TECHNICAL APPENDIX

THE COST OF CONVERTING LINE 204
TO TROLLEY COACH OPERATION

DECEMBER 1985

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT
425 SOUTH MAIN STREET
LOS ANGELES, CALIFORNIA 90013

TECHNICAL APPENDIX

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TECHNICAL APPENDIX

THE COST OF CONVERTING LINE 204 TO TROLLEY COACH OPERATION

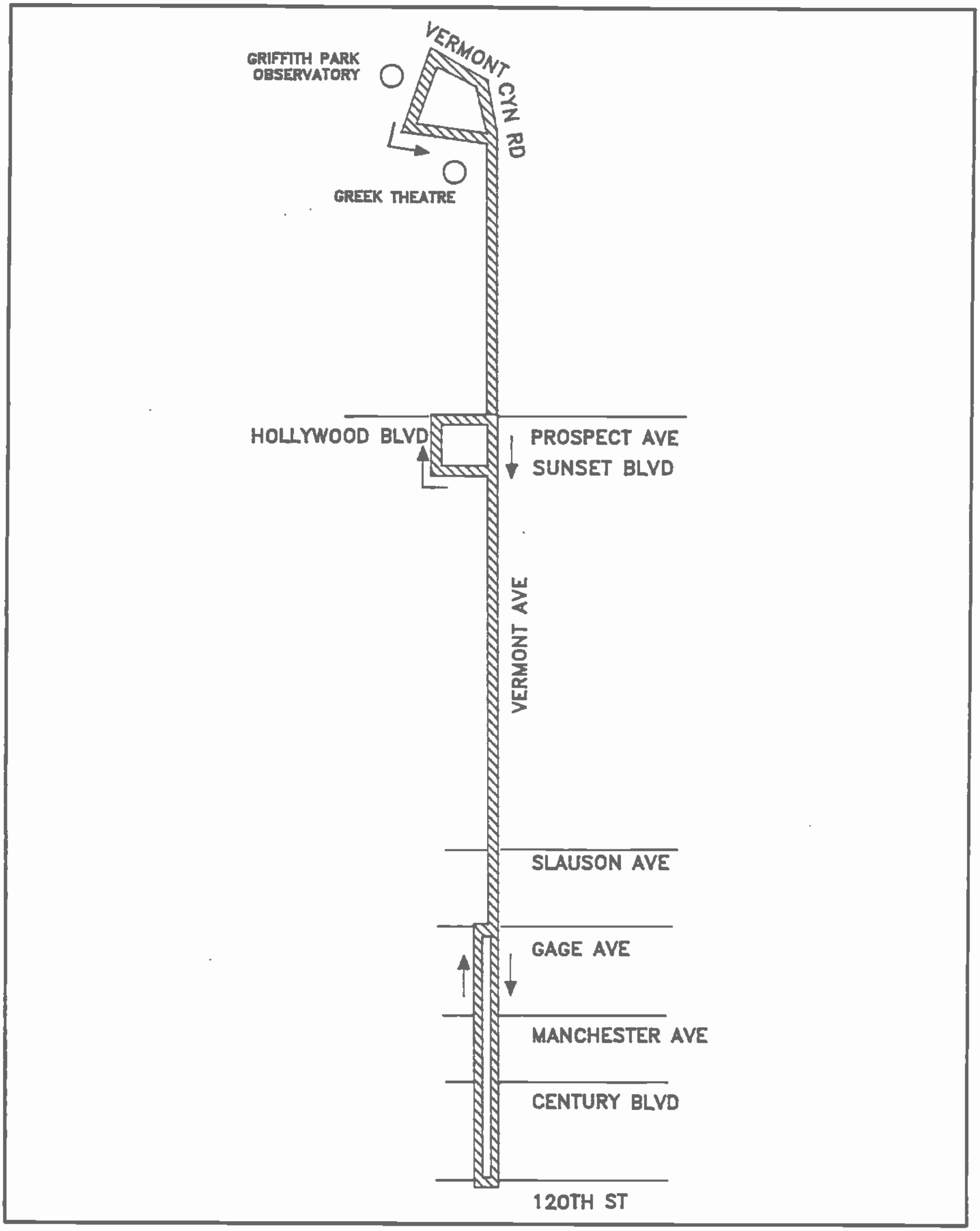
A. LINE 204

The purpose of this section is to describe the existing route of Line 204 and its currently scheduled level of service. Some minor alterations to the route and service are in order to make them more amenable to trolley coach (TC) operation. The resulting route alignments and service levels serve as the basis for estimating the cost of providing both TC and motor coach (MC) revenue service on Line 204.

A.1 The Route

The route of Line 204 as of April, 1985, is illustrated in Figure A-1. The most heavily traveled segment runs from Manchester Avenue north to Hollywood Boulevard. The daily schedule calls for 460 one-way trips to run along this segment. The route segment that lies south of Manchester Avenue to 120th Street is serviced by over 257 one-way trips on the daily schedule. Some weekend short lines turn back at Century Boulevard. At the north end of the route only 16 one-way trips are made Tuesday through Friday with the Griffith Park Observatory as its terminus. These runs originate at the corner of Beverly Boulevard and Vermont Avenue.

Until November, 1984, all turnbacks at Manchester, Century, and 120th Street were accomplished with U-turns. Vermont Avenue is 150 feet wide south of Gage and the 50-foot median south of Manchester provides a sufficiently large turning radius for such maneuvers. As of November, 1984, turnbacks for short lines that end at Manchester Avenue follow a loop along 88th Street, Budlong, and 89th Street in order to move the layover zone away from an on-street parking area just south of 89th Street. Turning back at Hollywood Boulevard involves a northbound loop along Sunset Boulevard, Kenmore Avenue and Hollywood Boulevard to a layover zone one block north of Sunset. Other turnback loops appear in the route master for Los Angeles City College, Vernon Avenue, and Florence Avenue. No scheduled trips are currently scheduled to use these loops. The turnback loop at Beverly Boulevard is only used for Griffith Park Observatory service.



RTD

EXISTING ROUTE OF LINE 204

FIGURE A-1

All vehicles assigned to Line 204 are garaged at Division 2.

The route to be used in this analysis is illustrated in Figure A-2. The most obvious difference is the absence of Griffith Park Observatory service. The light service and the residential environment along this branch cannot justify the capital cost of installing and powering overhead wires from Hollywood Boulevard to the Observatory. Henceforth, "Line 204" refers to existing scheduled trips along Vermont Avenue to the exclusion of Griffith Park Observatory service.

The turnback loop at the northern terminus will be a U-turn around the traffic island bordered by Vermont Avenue, Prospect Avenue, and Hollywood Boulevard. This would reduce tangent wire installation needs by one-half mile and eliminate the need for installing a crossing at Sunset Boulevard.

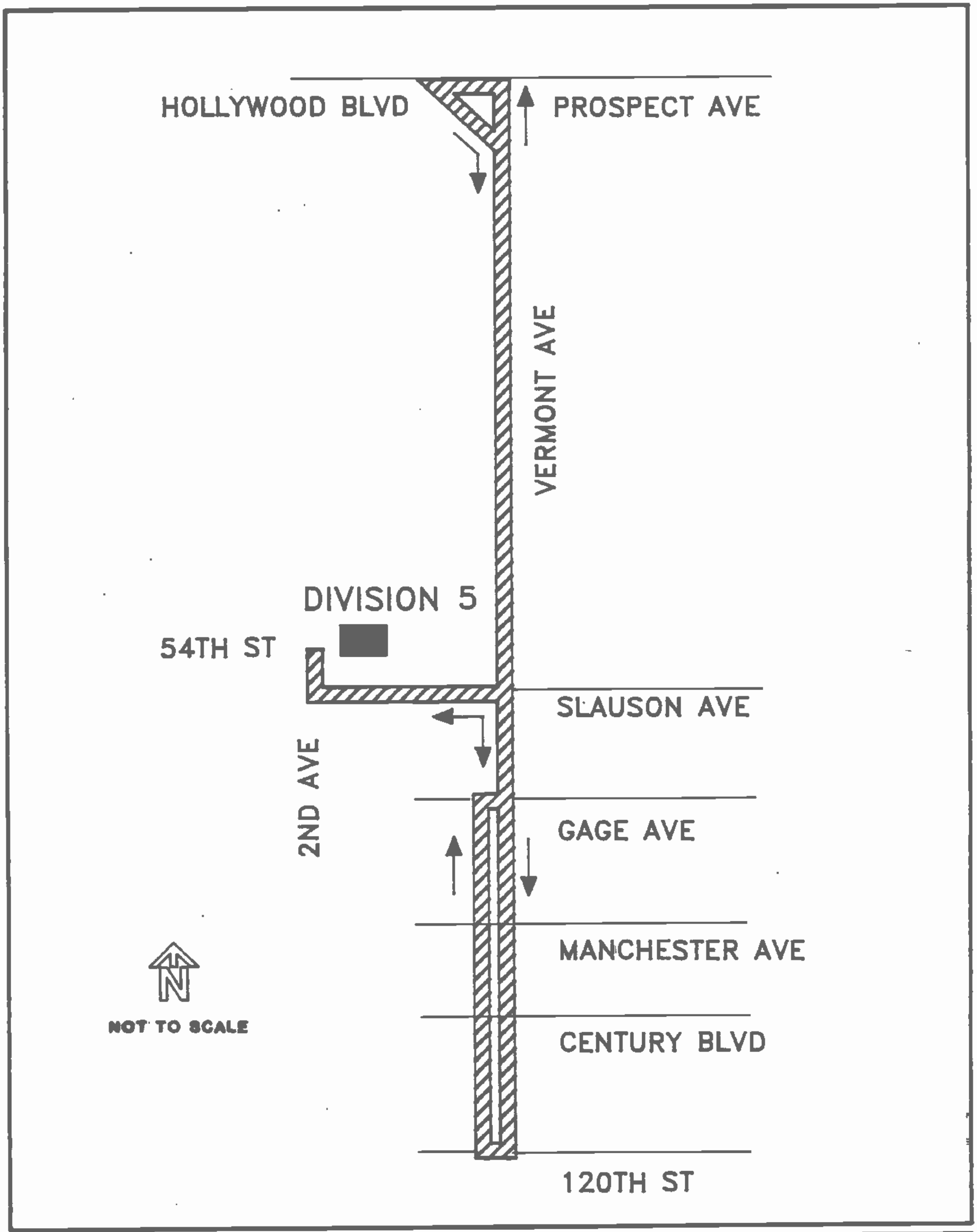
The U-turn turnback at 89th Street is restored. This, too, will save one-half mile of tangent wire.

No redundant turnback loops are included. Emergency turnbacks are to be accomplished by off-wire maneuvers using an emergency battery pack on board TC vehicles (See Section C.1). Vehicles assigned to Line 204 will be garaged at Division 5 instead of Division 2. This reduces the length of the deadhead route and its wiring needs. The deadhead route from Division 5 will be west one block on 54th Street to 2nd Avenue, south on 2nd Avenue to Slauson Avenue, and east on Slauson Avenue to Vermont Avenue. The choice of this route over 54th Street is motivated by Slauson's wide right-of-way and a reluctance to install overhead wire along a predominantly residential street.

At this preliminary planning stage, the route alignment should only be considered to be a case study for the purpose of estimating costs. More detailed engineering will probably require consideration of several alternatives before an alignment is recommended.

A.2 Existing Service

A maximum of 45 buses are assigned to existing service on Line 204 during the p.m. peak for Tuesday through Friday. Excluding the one vehicle assigned to the Griffith Park branch lowers this requirement to 44 vehicles. A 15% spare ratio implies that 51 vehicles are required to provide service on Line 204.



RTD

ROUTE OF PROPOSED TROLLEY COACH OPERATION ON LINE 204

FIGURE A-2

Table A-1 adjusts existing daily service measures as reported in RTD's Report No. 4-24 (September 9, 1984). Griffith Park service is deducted from the data for total vehicle hours and vehicle miles for Daily, Saturday and Sunday/Holiday service. Annual figures are derived by performing the indicated computations.

