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Cost Components for Selected Public Transportation Modes in the San Francisco Bay Area

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FOREWORD

The work presented in this report was undertaken as part of a research project on the Comparative Costs of Urban Transportation Modes, using the San Francisco Bay Area as a case study. Funding was provided by a grant from the National Science Foundation under the RANN (Research Applied to National Needs) program.

The data and many of the calculations presented here draw upon reports prepared by James Blachman, David Goldstein, David Minister, Randall Pozdena, and Philip Viton, who are Research Assistants on the project. An earlier draft was assiduously reviewed by the above and also Donald Clemons, as well as the two Co-Principal Investigators -- Theodore Keeler of the Department of Economics and Leonard Merewitz of the School of Business Administration. Helpful critical reaction was also gained from the Committee on Urban Economics. Hence the report represents the efforts of the group, in those areas covered. Results pertaining to automobile transportation, a private commuter railroad, taxicabs, ferryboats, demand-actuated bus, and other scheduled urban bus service have been obtained in preliminary form, and will be incorporated into subsequent reports.

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I. INTRODUCTION

A great deal of attention has been paid to the demand side of urban transportation -- particularly the modal choice decision -- and both theory and empirical evidence have made clear advances in the last decade. The supply side has been fashionable when new technologies were being considered, but not much effort has been spent on understanding the day-to-day operations of existing transportation modes and systems.[1] If the costs of urban transportation were self-evident and well known, this lack of interest might be excused; in fact, the costs are largely unknown and of considerable complexity, both conceptually and empirically.

Yet the time is ripe for introducing cost information into policy formulation. Multi-modal transportation planning may actually be undertaken soon in some metropolitan areas, and the recognition is coming, reluctantly, that pricing has been and is a major de facto instrument of public policy. Cost-based pricing allows revealed demand to be interpreted as signalling (or not signalling) the need for additional investment in specific alternative modes, reducing the need for elaborate

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[1] The three major works in the area are John Meyer, John Kain, and Martin Wohl, The Urban Transportation Problem (Cambridge: Harvard University Press, 1965); John D. Wells, et. al., Economic Characteristics of the Urban Public Transportation Industry (Washington: U.S. Government Printing Office, February 1972 and U.S. Government Printing Office, "Urban Commutation Alternatives," U.S. Congress, Joint Economic Committee, Subcommittee on Economy in Government, Analysis and Evaluation of Public Expenditures: The PPB System, Vol. 2 (1969), pp. 698-733. Meyer, Kain and Wohl state, "Perhaps no aspect of urban transportation planning has been talked about so often but examined so poorly as the cost of providing comparable urban transport services by different kinds of technologies." (p. 171). Each of the three works contains chapters devoted to empirical estimates of urban transportation mode costs on a comparable basis.

long-run demand forecasting. Thus the absence of comparable cost information is a serious handicap to improving public policy towards urban transportation.

The strategy chosen in the work presented below was to depend heavily on a detailed analysis of the experience of existing operating agencies, reconstructing their accounts to reflect the desired cost concepts. A case study laboratory was provided by the San Francisco Bay Area, which contains a rich mixture of agencies, modes, organizational structures, and operating environments for making cost comparisons. Only a portion of this wealth of information has been studied so far, but there seems to be little difficulty in generalizing this case study approach to other contexts. Further work will test the frameworks and parameters developed in the analysis already accomplished.

A major deficiency in making intermodal cost comparisons is the absence of a comprehensive accounting framework. Because of the varying organizational forms for production and the mixtures of private and public activity in different modes, the same costs appear in different accounts in different modes. Private railroads pay full right-of-way costs including property taxes, while Bay Area Rapid Transit (BART) District accounts reflect right-of-way only, automobiles cover these costs partially at best, and highway transit agency accounts show almost nothing for right-of-way. Many other examples can be cited. Considerable effort has been directed at developing a consistent accounting framework for empirical cost estimation, but the structure used below is still likely to be an evolutionary form that will soon be modified.

In constructing the cost framework, the overall viewpoint was that of measuring social costs, i.e., the full opportunity costs to society of providing a given level of service in a given mode. This means that capital was usually revalued in present dollars rather than using historical expenditures, discount rates were not the same as actual interest rates paid, and attempts were made to identify and measure hidden costs and negative externalities. While varying degrees of success have been met with in this endeavor, the framework at least incorporates these cost elements.

