount as a 4% reduction in maintenance costs, or a 1Ø% reduction in the cost of new vehicles.

The discount rate has a profound effect on total annualized costs. The scenarios presented here differ by $2ØØ,ØØØ to $4ØØ,ØØØ. This is a larger impact than either the cost of energy or the cost of maintaining the overhead wires and power supply.

TABLE 5.1.1

Annualized Cost of Existing
Motor Coach Service on Line 204
(thousands of constant 1984 dollars)

Item	Useful Life (years)	Discount Rate 7%	10%	12%
Vehicle Acquisition	12	$ 876	$1,040	$1,157
Fuel & Lubricants	N/A	642	642	642
Vehicle Maintenance	N/A	2,608	2,608	2,608
Revenue Operation	N/A	4,618	4,618	4,618
Totals		$8,744	$8,908	$9,025

TABLE 5.2.1
Annualized Cost of
Trolley Coach Service on Line 204
(thousands of constant 1984 dollars)

Item	Useful Life (years)	Discount Rate 7%	10%	12%
Vehicle Acquisition	25	$ 665	$ 906	$ 1,085
Overhead Line Materials	30	81	115	141
Poles, Spans & Brackets	50	245	400	515
Power Distribution Equipment	30	205	292	358
Other Capital Equipment	30	25	36	40
Total Annualized Capital Cost		$1,221	$1,749	$2,139
Energy		$ 376	$ 376	$ 376
Vehicle Maintenance	N/A	2,007	2,007	2,007
Revenue Operations	N/A	4,618	4,618	4,618
Overhead & Power Maintenance	N/A	347	347	347
Total Annual Operating Costs	N/A	$7,348	$7,348	$7,348
Total Annualized System Cost		$8,569	$9,097	$9,487

5.3 Marginal Costs and Savings

The cost structures of MC and TC systems are compared in Table 5.3.1 for all three discount rates. Only at the 7% rate does the TC system offer a net savings in providing bus service along Line 204. None of the differences in costs, however, are significant when compared to the probable error of the cost estimates. The capital cost estimates for TCs have been intentionally biased toward the high (conservative) side. More detailed engineering studies would be necessary to narrow this bias, particularly for the costs of overhead wiring and other capital expenses required for the conversion of Division 5 for servicing TC vehicles.

On an item by item basis, TCs enjoy the greatest advantage over MCs in vehicle maintenance costs. Energy savings amount to less than the additional cost required to maintain the network that supplies that energy to the TCs. Savings to be derived from vehicle costs vary with the interest rate. Higher discount rates favor shorter lived capital. The TCs' longer vehicle life and higher system capital requirements thus become a cost liability as discount rates increase.

TABLE 5.3.1
Annualized Cost Comparison of Motor Coach and Trolley Coach Service on Line 204
(thousands of constant 1984 dollars)

Item	Discount Rate 7%	10%	12%
Vehicle Maintenance			
Motor Coach	$2,608	$2,608	$2,608
Trolley Coach	2,007	2,007	2,007
Savings (Additional Costs)	601	601	601
Energy			
Motor Coach	$642	$642	$ 642
Trolley Coach	376	376	376
Savings (Additional Costs)	266	266	266
Other Trolley Coach Operating (Costs)	$(347)	$(347)	$ (347)
Total Operating Savings (Additional Costs)	$520	$ 520	$ 520
Vehicle Acquisition			
Motor Coach	$876	$1,040	$1,157
Trolley Coach	665	906	1,085
Savings (Additional Costs)	211	134	72
Other Trolley Coach Capital (Additional Costs)	$(556)	$ (843)	$(1,054)
Total Capital Savings (Additional Costs)	$(345)	$ (709)	$ (982)
Trolley Coach System Savings (Costs) Annually	$ 175	$ (189)	$ (462)
As % of Motor Coach Cost	2.0%	(2.1%)	(5.1%)

6.0 CONCLUSIONS AND RECOMMENDATIONS

At a discount rate in the 7% to 8% range TCs provide service on Line 204 at a cost comparable to MC service. Such a system would also reduce noise along Vermont Avenue and exhaust emissions in the air basin. The current economic climate, however, is not favorable for bus service technologies that require large capital investment. Discount rates over 8% increase the annualized TC system costs on Line 204 relative to MC system costs to the point where MC operations have a slight cost advantage.