TABLE A-1

Existing Service on Line 204

Schedule	DX	SA	SU	Total (000's)
Total Vehicle Hours/Day	579.2	355.1	320.6	
Less: Griffith Park Service	8.0*	11.7	9.3	
Equals: Vehicle Hours/Day	571.2	343.4	311.3	
Times: Days per Year	255	52	58	
Equals: Vehicle Hours/Year (000's)	145.7	17.9	18.1	181.6
Total Vehicle Miles/Day	6326	3824	3477	
Less: Griffith Park Service	62*	100	70	
Equals: Vehicle Miles/Day	6264	3724	3407	
Times: Days per Year	255	52	58	
Equals: Vehicle Miles/Year (000's)	1597	194	198	1989

* Average Monday through Friday

B. THE COST OF EXISTING SERVICE

With the adjustments in Line 204 data to exclude Griffith Park service, the marginal cost of opeating the remaining service by MC's can be estimated. This marginal cost is an estimate of how much money may be saved by eliminating such MC operations from the District's budget. It will be ultimately compared to the marginal cost of adding TC operations to provide the same service in order to determine the relative cost effectiveness of these modes along Line 204. <u>All costs in this study are expressed in constant 1984 dollars.</u>

B.1 Section 15 Cost Data

Established studies that compare the cost of MC and TC systems all use the UMTA Section 15 Report as their data base. Costs for MC service in this study are broken down into four categories: vehicle acquisition, vehicle maintenance, fuel and lubricants (or "energy"), and "revenue operations." This latter category is "vehicle operations" less "fuel and lubricants" as they appear on Form 301 of the Section 15 Report. Trolley coach costs have three additional categories: overhead wire installation, power supply installation, and power distribution maintenance. Pertinent data for the District during FY 84 are summarized in Table B-1.

B.2 Motor Coach Capital and Operating Costs

Data for various cost elements of motor coach operation are applied to service data for Line 204 to estimate its marginal cost. Each of four cost components are estimated in this section. The results are summarized in Table B-2.

B.2.1 Vehicle Acquisition

Line 204 requires a fleet of 51 active buses (44 peak fleet plus 7 spares). Current procurement policy requires these buses to be equipped with air conditioning and wheelchair lifts. Such vehicles cost approximately $171,000 each in 1984. The capital cost of Line 204 thus totals $8,721,000. This cost may be considered to be the savings in replacement vehicles -- expenditures that would result if buses now assigned to Line 204 were reassigned to other lines within the District, mitigating the need to purchase new replacement vehicles.

TABLE B-1

Data Summary
Southern California Rapid Transit District
Section 15 Report for Fiscal Year 1984

Total Vehicle Hours	7,633,000
Total Maintenance Personnel	2,352
Total Vehicle Maintenance Labor Cost	$ 86,001,000
Fuel & Lubricants Expenditures	$ 27,006,000
Vehicle Maintenance Expenditures	$ 109,594,000
Non-Vehicle Maintenance Labor	$ 2,957,000
Total Maintenance Labor	$ 88,958,000
Revenue Operations Expenditures	$ 194,104,000

TABLE B-2

Marginal 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 Costs	$ 7,868/year

B.2.2 Motor Coach Vehicle Maintenance

The cost of maintaining vehicles is based upon total vehicle hours of operation. Vehicle miles are not used due to the aggregation of high speed express service and low speed local service in the Section 15 Report. Low speed operations imply many stops and starts per mile that increase the stress experienced by brakes and drive trains. This, in turn, increases the maintenance costs per mile on vehicles that provide such low speed service. Several loads borne by engines are related to duration of operation rather than distance traveled. These loads include air conditioning, coolant circulation, and electrical generation for lights, dials, and radios. Most TC service is along routes in congested downtown areas or on lines that have steep gradients. Basing MC and TC vehicle maintenance costs on mileage would, therefore, be biased against TCs. For the range of speeds typical of local service operation, vehicle maintenance costs per vehicle hour are more stable.

The cost of maintaining an MC for one hour of operation is derived from Table B-1. Maintaining 181,600 hours of MC service on Line 204 amounts to $2,608,000 per year.

B.2.3 Fuel and Lubricant Costs

The cost of fuel and lubricants for MC operations is also estimated on an hourly basis. The rationale for this approach is similar to that for vehicle maintenance; slow speeds imply more incidences of acceleration and, hence, an increase in fuel consumption per mile. Within the narrow limits of bus speeds in the District's operations (14 total vehicle miles per vehicle hour system wide, 11 for 204) the hourly rate of fuel consumption is assumed to be constant.

Table B-1 data indicate that fuel and lubricants cost the District $3.538 for each vehicle hour of operation. At this rate the 181,600 annual vehicle hours of operation on Line 204 cost the District $642,000 a year for diesel fuel and oil at 1984 prices.

B.2.4 Motor Coach Revenue Operations

The major cost of revenue operations (vehicle operations less fuel and lubricants) is operator labor. Non-operators' labor comprises most of the remainder. The cost of revenue operations for the District as a whole amounts to $25.43 per vehicle hour in 1984. Applying this rate to Line 204 results in a revenue operations cost of $4,618,000 annually. Notice that this single cost category accounts for almost 60% of MC operating costs.

C. TROLLEY COACH SYSTEM CAPITAL COSTS

Conversion of Line 204 to TC operation requires additional capital investments beyond that of rolling stock. These investments include overhead wiring, power supply equipment, and some additional equipment at Division 5. The need for such capital outlays reduces TC cost effectiveness compared to that of MC operation. Trolley coach vehicles are more expensive than MC vehicles, but their longer serviceable lives result in lower life cycle costs than their MC alternatives. Were service on a line to increase, overhead wire and related equipment need not be procured. Additional power supply equipment and vehicles would need to be purchased, but the net effect is an increase in the cost advantage of TC operations.

This section discusses the capital alternatives available for TC service and estimates the cost of those alternatives chosen for this analysis of Line 204. Table C-1 summarizes these capital cost estimates.

C.1 Vehicle Acquisition

Suppliers of TCs are few in number, especially in North America. Current vehicle acquisition cost data is scarce due, in part, to the relatively infrequent purchases of these vehicles. The vehicle acquisition costs used here are estimates for TCs equipped with wheelchair lifts and air conditioning. Another feature to be included in the TC price is related to its off-wire capabilities and its power control system.

The standard TC must be in contact with two overhead wires in order to move. Where power outages or downed wires leave a segment of the route without power, other means of propulsion must be provided. San Francisco, for example, equips its line superintendents with pick-up trucks that are able to push a TC through an intersection, a construction zone, or other powerless route segment to a point where overhead wires can provide electricity for the remainder of the trip. Lack of any off-wire capability requires additional emergency turnback loops to be provided to allow operationally disabled vehicles to return to their garage under their own power. Garages need a complicated maze of wire and expensive special work designed to provide power to vehicles as they drive into maintenance stalls, tire stalls, and bus washers.

TABLE C-1

CAPITAL COSTS OF TROLLEY COACH

SERVICE FOR LINE 204
(thousands of constant 1984 dollars)

Vehicle Acquisition	$11,577
Overhead Wiring:	
Revenue Route	6,433
Deadhead Route	974
Division 5	483
Power Supply	4,025
Other Division 5 Equipment	490
Total Capital Cost	$23,982

Many of these emergency and garage movements can be powered by a bank of batteries on board the vehicle. Six or seven standard MC batteries can provide sufficient power to propel the TC at low speeds (three to five per hour) for short distances (3,000 feet). Vancouver has TCs so equipped. This feature is used for yard movements and emergency maneuvers only, so no provision for automatic pole raising is made. The system is modest in cost (about $8,000 per vehicle) and requires little maintenance. The batteries exhibit long life but add an additional 800 pounds to the weight of the vehicle.

The next level of off-wire capability is provided for by equipping the vehicle with an internal combustion generator. Such a vehicle could be scheduled for limited off-wire service. San Francisco is currently experimenting with both gasoline and diesel auxiliary generators, costing $19,000 and $23,000 per vehicle, respectively. Automatic pole raising equipment would also be advantageous where scheduled excursions from the wire are frequent.

Finally, dual-powered buses with both d.c. motors and full-sized diesel engines allow complete independence from overhead wires over long distances. Such vehicles are used in revenue service in Europe. Seattle is considering such vehicles to allow diesel-powered lines to use their proposed downtown bus subway.

This analysis adopts the battery powered, limited excursion option. The ability for a bus to make emergency off-wire maneuvers enhances the flexibility of TC operation under unforeseen conditions. The options that offer offer more off-wire flexibility only increase the maintenance and fuel costs of the vehicle as well as its purchase price.

Power control systems come in three configurations: resistor, chopper, and pulse width modulator. Until the late 1970's, only resistor control was offered. This system burned unneeded electrical current in a bank of resistors. In order to conserve energy, "chopper" control was introduced. This system uses solid state components to turn current on and off intermittently and to smooth out the current for vehicle use. The rate and dwell of "chopping" varies to meet the power needs of the vehicle.

Chopper controlled TC vehicles were first used in revenue service in the early 1980's. Once the initial difficulties were overcome, they have proven to be reliable and cost-effective. Energy costs are reduced by 10% to 25% with chopper control and maintenance costs are minimal.

The third power control device, the pulse width modulator (PWM), is still under development. Like the chopper, it is a solid state device that intermittently turns current on and off in response to the power needs of the vehicle. The output, however, is not d.c. but three-phase a.c.. These devices are intended to control power to a.c. motors, which promise to be smaller, cheaper, and easier to maintain than the d.c. motors that propel today's TCs.

In the light of chopper control's dependability, energy efficiency, and cost, this technology is adopted for cost analyses in this study. Recent deliveries of regular 40-foot chopper-controlled vehicles in Edmonton have cost approximately $200,000 each. Wheelchair lifts are estimated to add $11,000 to the cost of the vehicle, air conditioning another $8,000, and emergency battery packs an additional $8,000. At $227,000 per vehicle, a fleet of 51 vehicles is estimated to cost $11.6 million. The expected life of the vehicle is 25 years, about twice that of a diesel bus. Even under high discount rates, the life-cycle cost of TC's is less than that of its MC counterparts.

Trolley coaches are also available in articulated configurations. Little data is available on the purchase price and operation of these vehicles. Seattle is currently calling for bids on articulated TCs, but cost data will not be available for several years. An analysis incorporating the use of such vehicles is not attempted here in order to compare the relative costs of operating MC and TC systems having equal capacities, headways, and patronage.

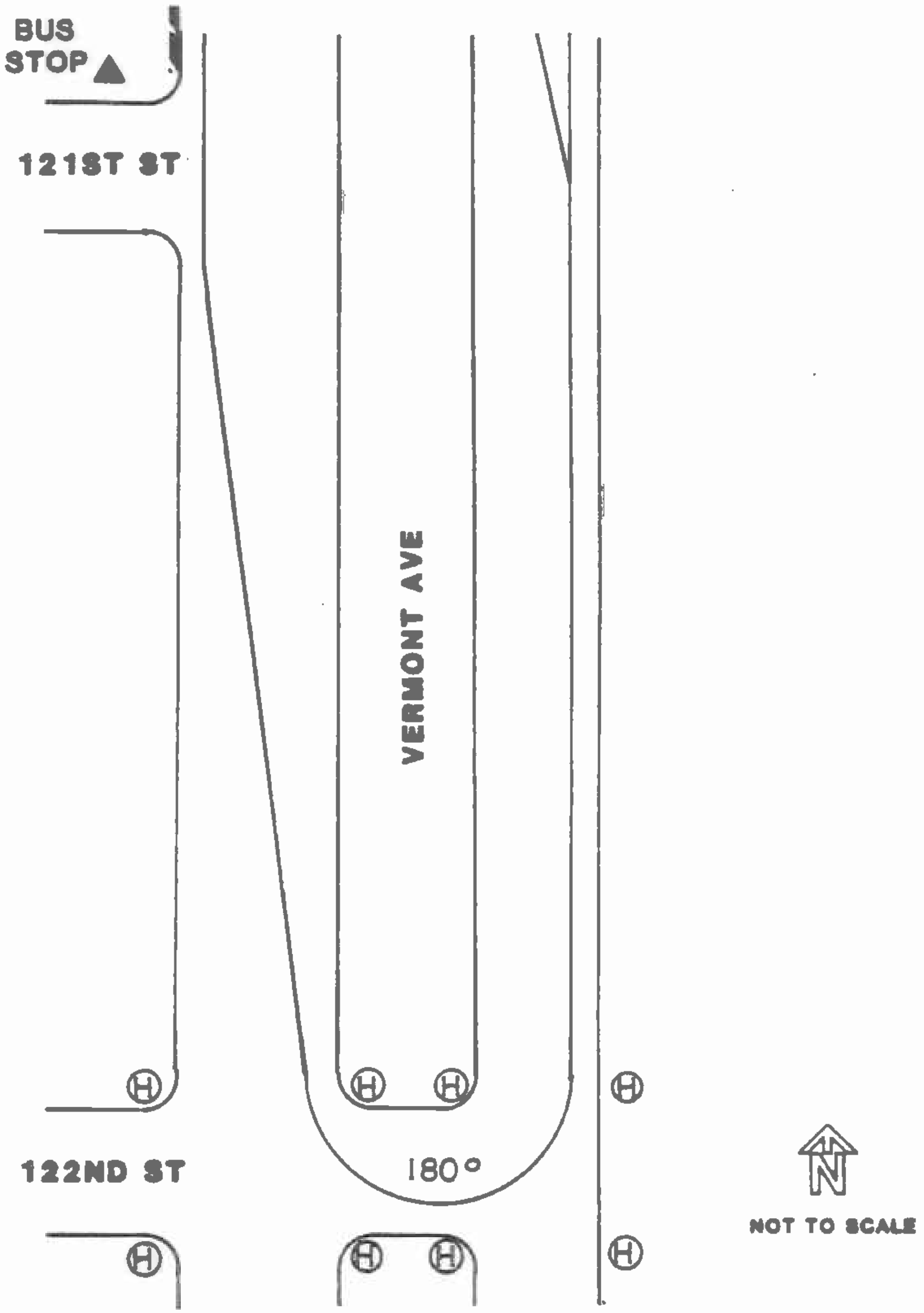
C.2 Overhead Wiring

Estimating the cost of installing overhead wire requires detailed layouts of wire configurations. This is a cost element where a little engineering can save a lot of money. The configurations presented in Figures C-1 through C-13 are only valid for cost estimate purposes. These figures only highlight additional poles and structures needed beyond normal straight-away tangent wiring. The precise placement of poles and the length of guys and spans requires final engineering. The maintenance structures on Division 5 may be able to support tangent wire much less expensively and with less hindrance to vehicle traffic than the poles assumed for this cost estimate. The cost estimates for Division 5 conversion are the least dependable of this study. To compensate for this, an engineering and contingency mark-up of 25% is used instead of the more common 15%. This adds $600,000 to the estimated capital cost of TC conversion.