II. COST COMPONENTS FOR SELECTED MODES

Estimates for a set of cost categories for the diesel motor coach, streetcar, trolley, cable car, and rapid transit modes are presented in Table 1. The figures are in 1972 dollars, and are based on actual operating experience of several agencies in the Bay Area. Additional modes -- as well as other agencies operating the same modes -- exist in the Bay Area, and many of these will be added later.

Three primary cost categories have been used: (1) operating expenses, not including maintenance; (2) maintenance; and (3) capital costs. Maintenance costs are commonly regarded as an operating expense, but because there are a number of tradeoffs between capital costs and maintenance it may be preferrable to analyze these last two costs in conjunction with each other. In any case, the three major categories can be separated fairly easily and analyzed independently.

Capital and maintenance costs are further subdivided into (a) rolling stock and other equipment, and (b) right-of-way and structures. Bus company operations do not include any outlays for public right-of-way acquisition and maintenance, so these costs must be estimated separately and added in. At this stage, estimates for the share of right-of-way cost assigned to buses and other transit vehicles are illustrative only, since they are of a much lower order of reliability than the other costs. External costs can be added in at the end, which permits their inclusion on whatever functional bases other than vehicle hours that can be established.

TABLE 1

Cost Components for Urban Public Transit Modes in the San Francisco Bay Area, 1971-72
(dollars per vehicle hour)

Agency[f] Mode	AC Transit Motor Coach	Muni Motor Coach	Muni Trolley	Muni Streetcar	Muni Cable Car	BARTD Rail Rapid[d]
1. OPERATING EXPENSES	10.98	13.26	13.08	14.11	30.02	31.09
Conducting Transportation	9.35	10.64	10.57	10.90	20.89	1.84[g]
Platform personnel }	8.11	6.70	6.79	6.88	14.49	
Supervisory }		1.17	.96	1.25	.51	
Other labor }		.14	.20	.07	.70	
Fringe	1.24	2.63	2.62	2.70	5.18	
Station expenses	(a)					7.18
Power	.36	.51	.48	.62	2.92	3.51
Accidents	.37	1.11	1.04	1.59	4.41	
Overhead	.90	1.00	.99	1.00	1.80	18.56
Administration	.50	.45	.45	.45	.84	
Fringe	.08	.15	.15	.15	.28	
Other	.32	.40	.39	.40	.68	
2. MAINTENANCE	3.20	4.16	3.63	5.11	12.57	22.61
Rolling Stock	2.12	2.74	2.20	3.23	7.06	9.60
Cleaning }	1.22	.83	.90	.37	1.75	
Other labor }		.70	.43	1.18	2.03	
Fringe	.19	.50	.44	.51	1.25	
Materials	.71	.71	.43	1.18	2.03	
Support Equipment	(c)	(c)	(c)	(c)	(c)	9.59
Way and Structures	1.08	1.42	1.43	1.88	5.51	3.42
[Right-of-Way][b]	[1.00]	[1.25]	[1.25]	[.50]	[.50]	
Structures	.08	.17	.18	1.38	5.01	
3. CAPITAL[e]	3.04	4.29	5.19	18.96	13.29	146.08
Rolling Stock	1.80	2.82	2.68	6.33	1.65	10.00
Way and Structures	1.24	1.47	2.51	12.63	11.64	136.08
[Right-of-Way][b]	[1.00]	[1.00]	[1.00]	[1.00]	[1.25]	20.41
Structures	.24	.47	1.51	11.63	10.39	115.67
TOTAL	17.22	21.71	21.90	38.18	55.88	199.78
operating speed (mph)	14.5	9.93	8.11	10.13	4.30	40.00
cost per vehicle mile ($)	1.19	2.19	2.70	3.77	12.99	4.99
seat capacity	48	48	48	55	30	72
cost per seat mile (¢)	2.5	4.5	5.6	6.8	43.3	6.9

NOTES: (a) AC operates a large terminal in San Francisco, but the expenses are subsumed into other categories.