Were TC service established on Line 204, yard facilities and deadhead wiring could be shared with TC vehicles on other lines, thus reducing the incremental cost of extending the system. On the other hand, more extensive systems require more complicated special work at crossings and junctions. For example, in order for Line 207 to share Line 204's deadhead route, a grand junction is needed at the intersection of Western and Slauson Avenues. Such an installation costs about the same as a separate deadhead route down 54th Street to Western Avenue.

The incremental cost of converting Line 204 to TC operation (i.e., its total capital cost less the capital costs of the deadhead route and conversion of Division 5) is equal to the value of long run savings in operating TCs for the 10% discount rate scenario. This leaves no additional savings to offset the cost of yard and deadhead route facilities. Considering Line 204's many favorable characteristics for TC operation, particularly its 460 scheduled trips per weekday, few, if any other lines in the District's service area could pay the incremental cost of their conversion with savings in operating TCs instead of MCs. With the possible exceptions of Wilshire Boulevard (660 trips per weekday) and Pico Boulevard - East First Street (390 trips per weekday) <u>the installation of TC service on Line 204 will not make extensions of this service to other lines cost effective.</u>

Vermont Avenue is also a good operating environment for motor coaches. Average speeds in the southern segments of the route lie between 13 and 14 miles per hour. Such speeds are adequate for diesel engines to exhibit their fuel efficiencies and favorable operating characteristics. The route has no significant gradients that overtax the climbing abilities of a diesel-powered bus.

This analysis has restricted its scope to a head-to-head comparison of TC and MC operation of currently scheduled service on Line 204. Extension of these results to alternative scenarios does not significantly alter the cost relationship between these two technologies.

It is difficult to ascertain whether the conversion from regular 40-foot vehicles to high capacity (articulated) vehicles is likely to give TC operation a significant edge over MC operation. There are as yet no data on the operating costs and characteristics of articulated TCs in North America. Some gains in revenue operation cost may be made using this technology, but the energy efficiency and maintenance costs of these vehicles is not known. Where used in Europe, articulated TCs operate in a self-service fare environment in order to decrease vehicle dwell times. Studies conducted by the District of the cost effectiveness of articulated MC operation have not uncovered any significant cost advantage of using these vehicles.

An increase in scheduled service for Line 204 would favor TC operations. The savings that accrue from increasing service by one bus that averages 3,600 vehicle hours per year is $11,600 in the 12% discount rate scenario. The power distribution system of this analysis is designed to handle 13 more vehicles than are now used on this line. This implies an additional savings of $150 million annually, far short of the $460 million advantage that MC operation enjoys in this scenario. For the 10% discount rate scenario, TC operation would save an additional $193 million, just barely tipping the cost scale in its favor. The proposed Harbor Busway may make such increases in patronage unlikely.

The establishment of exclusive bus lanes on Vermont Avenue would favor MC operations. Each 2.5% increase in average speed would reduce the fleet requirement for Line 204 by one vehicle. In every discount rate scenario modeled here the annualized vehicle acquisition cost of MCs is greater than that of TCs. Thus reducing fleet size would save the MC system more than it would save the TC system. The energy cost advantage of TCs would be reduced, too, as higher speeds would increase the fuel efficiency of MCs to a greater degree than TCs. Operating TCs at higher speeds would also increase the risk of dewirements.

In light of these alternative operating scenarios it is unlikely that any radical alteration of the bus service currently operated along Line 204 would justify the conversion of this line to TC operations <u>by cost considerations alone.</u> The environmental advantages of less noise, enhanced passenger comfort, and reduced toxic emissions may be deemed worth the cost. Measuring the noise impact would require monitoring average noise levels along the route and estimating how this level would change if TCs operated in MC's stead. The air quality impacts upon the air basin would require preliminary environmental impact analysis. Transit riders generally prefer TCs to MCs, but it is not yet established that this preference is strong enough to alter patronage. The value of environmental effects and operational characteristics is the arena in which the decision whether to convert Line 204 to TC service must be made.

Staff recommends that either of two policies be pursued with regard to operating TCs in the District:

Either - Wait until such a time as changes in vehicle maintenance labor costs and the cost of money increase the financial advantages of TC operation over MC operation,

Or - Conduct engineering studies to refine the cost estimates developed in this study and to estimte the environmental impacts of trolley coach operation as part of a program for adopting trolley coach technology to mitigate some of the damages to the environment caused by motor coach operation.

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