TABLE C-2

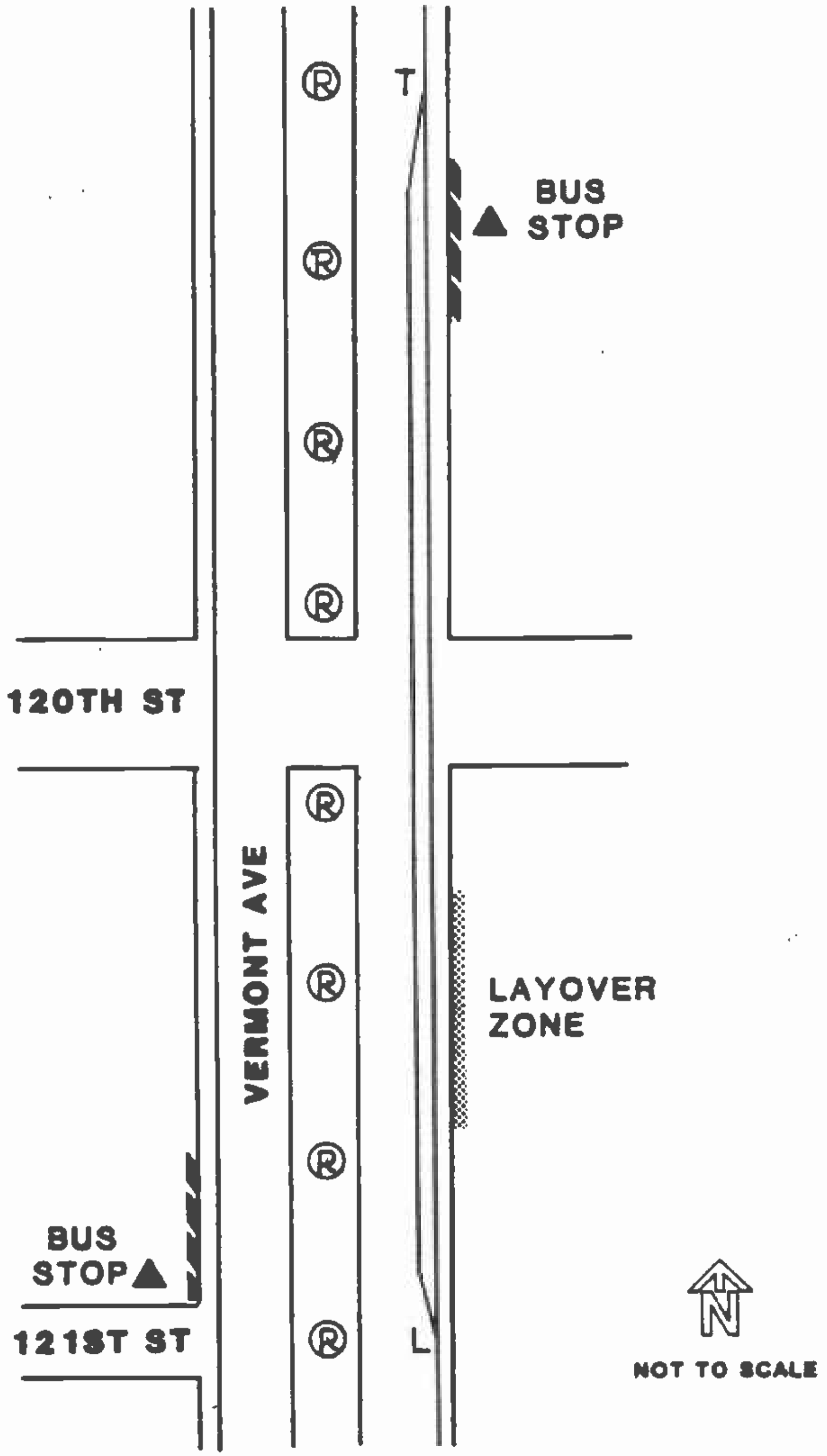
Legend
For Figures C-1 through C-12

Symbol	
B	Bracket
L	Leading switch w/inductive control
S	Span
T	Trailing switch
X	Crossing
90 degrees	Angle of Curve
H	Heavy duty pole
R	Regular pole
IS	Traffic Island