(b) Expenses enclosed in brackets are not borne by the operating agency at the head of the column, and are only roughly estimated (with the exception of BART).

(c) BART support equipment includes communications and train control systems; to the extent these exist for other modes, they are subsumed into the rolling stock account.

(d) BART costs are based on partial operation, and have been extrapolated statistically to 25 million car miles, which results in an average of 100,000 miles and 2500 hours annually per car. Four-car trains are assumed.

(e) All capital costs are annualized using a discount rate of 6% and the relevant asset lifetime.

(f) The agencies are, respectively, the Alameda-Contra Costa Transit District, the San Francisco Municipal Railway, and the Bay Area Rapid Transit District.

(g) Train attendants only.

Operating Expenses. Two types of costs are included in the operating cost category: costs which are in some way fairly directly related to the provision of transit service, whether by the hour or by the mile; and general overhead and administration costs. The former type includes platform personnel, supervisory and support personnel, fringe benefits for operating personnel, power or fuel costs, and accident costs. The remaining general overhead costs include administration personnel and supplies.

Fringe benefits cover pension funds, social security, sick leave, workmen's compensation, and other mandatory fringe benefits. These costs are usually reported as totals for the agency, rather than by functional category, so they were allocated to categories as a uniform percentage of labor costs. For wage earners, this procedure is probably quite reliable, but administrative personnel (e.g., managers, clerical) may receive distinctly different fringe benefit rates. In many of the agency accounts, labor is not separated from materials in the maintenance categories; these were split arbitrarily at 50% each, which generally agreed with the actual distribution where the data were available.

Accident costs presented some problems. The San Francisco Municipal Railway (MUNI) pays off claims when it gets the money to do so, not when the claims are due; as of the last budget, there were over $5 million in outstanding claims. From looking at a fifteen-year history of accident claims, the ratio of actual claims to budgeted amount is roughly 1.4, and this figure was used to generate the 1.11 in the table. Alameda-Contra Costa Transit (AC) also self-insures, but has a stable rate and pays its claims. Accident costs for BART are not known; several accidents have already occurred, but the long run rate is harder to estimate.

Diesel fuel represents little more than 2% of the total costs. Unlike auto or air travel, fuel costs are an almost negligible component of bus service provision, and total costs are not sensitive to large changes in the price of fuel. Electric power forms a similar share of costs for those modes using it. Fuel or power costs for transit modes averages less than one tenth of a cent per seat mile.

Maintenance. Equipment maintenance includes cleaning and washing, repair of passenger compartments and bodies, motors, shop and tool expenses, accident repairs, chassis, tires, brakes, transmission, etc. Way and structures includes rails, roadways, storage yards and garages, offices, fences, signs, and others. No particular item stands out as dominant, but the figure for maintenance of the City streets is unknown and may be understated. BART costs were estimated statistically from monthly operating data of approximately one year's duration, while the other transit costs were derived from annual reports from the agencies.

Capital Cost of Way and Structures. The replacement value of the various offices, shops, garages, yards, and other real property was estimated from agency accounts. Capital cost of street right-of-way is a separate problem and is dealt with elsewhere; for our purposes, a plausible number was assumed, until more definitive information becomes available. Again, the real opportunity costs of the streets system may be understated. For BART, these costs were incurred recently and are visible in the District's records.

Vehicle Capital Costs. Entries in agency accounts for depreciation usually bear no relation to the economic cost of investment in rolling stock and equipment. Capital recovery factors were applied to estimated replacement cost values, using actual agency experience with vehicle lifetimes, and this annual sum allocated over actual vehicle hours per vehicle. This method assumes either that the quality of service is constant over the life of the vehicle (clearly not true) or that the distribution of vehicle age within the fleet remains constant over time and between agencies (partially true). A discount rate of 6% was used.

Implied Assumptions. Presumably such characteristics as speed and annual vehicle hours per vehicle are not set by management, but are a consequence of conditions in the operating environment. Although the number of vehicle hours operated seems consistent from year to year and from one bus company to another, it is possible that if peaking characteristics were considerably different this difference would be reflected in annual vehicle utilization. On the other hand, it may be that peaking has no effect on vehicle utilization. Our calculations assume these conditions remain constant, and we have little way of knowing whether they would change other parameters a great deal or only a small amount.