122ND ST.
TURNBACK LOOP

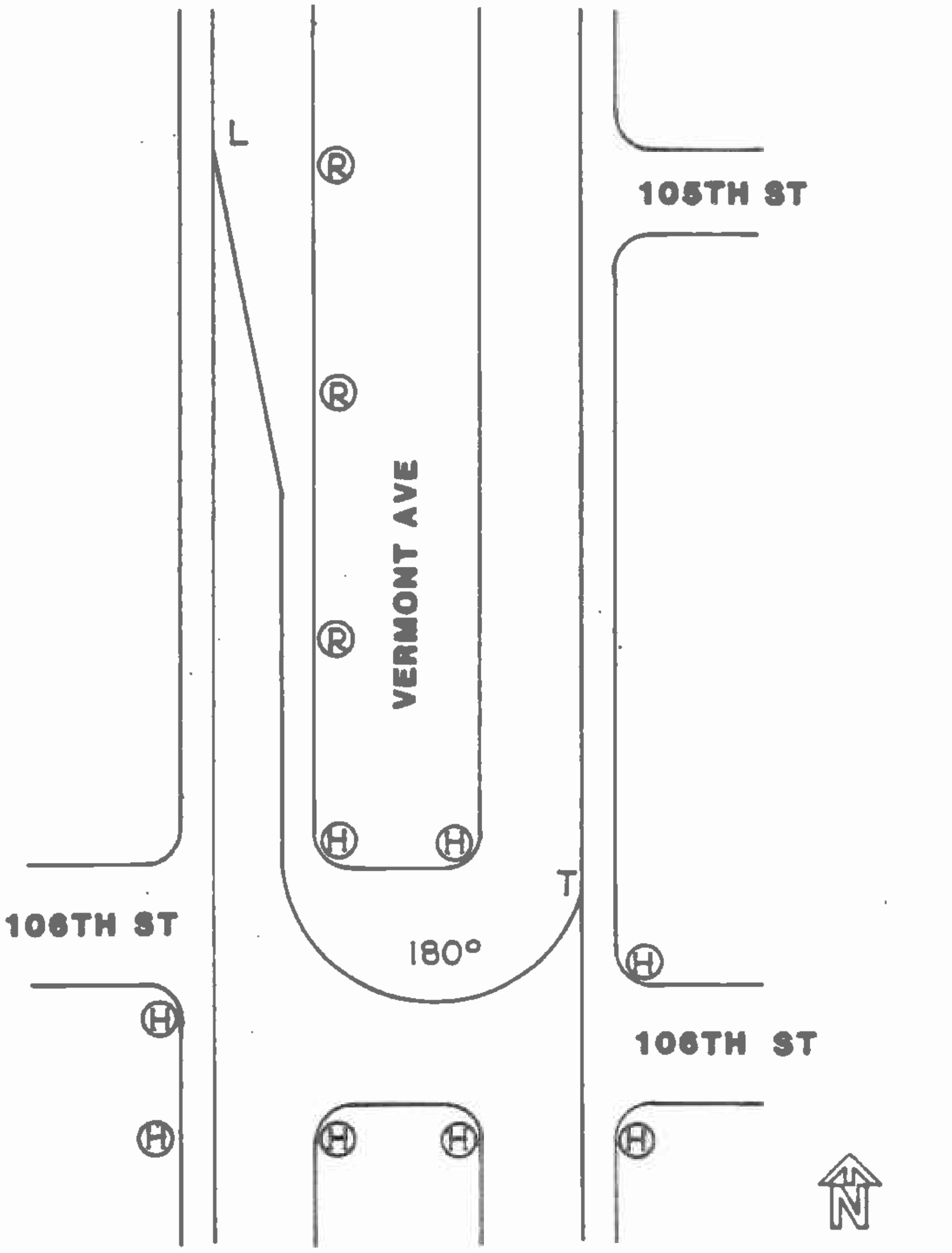
FIGURE C-1



RTD

120TH ST.
LAYOVER ZONE

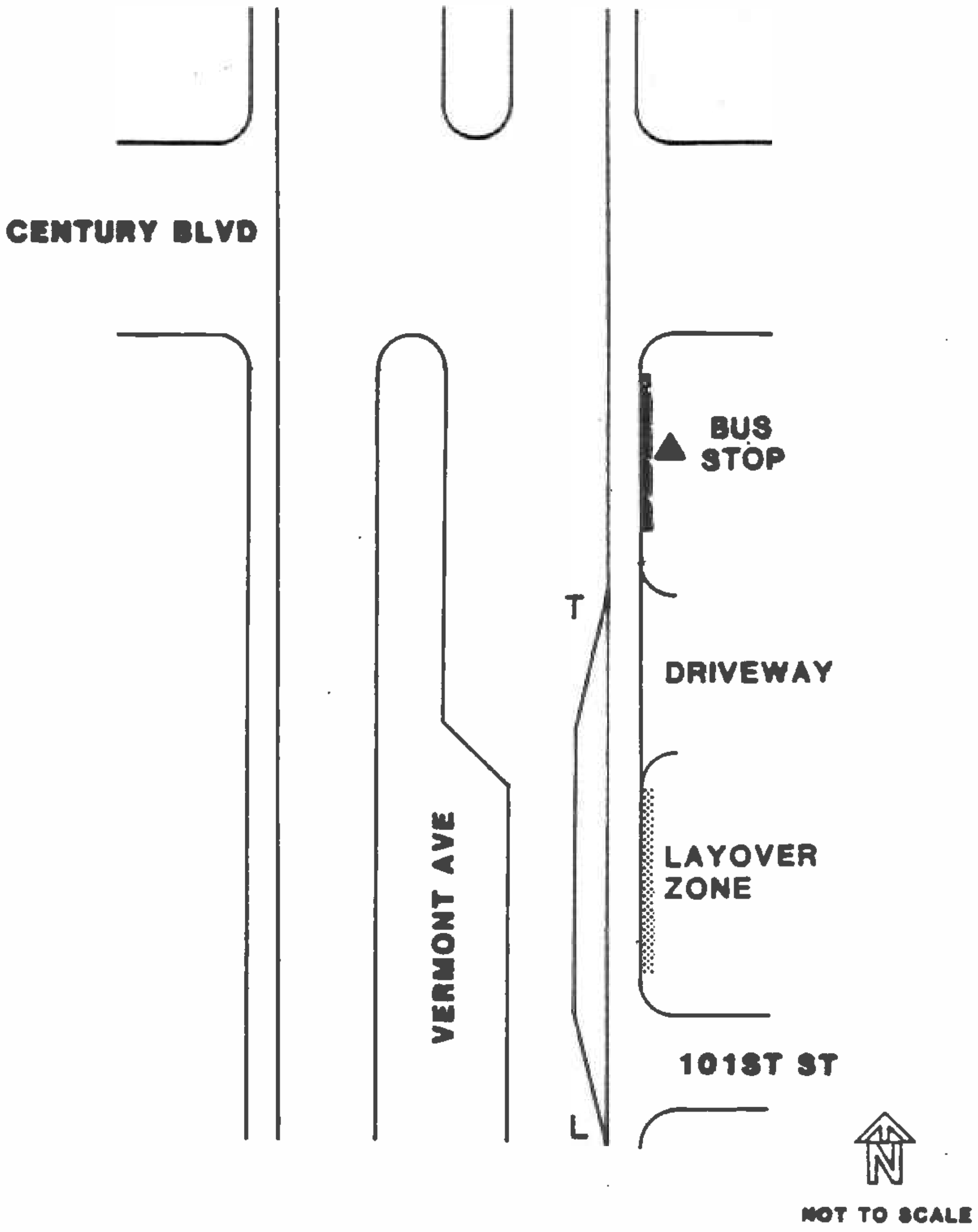
FIGURE C-2



RTD

106TH ST.
TURNBACK LOOP

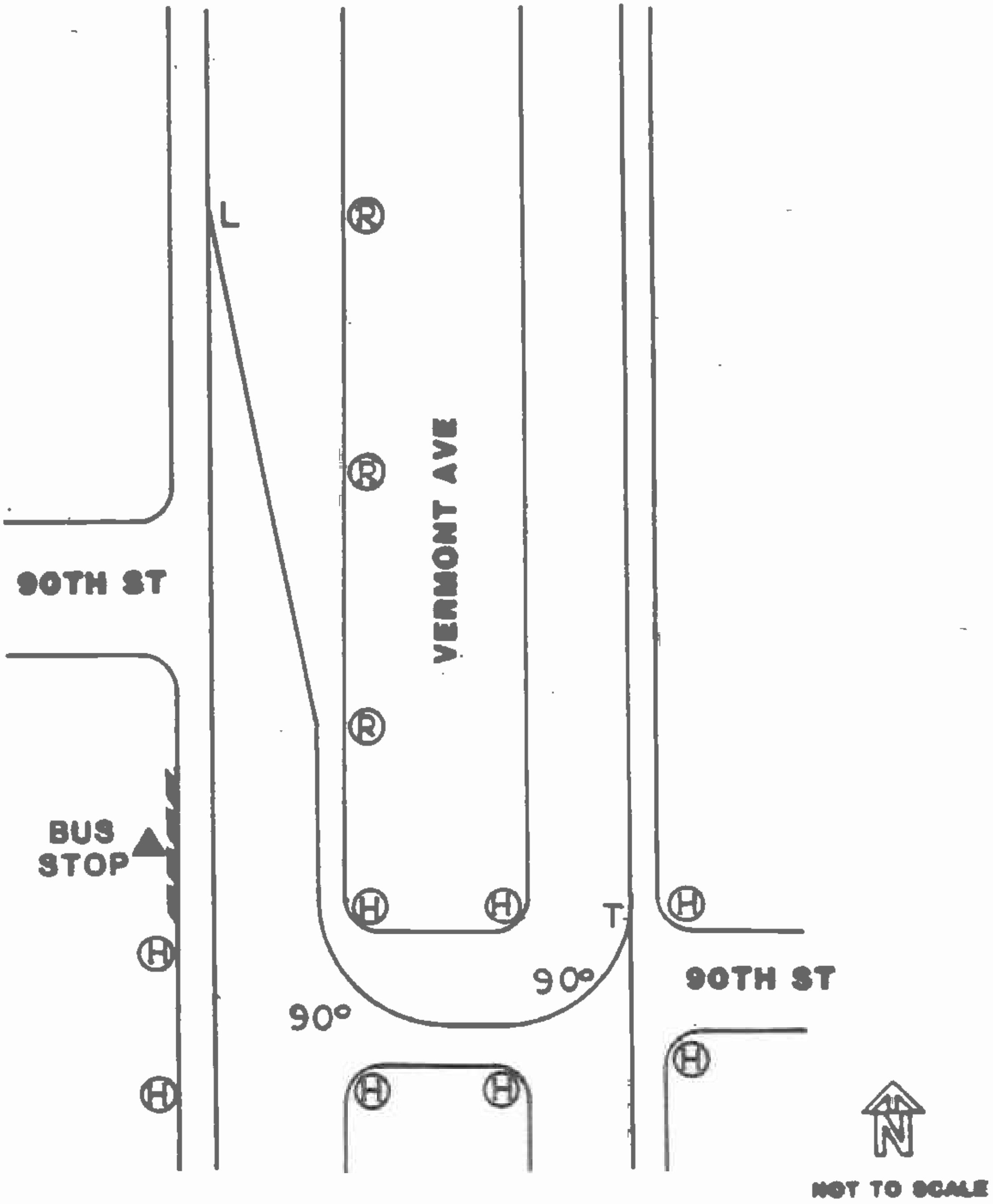
FIGURE C-3



RTD

CENTURY BLVD.
LAYOVER ZONE

FIGURE C-4



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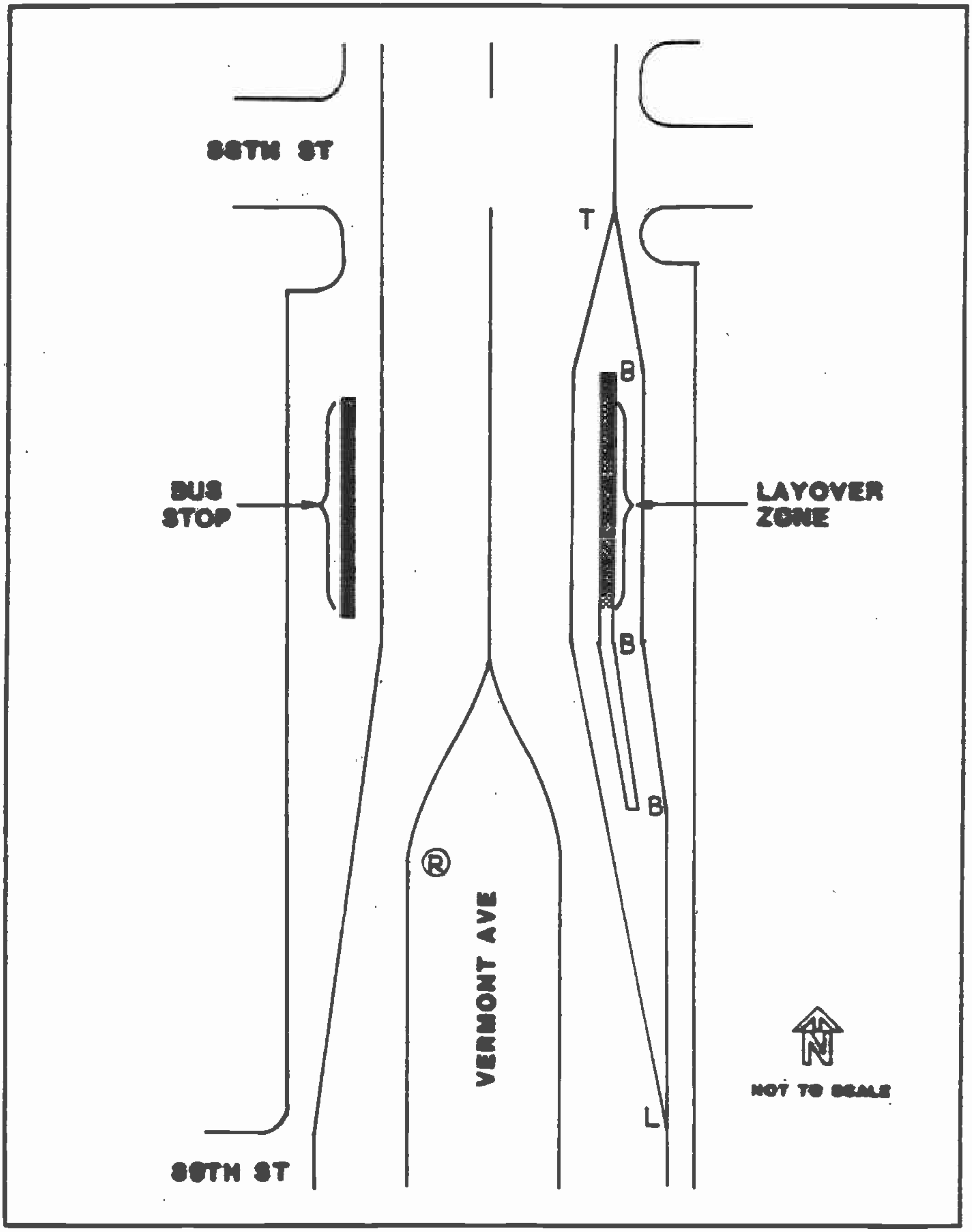
90TH ST.
TURNBACK LOOP

FIGURE C-5



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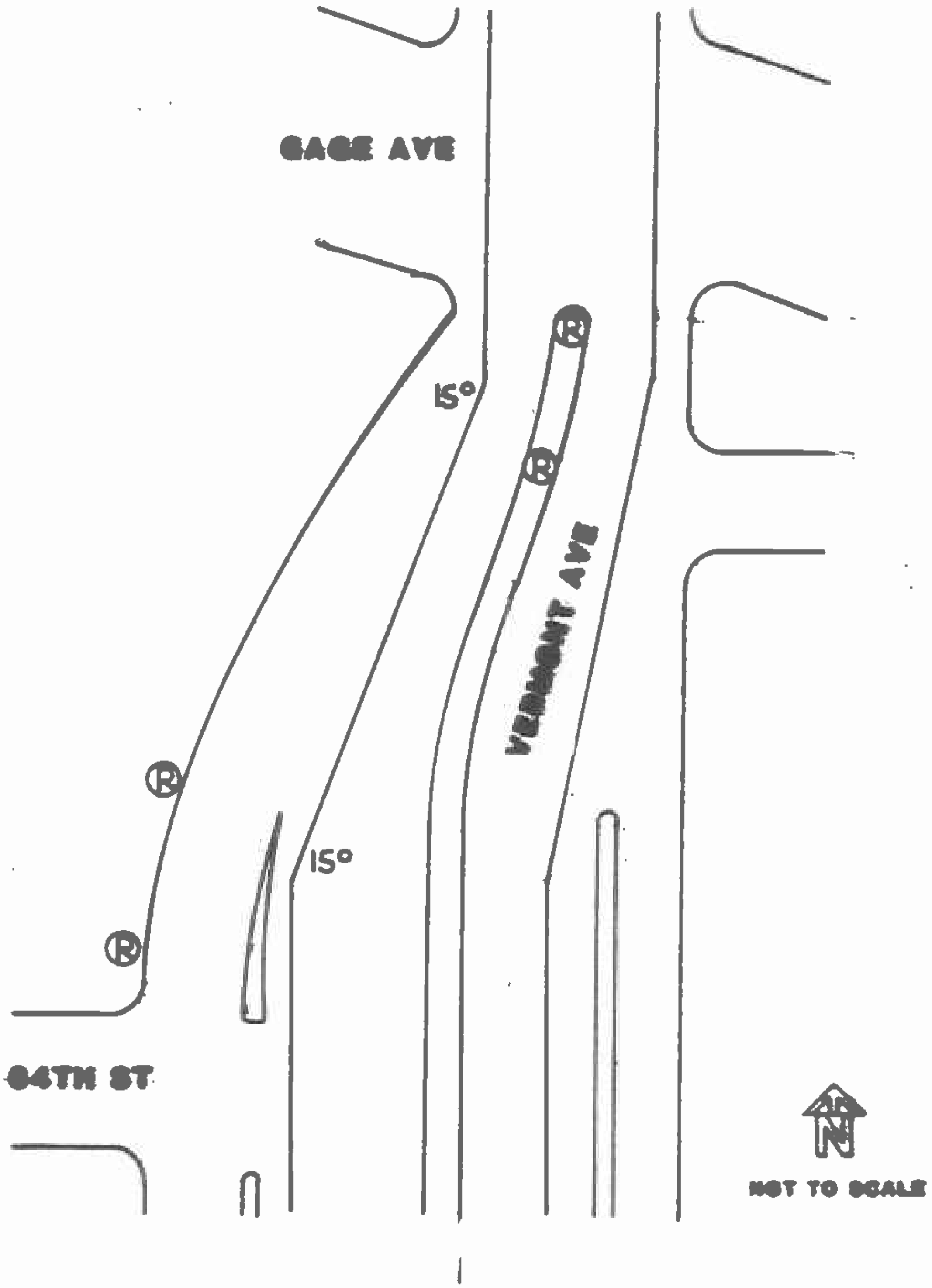
88TH ST
LAYOVER ZONE

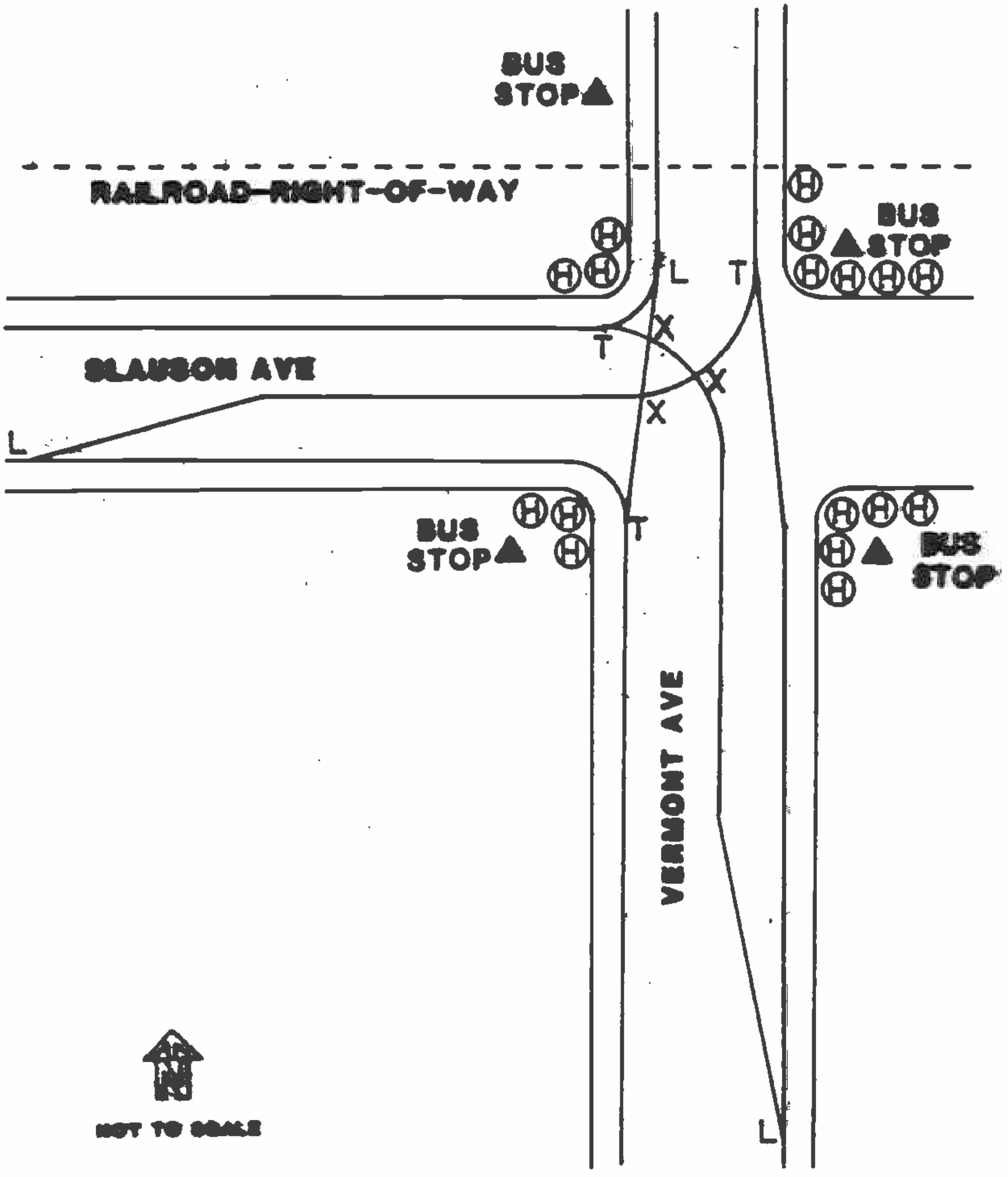
FIGURE C-6



RTD

GAGE AVE.
"S" CURVE

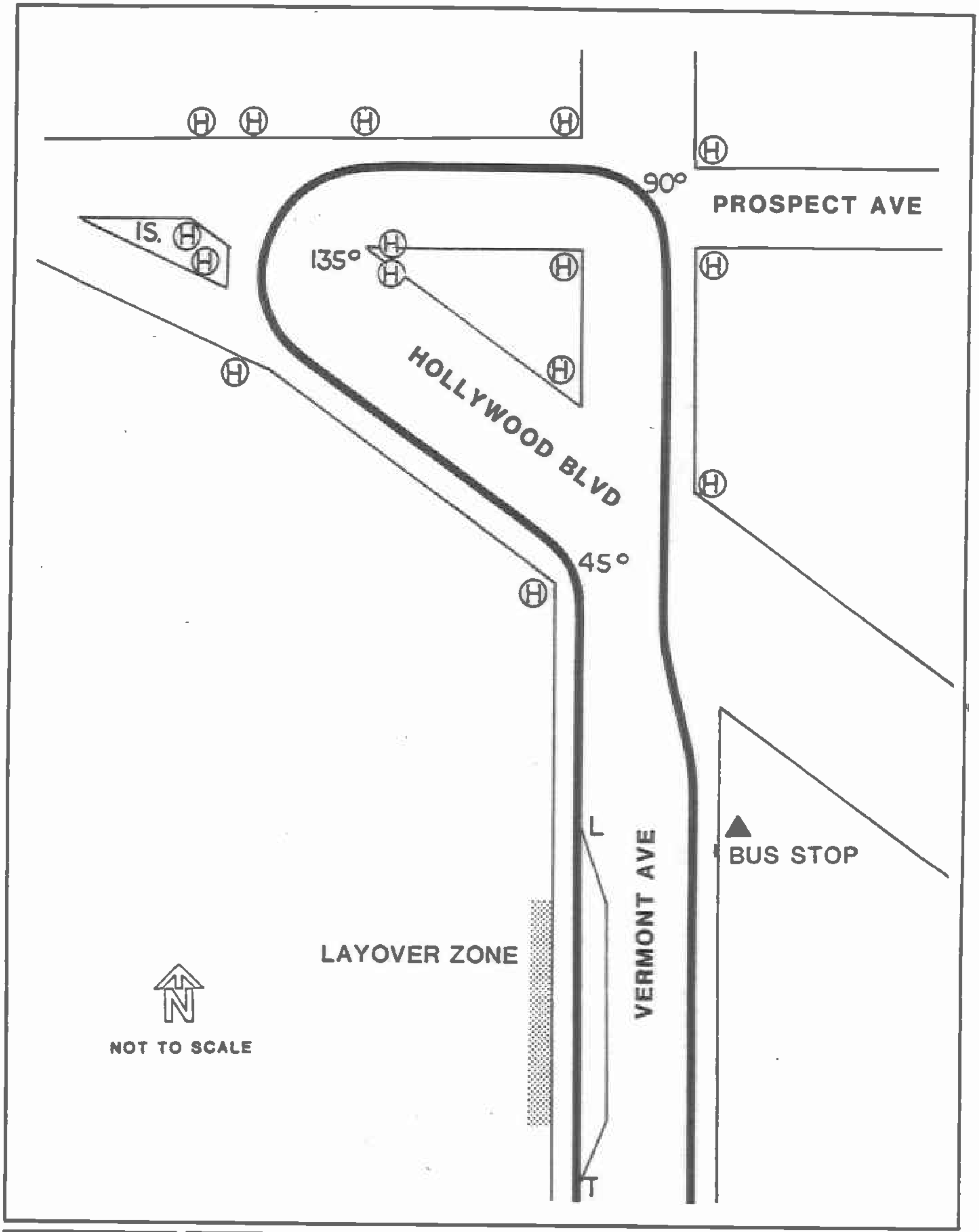
FIGURE C-7



RTD

SLAUSON AVE.
TEE JUNCTION

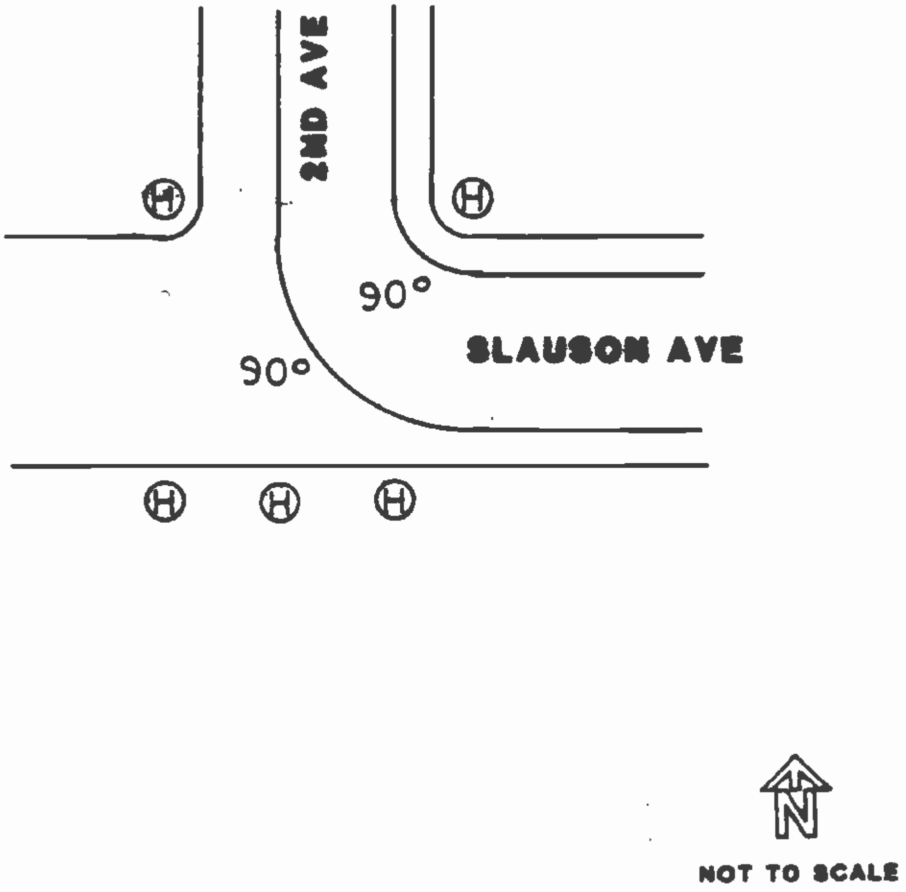
FIGURE C-8



RTD

HOLLYWOOD BLVD TURNBACK LOOP AND LAYOVER ZONE

FIGURE C-9



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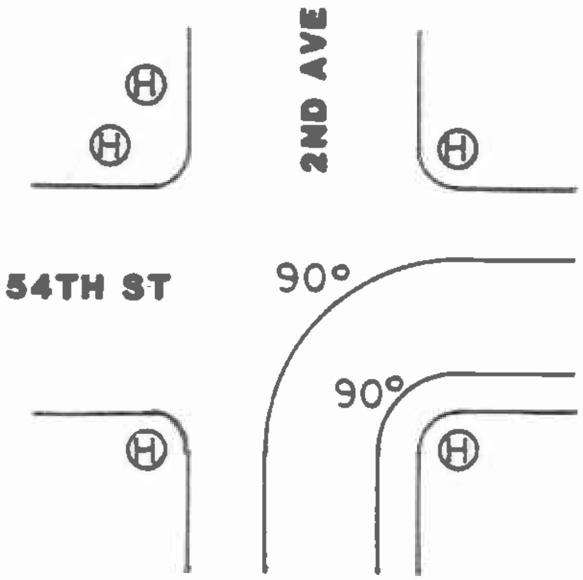
SLAUSON AVE/2ND AVE
90° TURN