Other implied parameters related to such conditions as type of surface and terrain covered, the amount of congestion, union work rules or other hiring and firing procedures imposed upon or negotiated by the agency, climate, etc. Some of these factors differ greatly between agencies observed, and may be causal factors that explain some of the differences observed; other factors are either irrelevant or are similar among the agencies observed, and the effects cannot or have not been determined.

III. CASE STUDY COMPARISONS: MODES AND PROPERTIES

The analysis so far includes three transit properties (San Francisco Municipal Railway, Alameda-Contra Costa Transit District, and the Bay Area Rapid Transit District) which run five modes (motor coach, trolley, streetcar, cable car, and rail rapid). Although these modes and properties do not constitute a comprehensive set of examples, sifting data from them into a consistent accounting framework does permit some interesting comparisons to be made.

Motor Coaches. Two of the agencies run standard diesel buses, or motor coaches, the basic vehicle in the industry. Muni operates in the City and County of San Francisco, over hilly terrain and often narrow and congested streets; AC Transit provides service over a large area in two Eastbay counties. A comparison between the two properties is particularly interesting because they are thought to represent opposite ends of the scale on a number of attributes. Muni carries out maintenance more or less as the need appears -- often as a result of breakdowns -- while AC adheres to a schedule of preventive maintenance. AC's service is "professional" while Muni's is colorful, erratic, or shoddy, depending on one's viewpoint. AC management is "modern" but Muni's is "archaic." While many of these characteristics refer to quality of service, differences between the agencies are illustrated by the overall indicators shown in Table 2.

TABLE 2

SELECTED PERFORMANCE CHARACTERISTICS FOR MUNI AND AC TRANSIT

	industry[a] median	Muni	AC
operating speed	12.0 mph	9.93	14.5
percentile[b]	50	24	98
passengers/vehicle hour	29.9	40.4	28.2
percentile	50	87	46
annual miles/vehicle	29,500	24,000	36,000
percentile	50	35	90

[a] As reported in Wells. et. al., from a sample of roughly 50 properties in the U.S. and Canada.

[b] Percentage of firms with values equal to or less than the specified value.

Total costs differ between the two agencies by \$4.49 per vehicle hour, but the significant differences between the two are concentrated into a few key parameters. Base wage rates for drivers are adjusted almost every year, and are currently \$5.54 for Muni and \$5.22 for AC; in 1972, however, they were both paying \$4.93 per hour. For a number of reasons, one pay hour is less than one vehicle hour: drivers earn overtime, and work rules may require drivers to be paid even though there is no need for vehicles to be operated. For Muni, these costs are 34% of base pay per vehicle hour.

In addition, there are supervisors and other personnel involved in conducting transportation (not including administration). The ratio of wages per vehicle hour for conducting transportation to base wage is 1.62 for Muni and 1.64 for AC. Factors influencing this ratio include work rules, peaking characteristics, scheduling efficiency, driver behavior, management style, etc., and hence it is some surprise that the two properties are so similar in this respect.

Administration and maintenance labor is another component that needs to be added. For Muni, this amounts to 25% of the cost of platform and related personnel, and for AC it is 21%. Since maintenance is at least as much a function of vehicle hours as anything else, and administration is related to the number of employees, using a multiplier relationship based on vehicle hours seems plausible.

Finally, there are fringe benefits paid on top of wages. For Muni, fringe benefits appear to be 33% of base wage, while for AC it is 15%. This adds \$3.32 per vehicle hour to Muni's costs and \$1.52 to AC's, and explains \$1.80 of the hourly cost difference between the two agencies. Base labor for Muni is \$10.11 versus AC's \$9.90 -- not a great deal of difference --

and fringe benefits bring the total labor bill to $13.43 and $11.42, respectively; labor is then 62% of Muni's total and 65% of AC's.

Non-labor costs include materials and supplies, accidents, and capital costs. Materials -- ranging from paper clips to spare parts and tires -- accounted for $1.63 per vehicle hour on Muni's books and $1.40 for AC, and again the costs are fairly similar. A difference appears in accidents, where the $1.11 for Muni is $.74 higher than AC's accident costs per vehicle hour. The cause of this difference may be attributable to the characteristics of the operating environment, the equipment, or the drivers.