FIGURE C-10

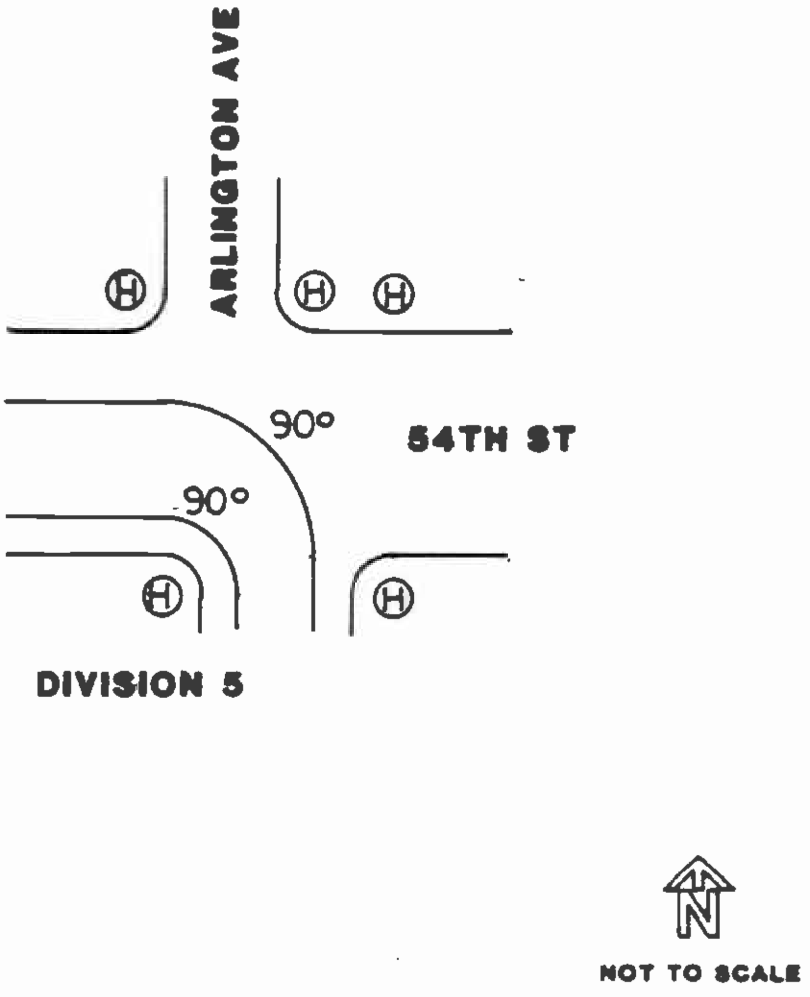


NOT TO SCALE

RTD

2ND AVE./54TH ST
90° TURN

FIGURE C-11



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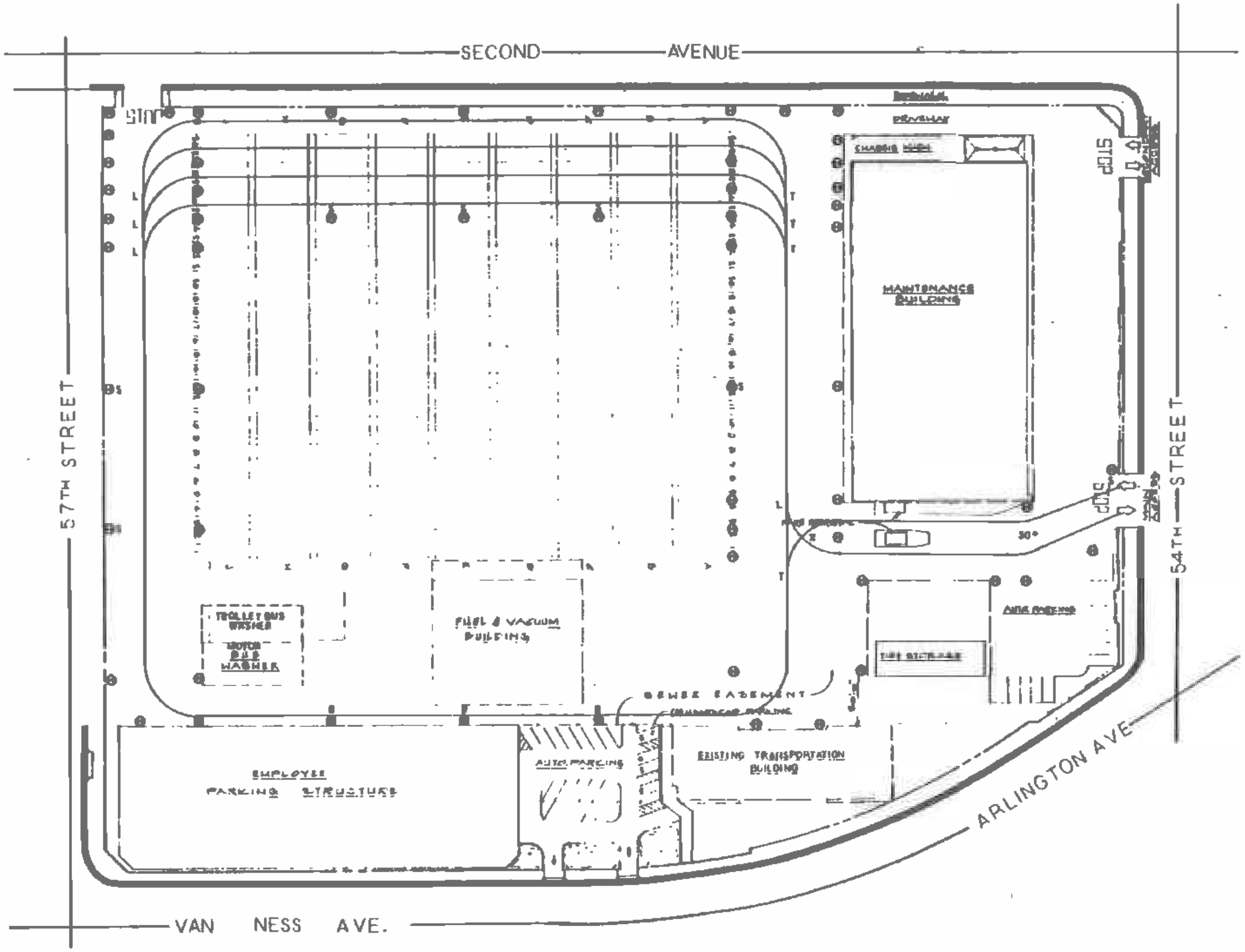
DIVISION 5 ENTRANCE
90° TURN

FIGURE C-12



DIVISION 5 CONVERSION PLAN

FIGURE C-13

Overhead wire cost estimates are based upon recent experiences in Seattle and San Francisco. A preliminary plan in Portland is also used as a source of information. Costs for similar wire configurations from each study are adjusted to 1984 prices in Los Angeles using cost indices from Engineering News Record and Means cost data. Any large deviations in cost were researched and reconciled. The result of this effort was to establish a consistent method whereby the cost of installing tangent wire and special work can be estimated.

The cost of materials and installation of overhead wiring is based upon San Francisco Municipal Railway's 1983 Study. This study is expressed in 1982 prices. Adjusting upward for inflation and downward for Los Angeles' lower construction costs results in very small changes in unit prices. As a result, San Francisco Municipal Railway's unit costs were adopted without any adjustment. These costs are listed in Table C-2.

The cost of overhead wiring to components are those for Ohio Brass "rigid" wiring system. The more expensive "elastic" wiring systems are designed to maintain wire contact at higher speeds. Such technology is deemed unnecessary for the low speed operations along Vermont Avenue.

Switches for this system are the "inductive control" type. This mode of switch control uses an inductive signal from the vehicle's contact pole to make the lead switch guide these poles in the proper direction. Other modes of switch control are "selectric" and "power on - power off." Selectric switches only operate where the switch assembly angle is 23 degrees or more. At these angles, a turning TC's contact poles will be staggered instead of parallel. Contactors are located one or two bus lengths in front of the switch and sense any staggered vehicle contacts. The switch will then align itself for turning movements. No operator participation is required for this type of control. Power on - power off control requires the operator to depress the accelerator prior to turning. Sensors just in front of the frog detect the power draw and align the switch accordingly. Power on - power off control may become confused when actual headways become tight. The three-minute peak direction headways on Line 204 frequently result in bunching of vehicles. Inductive control performs more reliably under these circumstances. Inductive control may be activated by the vehicle's turn signal, minimizing operator participation in its operation. The estimated cost is $1,000 per leading switch and negligible for on-board vehicle equipment.

TABLE C-2

Overhead Wire Component Costs (thousands of constant 1984 dollars)

Item	Unit	Cost Per Unit	Expected Life (Yrs.)
Regular Steel Poles	@	$ 2.5	50
Heavy Steel Poles	@	3.4	50
Brackets	@	.9	50
Spans	@	.9	50
Leading Switch	@	6.3	30
Inductive Control	@	1.0	30
Trailing Switch	@	5.0	30
Crossing	@	2.0	30
Curve Segment	@	3.0	30
4/0 Tangent Wire	1,000 ft	2.5	30
Concrete Work	1,000 sq ft	10.0	50
Traffic Signal	@	50.0	30
One-way Tangent Wire Supported by Brackets	mile	196.4	50
Two-way Tangent Wire Supported by Spans	mile	354.4	50

Curves of 15 degrees or more are drawn to consist of one or more curve segments. Three of these curve segments are used for wide 90-degree turns with a wire radius of 40 feet or more. Right turns are much tighter. For such turns two curve segments are assumed to be needed.

Tangent wire is size 4/0 to allow use of feederless power supply stations (See C.3 Power Supply). Where the right of way is less than 80 feet in width, two-way tangent wire is suspended from overhead spans that are supported by steel poles on both sides of the street. Wider rights of way and one-way wiring use a single steel pole and brackets to suspend tangent wire. Poles for both of these suspension systems are the less expensive "regular" type.

Special work is suspended by "heavy" poles. Such poles are necessary to support the additional weight of switches and crossings and to withstand the tension of guys for maintaining curve segment alignments.

The serviceable life of tangent wire and special work is assumed to be 30 years. Poles, spans, and brackets are assumed to last for 50 years.

Materials lists and installation costs for overhead wiring are found in Table C-3. These costs are subdivided into three categories: revenue route, deadhead route, and the Division 5 yard. All new metal poles and wiring are assumed to be installed throughout the route. The south side of Slauson and the east side of Vermont south of Manchester have poles that were once used to support trolley wire. These poles are made of wood and may not be able to bear the stress of supporting TC wiring. Some savings in capital may be possible by reusing these poles. Only detailed engineering can verify this potential.

All wiring in Division 5 is assumed to be supported by heavy poles. Suspending tangent wire from existing structures provides the potential for further cost savings. Pole support also introduces obstructions to traffic within the yard. Suspension from existing structures would reduce such obstructions to a minimum.

Costs are subtotaled for items with serviceable lives of 30 and 50 years. This becomes an important consideration when capital costs are amortized (annualized) over the life of the assets. The up front capital cost of installing tangent wire and special work for Line 204 comes to nearly $8 million. Of this total, approximately $6.4 million ($500,000 per mile) is spent on the revenue route. The remaining $1.6 million is spent on Division 5 and the deadhead route, both of which may be shared by any extension of TC service to other lines out of Division 5.

TABLE C-3

OVERHEAD WIRING COSTS
(thousands of constant 1984 dollars)

Location	Item	Quantity	30-Year Life	50-Year Life
REVENUE ROUTE:				
122nd Street Turnback Loop	Heavy Poles	8 @		$ 27.2
	Curve Sections	6 @	$ 18.0	
	Subtotals		$ 18.0	$ 27.2
	Total Item Cost: $	45.2		
120th Street Layover Zone	Regular Poles	8 @		$ 20.0
	Leading Switch	1 @	$ 6.3	
	Inductive Control	1 @	1.0	
	Trailing Switch	1 @	5.0	
	4/0 wire	1400 ft	3.5	
	Subtotals		$ 15.8	$ 20.0
	Total Item Cost: $	35.8		
106th Street Turnback Loop	Regular Poles	3 @		$ 7.5
	Heavy Poles	8 @		27.2
	Leading Switch	1 @	$ 6.3	
	Inductive Control	1 @	1.0	
	Trailing Switch	1 @	5.0	
	Curve Segments	6 @	3.0	
	4/0 Wire	600 ft	1.5	
	Subtotals		$ 16.8	$ 34.7
	Total Item Cost: $	51.5		

TABLE C-3 (continued)

OVERHEAD WIRING COSTS
(thousands of constant 1984 dollars)

Location	Item	Quantity	30-Year Life	50-Year Life
REVENUE ROUTE (continued):				
Century Boulevard Layover Zone	Regular Poles	5 @		$ 12.5
	Leading Switch	1 @	$ 6.3	
	Inductive Control	1 @	1.0	
	Trailing Switch	1 @	5.0	
	4/0 wire	800 ft	2.0	
	Subtotals		$ 14.3	$ 12.5
	Total Item Cost: $	26.8		
90th Street Turnback Loop	Regular Poles	3 @		$ 7.5
	Heavy Poles	8 @		27.2
	Leading Switch	1 @	$ 6.3	
	Inductive Control	1 @	1.0	
	Trailing Switch	1 @	5.0	
	Curve Segments	6 @	18.0	
	4/0 Wire	600 ft	1.5	
	Subtotals		$ 31.8	$ 34.7
	Total Item Cost: $	66.5		
88th Street Layover Zone	Regular Poles	1 @		$ 2.5
	Brackets	3 @		2.7
	Leading Switch	1 @	$ 6.3	
	Inductive Control	1 @	1.0	
	Trailing Switch	1 @	5.0	
	4/0 Wire	600 ft	1.5	
	Subtotals		$ 13.8	$ 5.2
	Total Item Cost: $	19.0		

TABLE C-3 (continued)

OVERHEAD WIRING COSTS
(thousands of constant 1984 dollars)

Location	Item	Quantity	30-Year Life	50-Year Life
REVENUE ROUTE (continued):				
Gage Avenue "S" Curve	Regular Poles	4 @		$ 10.0
	Curve Segment	2 @	$ 6.0	
	Subtotals		$ 6.0	$ 10.0
	Total Item Cost: $ 16.0			
Slauson Avenue "Tee" Junction	Heavy Poles	17 @		$ 57.8
	Utility Relocation	1 @		10.0
	Leading Switch	3 @	$ 18.9	
	Inductive Control	3 @	3.0	
	Trailing Switch	3 @	15.0	
	Crossings	3 @	6.0	
	Curve Segments	10 @	30.0	
	4/0 Wire	1200 ft	3.0	
	Subtotals		$ 75.9	$ 67.8
	Total Item Cost: $ 143.7			
Prospect Avenue 90 degree turn	Heavy Poles	4 @		$ 13.6
	Curve Sections	3 @	$ 9.0	
	Subtotals		$ 9.0	$ 13.6
	Total Item Cost: $ 22.6			
Hollywood Blvd. 135 degree turn	Heavy Poles	8 @		$ 27.2
	Cement Work	1600 sq ft		16.0
	Curve Sections	5 @	$ 15.0	
	Traffic Signal	1 @	50.0	
	Subtotals		$ 65.0	$ 43.2
	Total Item Cost: $ 108.2			

TABLE C-3 (continued)

OVERHEAD WIRING COSTS
(thousands of constant 1984 dollars)

Location	Item	Quantity	30-Year Life	50-Year Life
REVENUE ROUTE (continued):				
Hollywood Blvd. 45 degree turn	Heavy Poles	3 @		$ 10.2
	Curve Segments	1 @	$ 3.0	
	Subtotals		$ 3.0	$ 10.2
	Total Item Cost: $ 13.2			
Hollywood Blvd. Layover Zone	Leading Switch	1 @	$ 6.3	
	Inductive Control	1 @	1.0	
	Trailing Switch	1 @	5.0	
	4/0 Wire	800 ft	2.0	
	Subtotals		$ 14.3	
	Total Item Cost: $ 14.3			
Hollywood Blvd. to Gage Avenue Tangent Wire	2-Way Tangent Wire Suspended by Spans	8.5 mi	$ 449	$2564
	Total Item Cost: $3013			
Gage Avenue to 122nd Street Tangent Wire	1-Way Tangent Suspended from Brackets	8.0 mi	$ 211	$1360
	Total Item Cost: $1571			
	REVENUE ROUTE SUBTOTALS		$944	$4203
	TOTAL REVENUE ROUTE COST: $5147			

TABLE C-3 (continued)

OVERHEAD WIRING COSTS
(thousands of constant 1984 dollars)

Location	Item	Quantity	30-Year Life	50-Year Life
DEADHEAD ROUTE:				
Slauson Avenue between Western Ave. & Denker Ave. Utility Relocation	Utility Relocation	1 @		$ 10.0
	Subtotals			$ 10.0
	Total Item Cost: $	10.0		
Slauson Ave./ 2nd St. 90 degree turn	Heavy Poles	5 @		$ 17.0
	Curve Segments	5 @	$ 15.0	
	Subtotals		$ 15.0	$ 17.0
	Total Item Cost: $	32.0		
2nd Ave./54th St. 90 degree turn	Heavy Poles	5 @		$ 17.0
	Curve Segments	5 @	$ 15.0	
	Subtotals		15.0	17.0
	Total Item Cost: $	32.0		
Division 5 Entrance 90 degree turn	Heavy Poles	5 @		$ 17.0
	Curve Segments	5 @	$ 15.0	
	Subtotals		$ 15.0	$ 17.0
	Total Item Cost: $	32.0		
Vermont Ave./ Slauson Ave. to Division 5 Tangent Wire	2-Way Tangent Wire Suspended from Spans	1.9 mi	$ 100.0	$ 573.0
	Total Item Cost: $	673.0		
	DEADHEAD ROUTE SUBTOTALS		$ 145.0	$ 634.0
	TOTAL DEADHEAD ROUTE COST: $	779.0		

TABLE C-3 (continued)

OVERHEAD WIRING COSTS
(thousands of constant 1984 dollars)

Location	Item	Quantity	30-Year Cost	50-Year Cost
DIVISION 5 CONVERSION:				
Division 5	Heavy Poles	58 @		$ 197.2
	Brackets	3 @		2.7
	Spans	7 @		6.3
	Leading Switch	4 @	$ 25.2	
	Inductive Control	4 @	4.0	
	Trailing Switch	4 @	20.0	
	Crossing	1 @	2.0	
	Curve Segments	38 @	114.0	
	4/0 Wire	6000 ft	15.0	
	Subtotals		$ 180.2	$ 206.2
	TOTAL CONVERSION COST	$ 386.4		
	SYSTEM SUBTOTALS		$1269	$5043
	TOTAL SYSTEM COST	$6312		
	PLUS 25% ENGINEERING AND CONTINGENCIES:			
	COST ESTIMATE SUBTOTALS		$1586	$6304
	TOTAL ESTIMATED COST	$7890		

C.3 Power Supply

There are two technologies currently available for supplying electricity to the overhead wires: substations with feeders and feederless substations. The older technology that uses feeders exhibited considerable economies of scale in converting a.c. line voltages to d.c. voltages suitable for transit vehicle use. Large substations would be centrally located and heavy feeder wires would feed d.c. current to several power segments. These feeder wires are visually obstrusive if suspended and expensive to install if run underground. Such large substations require the purchase or lease of land, making their location subject to local land use restrictions and their costs difficult to estimate.

Feederless substations are the product of modern solid state technology. Each substation powers only two adjacent power segments by using the overhead wire to provide the feeder function. For this reason, the heavier 4/0 copper wire is used in the overhead wire cost estimates. These units require no additional land; they may be installed in small underground vaults or on small pads. Another advantage of feederless stations is their reliability. Should one of many such units burn out, several other nearby units can deliver power to the stricken segment. For these reasons this study assumes that power will be supplied by 500 kilowatt feederless substations.

The TC system's power requirements are broken into three parts: Division 5, the deadhead route, and the revenue route.

Seattle's maintenance yard uses two 500 kilowatt feederless substations to provide power for 109 40-foot Flyer TCs. Much of this capacity is necessary to power the vehicles as they warm up on winter mornings. Based upon this experience and assuming that air conditioning requires the same power capacity as heating, one 500 kilowatt substation is assumed to provide sufficient power to the 51 vehicles located at Division 5.

The deadhead route's power requirements are determined by the number of vehicles that will be using this power segment at any given time. The minimum pull-in or pull-out headway is two minutes. Assuming a conservative 15 miles per hour deadhead speed implies that up to four buses would travel this segment (1.9 miles in length) at any given time. One 500 kilowatt feederless station is sufficient to power six buses along this segment. Thus one such station is all that is needed for powering TCs as they deadhead to and from Division 5.

The revenue route is a bit more complicated to model due to its length and the effects that traffic can have on the spacing of vehicles. To simplify this analysis the average mile of revenue route is modeled. The actual placement and spacings of substations requires more refined engineering.

Average operating speed on Vermont Avenue is 12 miles per hour. The minimum scheduled headway is three minutes. This implies a minimum scheduled distance between buses of 0.6 miles, or 1.7 buses per mile in one direction. Two-way scheduled vehicle density, therefore, is at maximum 3.4 TCs per mile. In actual practice, buses often bunch up, particularly during peak hours. This requires an increase of power capacity to supply sufficient current when such platoons of buses move through through a power segment. Typically, an "off-schedule" factor of 30% is added to the bus density to deal with such problems. The possibility of service growth is dealt with in a similar way. An additional 30% is added to bus density in order to allow scheduled headways to fall as low as two minutes. Finally, a fraction of rated power is lost in the rectification process of the substation. An additional 5% is added to compensate for these losses. In all, current scheduled bus density is increased by 77% to compensate for vehicle bunching, future service growth, and substation losses. This results in providing power along the route that is capable of handling up to six buses per mile.

Table C-4 is a list of several diversity curves. These curves measure the peak amperage drawn by a group of buses. The Ohio brass curve is the industry standard but appears to be too low for modern TCs. The approach used here is to use the (low) Ohio brass curve and a (high) minimum voltage equal to the full 600 volt rating. Thus the 810 amps and 600 volts of the average mile of route segment requires 486 kilowatts of capacity. For the purposes of this study, twelve 500 kilowatt substations are sufficient to power the 12.5 miles of Line 204's revenue route. This power capacity is similar in magnitude to that installed by Seattle in its CBD where similar vehicle densities occur. Such a power supply is sufficient for a power segment stricken by a forced outage to be powered by adjacent substations at approximately 400 volts.

All 14 substations required for Line 204 are assumed to cost $250,000 each to install. Adding 15% for engineering and contingencies brings the bill for the power supply to $4.025 million.

TABLE C-4

Comparison between Diversity Curves
(amperes)

# Buses	CBD	Seattle Outlying	McDonald	Ohio Brass	Modified McDonald
1	400	500	450	200	350
2	600	600	771	400	604
3	800	800	998	530	788
4	960	1030	1157	640	921
5	1100	1350	1271	730	1019
6	1200	1560	1348	810	1093
7	1320		1404		1151
8	1400		1448		1198

(Source: Akio Ueno, 1983)

C.4 Other Trolley Coach System Capital

Division 5 is currently equipped only for the servicing and maintenance of MCs. Additional investment in Division 5 is necessary beyond overhead wiring and power supply to support TC operations.

The bus washer is not compatible for TC use. The side brushes wrap around the rear of the vehicle where the TCs' pole guys are located. These components cannot be washed in such a manner. The roof brush cannot properly wash the TC roof and can damage poles, guys, and contacts. Hybrid washers are available that can wash both MCs and TCs. For the purposes of cost estimation, a second washer dedicated to TCs is assumed to be built next to the existing bus washer in Division 5. The equipment for the MC washer in Division 10 costs $160,000. Concrete pads, power connections, and shelter structure are estimated to run the cost up to $400,000.

Several of the maintenance bays at Division 5 will need to be supplied with 600 volt electrical service. Because TCs are assumed to pull into service bays under battery power, either umbilicals or overhead wires may be used as a means of power supply. The cost estimate of 600 volt electrification is generous. Three of the nine bays at Division 5 are assumed to be electrified at a cost of $30,000 per bay. This unit cost is probably high, but small when compared to total wiring costs. It is doubtful that more than two bays are needed for a fleet of 51 TCs, but system growth and flexibility of the maintenance facilities demands that three bays be converted. All told, a total of $490,000 in additional capital costs is estimated for the conversion of Division 5 into a TC servicing yard. All of this equipment has a serviceable life of 30 years.

D. TROLLEY COACH SYSTEM OPERATING COSTS

The annual cost of operating TCs is analyzed in four parts. Energy, vehicle maintenance, and revenue operation correspond to similar components of MC operating costs. The additional component of overhead wire and power supply maintenance is dealt with last. Table D-1 summaries the findings.

D.1 Energy

The utility bill structure of the Los Angeles Department of Water and Power is used for this study, primarily because Line 204 lies almost entirely within its service area. Southbound trips travel in Southern California Edison territory between Manchester Avenue and 122nd Street (approximately 2.5 miles). It is assumed that differences in electricity costs between these two companies for this segment of the route are small compared to the total electric bill.