Capital cost differences center on vehicle lifetime, which is fifteen years for AC and eight for Muni and leads to $1.02 per vehicle hour more for Muni. Vehicle utilization (annual vehicle hours per vehicle), way and structures costs, and equipment purchase prices appear to be similar for the two agencies. Adding up the three significant factors -- fringe benefits, accidents, and vehicle life -- results in $3.56 and covers the bulk of the cost difference between the two agencies. When the hourly cost is converted into vehicle mile costs, AC's higher speeds exaggerate the cost differential to a factor of almost two.

Missing ingredients in this picture are external costs (noise and air pollution, and congestion) and way and structures costs. The environmental costs do not appear to be great on a seat mile basis, but this does not mean they can be ignored; it may easily be worth the price to buy quiet, non-polluting buses. Congestion has not yet been treated as a cost, in our accounts, and there are some conceptual issues yet to be resolved. Right-of-way capital and maintenance figures depend first upon estimating the value of land, paving, etc., residing in the highway and street system, and then allocating those costs to the various users. At the moment, this work is in progress. Capital costs of structures used for storage yards and maintenance shops has been included in the estimates, but they are small on a vehicle hour basis.

Electric and Mechanical Vehicles. San Francisco also provides an unusual opportunity to compare conventional motor transit with electrically-powered equipment, since this City is one of the few places in the US that still operates trolleys (trackless trolley buses) and streetcars. For convenience and an additional comparison, the cable car has been included.

On operating costs, the trolley and the streetcar do not differ greatly from the motor coach; the cable car is roughly double the others by virtue of its need for two operating personnel -- a gripman and a brakeman-conductor. The cable car also has a considerably higher accident rate, even on an hourly basis.

Maintenance costs differ more systematically between the three. While the trolley requires maintenance of overhead wires as part of its operation, the simplicity of the motors results in net savings over the diesel coach. The streetcar has both overhead wires and tracks to maintain, as well as tunnels and other sections of exclusive right-of-way, so its costs are slightly higher than the diesel. The cable car has the most extensive and most costly power and track system to maintain, but some of these costs are in reality a gradual replacement of capital.

Capital costs are more uncertain, since no electric equipment has been produced in over twenty years. San Francisco's trolleys and streetcars were built between 1946 and 1952, and cost $20,000 and $70,000 each, respectively. At an average inflation of 4% per year these prices would be approximately $47,000 and $166,000 in 1972. In actuality, costs of this type of equipment have been increasing at a rate of around 7% per year: New York purchased some rail transit cars for $120,000 in 1961, and San Francisco and Boston have joined together to purchase new 68-seat articulated streetcars at a cost of $325,000 each. From these data, current prices for trolleys are estimated at $75,000 and streetcars at $260,000.

Used equipment seems to come cheaper than new by a large margin. San Francisco bought a number of streetcars from Toronto and is refurbishing them, for a total cost of about $10,000 each. Even if these last only five years (until the new ones are operating) the annual cost is much less than for comparable new equipment.

Rail Rapid Transit. One of the unique features of BART as a subject of cost analysis is the fact that it was produced from scratch in recent times, which means that there is much less ambiguity about what constitutes full costs. Also, since the right-of-way is not shared, there is no problem with joint products. Fortunately, there are also few negative externalities; air pollution from power generation is estimated at less than .1¢ per car mile, and noise and visual pollution are at least no worse than other modes. Disruption of commercial activities has been substantial in some locations, but this can be added as a capital cost.

Costs were categorized into homogeneous groupings and estimated statistically from monthly operating data, where applicable. A problem here is to separate our start-up or learning costs from long run operating costs, and extrapolate these to what they would be under full operation. Our estimates are based on a little more than one year's experience with partial operation in the East Bay, which excludes the trans-bay tube and the San Francisco-Daly City line.

Since 68% of the total costs are in the annualized opportunity costs of way and structures, these loom an order of magnitude larger than any other component. Removing way and structure costs leaves $63.70 per vehicle hour in operating, maintenance, and capital costs of rolling stock, which is comparable with a bus or streetcar both in terms of amount and in that these latter modes pay little or nothing for the way and structures they use.