The chopper equipped TCs of this study are assumed to consume 3.3 kilowatt-hours of electricity per vehicle mile. This estimate is based upon the energy consumption of TCs in other properties, particularly those having chopper control. Energy consumption with resistor bank control is usually 4.5 kilowatt-hours per mile. Assuming a 25% increase in energy efficiency for chopper control implies 3.3 kilowatt-hours per mile. San Francisco Municipal Railway reports power consumption of three kilowatt-hours per mile. Adding 10% for air conditioning arrives at the adopted number. The average speed of 12 miles per hour and a line voltage of 600 volts implies an RMS current of 66 amperes per vehicle. Actual current consumption in other properties ranges from 54 amperes (San Francisco) to 93 amperes (Seattle). This is consistent with the addition of air conditioning which draw more current than San Francisco's vehicles, and less vehicle heating which would draw less current than Seattle's vehicles. Because of Line 204's high vehicle speeds relative to other TC lines, these mileage-based energy costs are likely to be biased upward.

Electricity estimates are based upon DWP's Rate Schedule A-3A for regular large general service. This schedule has four components: a capacity charge, an on-peak energy charge, an off-peak energy charge, and an energy cost adjustment.

The capacity charge is a billing of 30 cents per kilowatt of capacity per month, based upon the highest 15-minute average peak experienced during the previous 12 months. Each vehicle of the system modeled here averages 40 kilowatts. Each feederless substation on the route is

TABLE D-1

Trolley Coach System Operating Costs
(thousands of contant 1984 dollars)

Energy	$ 376/year
Vehicle Maintenance	2,007/year
Revenue Operations	4,618/year
Overhead Wiring & Power Supply Maintenance	347/year
Total Operating Cost	$7,348/year

designed to power six vehicles. Should one substation experience a forced outage, each of the two adjacent substations may power as many as nine vehicles. This implies a peak power capacity of 360 kilowatts. Such capacity for 14 stations and 12 months per year would cost $18,100 annually. Line losses are not accounted for in this estimate, but the full 600 volt potential is assumed to compensate for such losses.

The on-peak period is defined as 11:00 a.m. to 7:00 p.m. on weekdays. Line 204's schedule calls for 682,000 vehicle miles to be traveled annually during this period. At $0.048 per kilowatt-hour and 3.3 kilowatt-hours per mile, on-peak energy charges would cost $108,000 per year. The remaining 1.3 million vehicle miles traveled each year occur during the off-peak power period costs $0.02 per kilowatt-hour. This would cost $85,800 per year.

The energy adjustment charge is applied to all electricity consumption regardless of the time of day. This charge is linked to the price of oil. No attempt has been made to predict changes in real oil prices. Such changes would only affect relative diesel and electricity costs in a small way due to compensating changes in the energy adjustment charge. At the current $0.025 per kilowatt-hour, this charge would add $164,000 to the annual electricity bill. The total electricity bill for one year of TC operation on Line 204, therefore, comes to $376,000.

D.2 Vehicle Maintenance

There are several reasons for TCs to require less mainteenance than MCs. Trolley coaches have no transmissions to wear out or radiators to overheat. They operate with less vibration than MCs, reducing internal mechanical stress. Dynamic braking, whereby the vehicle's momentum generates electricity which is then burned in a resistor bank, reduces wear on mechanical brakes. The labor required to fill fuel tanks is unnecessary. Finally, on-road breakdowns are fewer in number, requiring less travel time for on-road mechanics.

Studies of the relative cost of vehicle maintenance compared TCs and MCs on a cost per mile basis. Such studies are biased toward overestimating the maintenance costs of TCs by virtue of their normal deployment to routes that exhibit either slow speeds in CBDs or steep gradients. Both of these conditions raise maintenance costs per mile traveled. The results of such studies tend to support UMTA's recommendation of an MC to TC vehicle maintenance cost ratio of 1.3. This is equivalent to a 23% savings in vehicle maintenance costs that can be gained by replacing MCs with TCs.

The estimated $2.6 million annually to maintain MCs for Line 204 is based upon vehicle hours of operation. To the extent that buses assigned to Line 204 travel more slowly than the District average, fewer actual mileage-based costs accrue to this line than this estimate predicts. This implies that $2.6 million is too high. Applying the 23% savings rate, which is biased downward, to this high MC maintenance cost estimate results in a reasonable approximation of the difference between MC and TC costs for this category. This difference is estimated to be $602,000 annually, implying a TC vehicle maintenance cost of $2.006 million per year.

D.3 Revenue Operations

Revenue operation includes driving, dispatching and supervising the revenue vehicle. There are several conditions that could account for TCs costing less under this category than MCs. The TC is a faster vehicle in the face of steep gradients and acceleration that is unimpeded by traffic. Owl service vehicles need not deadhead back to the yard for refueling. Increased reliability on the road reduces the need for supervision labor time. The few of these factors that come into play along Line 204 are not considered significant compared to the total operating costs of the line. The same $4.618 million a year it takes to operate 40-foot MCs along their scheduled course is assumed to be the cost of operating 40-foot TCs on the same schedule.

Conversion of Line 204 to high capacity (articulated) TCs would significantly affect the cost of revenue operation. Reduction in operator time would tend to reduce this cost component. The effects on running times, maintenance, insurance and energy costs for such vehicles need also be accounted for. No articulated TCs now operate in North America, so cost data are nonexistent. In Europe, articulated TCs operate in a self-service fare environment in order to decrease dwell times. The extent to which the Monthly Pass approximates self-service fares needs to be determined. District studies on articulated diesel bus operation on Line 1 may shed some light on this issue. For the purposes of this study, introducing articulated vehicles on Line 204 would distort the value of any results for head-to-head comparisons of MC and TC costs under equal operating conditions.

D.4 Overhead Wiring and Power Distribution Maintenance Costs

The approach taken for estimating the cost of maintaining overhead wiring is to assume that such work is done in-house by District employees. Several transit properties contract such maintenance duties out to local electric utility companies. The advantage to such arrangements is in the nature of the work -- most labor time is spent waiting for an emergency to happen, and labor is the major cost element for maintaining the power distribution system for TC service. Thus, this cost estimate should be considered to be an upper bound for the cost of maintaining overhead wiring.

The labor requirement assumes round-the-clock preparedness for emergency repairs and for route inspection and maintenance during daylight hours. For this purpose, four full-time equivalent employees are assumed to be needed for the day shift, and two full-time equivalent employees are assumed to be needed for each the swing shift and the graveyard shift. The Section 15 Report for the District implies an average labor cost (including fringe benefits) of $37,820 per employee-year. These eight employees would, therefore, require $303,000 annually in wages and benefits.

Equipment for the maintenance crew includes a cherry picker ($50,000) and a service van ($15,000). Assuming a six-year useful life for such equipment implies an annual cost of $11,000. Each vehicle is assumed to require an additional operating and maintenance cost of $2,000 per year. Thus, the annual cost of maintenance equipment is $15,000. The effects of variations in the rate of interest for annualizing the capital cost of these vehicles are small enough to be ignored in this analysis.

Materials costs are small. Based upon Seattle Metro's materials costs, $2,000 per mile is assumed to be required each year. Thus, $29,000 annually is the estimated cost of materials for maintaining 12.5 revenue route miles plus 1.9 deadhead route miles of wiring.

Total annual cost for overhead maintenance amounts to $347,000. Of this amount, 87% is labor. Contracting maintenance out to the Los Angeles Department of Water and Power and Southern California Edison could result in significant savings - perhaps as much as $100,000 each year. This is a significant order of magnitude when compared to the differences in the annualized costs of TC and MC service that are estimated in the next chapter.

E. ANNUALIZED COSTS

E.1 Annualized Capital Costs

Converting up front capital costs into annual costs in constant 1984 dollars requires the adoption of a real discount rate, i.e., the rate of discount net of the rate of inflation. The rate of inflation for the United States has averaged 3.5% over the past 30 years, 4.5% over the past 20 years, and 4% over the past three years. The constant 4% inflation rate is adopted over the entire 50-year horizon of this analysis.

The long run average real rate of interest, i.e., the market's discount rate, in the industrialized world is generally accepted to be 3%. Adding 4% inflation to this figure results in a nominal rate of 7%. This is the lowest discount rate used in this analysis.

The current (April 1985) nominal rate of interest on tax free bond issues is approximately 10%. Such bonds may be issued if backed by such local revenue sources as the Proposition A retail sales tax. This rate represents the current cost of money to local public entities. Coincidentally, it is also the rate at which UMTA discounts transit capital investments. Real interest rates are now at post-war high levels. If these bonds were callable, the long term nature of investments in TC capital would allow a lower rate of interest to be paid; callability would allow any debt to be refinanced in the event that inflation remains steady and the real rate of interest returns to its historical level.

The current nominal prime rate of interest now stands at 12%. This is the rate paid by low risk private borrowers. As such, it measures the opportunity cost of money to the economy as a whole. This rate is adopted as the highest of the three discount rate scenarios used in this analysis.

The "correct" rate of discount is that rate which equals the opportunity cost of money for the District. Were capital financed out of cash reserves, the interest earned by such reserves would be the appropriate rate. Were capital financed by postponing investment in other capital projects, the internal rate of return on those projects would be the appropriate rate. If bonds are issued, the yield on such bonds should be used. The 7 to 12% range adopted here is wide enough to include these rates.

TABLE E-1

Sinking Fund Ratios

Asset	Useful Life (Years)	Nominal Discount Rate		
		7%	10%	12%
Diesel Bus	12	0.10046	0.11928	0.13269
Trolley Coach	25	0.05743	0.07823	0.09368
Tangent Wire Special Work Traffic Signals Power Stations Other Equipment	30	0.05102	0.07263	0.08883
Poles Spans Brackets Cement Work	50	0.03887	0.06344	0.08174

Table E-1 lists the sinking fund ratio for each interest rate at each term for useful life adopted in this study. These ratios represent the number of constant 1984 dollars that must be spent each year for each dollar's worth of capital purchased now over the useful life of the capital asset. In this manner, capital expenditures stop when the asset is retired from service. The discount rates in Table E-1 are adjusted for 4% inflation prior to calculating the sinking fund ratio. The annualized costs of capital assets for both MC and TC systems systems are listed in Table E-2. These assets are itemized by equipment type, useful life, and (where applicable) route segment. Capital costs are collected from from previous tables in this appendix. Annualized costs are calculated from the sinking fund ratios listed in Table E-2.

E.2 Annualized Marginal Costs

Operating costs have already been derived for MC and TC systems as annual expense expressed in constant 1984 dollars. Combining these expenses with those computed in E.1 for capital costs yields the marginal annualized cost of operating MCs versus TCs on Line 204. Table E-3 computes these values for MC service. Table E-4 computes these values for TC service.

TABLE E-2

Annualized Costs of Capital Assets
(thousands of constant 1984 dollars)

	Useful Life (Years)	Capital Cost	Annualized Cost Nominal Discount Rate		
			7%	10%	12%
VEHICLES:					
Diesel Coaches (51)	12	$ 8,721	$876	$1,040	$1,157
Trolley Coaches (51)	25	11,577	665	906	1,085
REVENUE ROUTE:					
Poles, Spans, Brackets & Cement Work	50	$ 5,254	$204	$ 334	$ 429
Tangent Wire, Special Work & Signals	30	1,180	61	86	105
Power Stations	30	3,450	175	250	306
DEADHEAD ROUTE:					
Poles, Spans, Brackets & Utility Relocation	50	$ 793	$ 31	$ 50	$ 65
Tangent Wire & Special Work	30	181	9	13	16
Power Stations	30	288	15	21	26
DIVISION 5 CONVERSION:					
Poles, Spans & Brackets	50	$ 256	$10	$ 16	$ 21
Tangent Wire & Special Work	30	225	11	16	20
Power Stations	30	288	15	21	26
Other Equipment	30	490	25	36	40

TABLE E-3

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

	Nominal Discount Rate		
Item	7%	10%	12%
Vehicle Acquisition	$ 876	$1,040	$1,157
Fuel & Lubricants	642	642	642
Vehicle Maintenance	2,608	2,608	2,608
Revenue Operation	4,618	4,618	4,618
Totals	$8,744	$8,908	$9,025

TABLE E-4

Annualized Costs of Trolley Coach Service on Line 204
(thousands of constant 1984 dollars)

Item	Nominal Discount Rate 7%	 10%	 12%
CAPITAL COSTS:			
Vehicle Acquisition	$ 665	$ 906	$1,085
Overhead Wiring	326	515	656
Power Supply Equipment	205	292	359
Other Capital Equipment	25	36	40
Total Annual Capital Costs	$1,221	$1,749	$2,139
OPERATING COSTS:			
Energy	$ 376	$ 376	$ 376
Vehicle Maintenance	2,007	2,007	2,007
Revenue Operations	4,618	4,618	4,618
Overhead & Power Maintenance	347	347	347
Total Annual Operating Costs	$7,348	$7,348	$7,348
TOTAL ANNUAL SYSTEM COST	$8,569	$9,097	$9,487

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