It makes some sense, then, to concentrate attention on the capital cost of way and structures for a moment.[2] Roughly twenty-five percent of BART's tracks are underground or underwater, which greatly increases construction costs but eliminates right-of-way costs on some of the highest priced land. The remaining trackage is mostly on aerial structures -- some of which are in or near the median strips of freeways -- or else at grade. Where BART is not integrated with a freeway it often parallels or uses an existing railroad right-of-way, all of which means that not much demolition was required and BART right-of-way is relatively cheap for urban land.

In theory, a higher capital cost allows the system to have either lower operating costs or lower unit costs because of increased capacity. Seat mile costs reflect the latter idea of scale economies, but the trade-off between capital and operating costs has not been investigated. Table 3 shows the distribution of costs per vehicle hour over the three major categories, for several modes. Both the streetcar and BART are heavy on the capital cost end, and also appear to be high cost modes (without

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[2]Overhead is the other category that stands out as large, and perhaps the management costs deserve some scrutiny. BART labor costs have also increased since these data, as a result of a strike settlement in the Summer of 1973.

TABLE 3

COMPARISON OF COST DISTRIBUTIONS

	AC Bus	Muni Bus	Trolley	Street-car	Cable car	BART
$/vehicle hour	17.22	21.71	21.90	38.18	55.88	199.78
cost distribution						
operating	64%	61%	60%	37%	54%	16%
maintenance	18	19	17	13	22	11
capital	18	20	24	50	24	73
way and structures						
$/vehicle hour (capital cost)	1.24	1.47	2.51	12.63	11.64	136.08
cost distribution without way and structures						
operating	69%	65%	67%	55%	68%	49%
maintenance	20	21	19	20	28	35
capital	11	14	14	25	4	16

considering cost per seat or per passenger); if we remove, however, the allowance for the capital cost of way and structures, the distributions change. Streetcars and BART still are towards the high capital cost side, but much less out of line with the others. No pattern of substitution between capital and maintenance is discernible from these data. The cable car is non-conforming for two reasons: it requires two operating personnel per vehicle, and a sizable share of the capital costs are disguised as maintenance.

The hypothesis suggested by the foregoing is that way and structure costs may be the dominant ones for <u>all</u> urban transportation modes, and BART is simply the only clear observation available. If this is the case, then the normal farebox revenues and operating costs that are typically considered are relatively trivial with respect to guiding investment.

<u>Performance Comparisons</u>. Rather surprisingly, no mode or set of modes dominates the others, and no mode comes out uniformly badly. Another set of comparisons is given in Table 4. AC buses look good on a vehicle hour basis and even better on a vehicle mile comparison, but they simply have to go farther between passengers. The trolley, which is so-so on costs and low on speed, manages to achieve a high enough utilization to achieve the lowest trip cost; presumably the trolley routes are high density lines. The streetcar, with higher capacity and somewhat higher speeds, nonetheless carries a high capital burden and fails to achieve a favorable utilization. Muni's streetcars have the worst of all possible worlds -- a high capital cost associated with an exclusive right-of-way and the slow speeds resulting from congestion in a shared right-of-way. Strangest of all, the cost per vehicle mile for the cable car is over ten times that of AC's buses, yet the costs per passenger are roughly the

TABLE 4

ACTUAL PERFORMANCE INDICATORS

	$/ Veh Mi	Revenue Pass./Veh Mi	$/rev.pass. (trip)
AC Bus	1.23	1.92	$ .64
Muni Bus	2.31	4.07	.57
Trolley	2.67	5.50	.48
Streetcar	3.74	5.28	.71
BART	4.69	2.00[a]	2.34
Cable car	12.79	16.99	.75

[a] estimated

same -- due apparently to high utilization of the cable cars for short trips. BART's problem seems to be one of achieving a high enough utilization of its exclusive right-of-way to be able to justify its costs.

A great deal of caution must be exercised in making comparisons between modes, even if it is long run average costs that are of interest. Trip length obviously various between modes -- from a low on the cable car to an estimated 11 miles on BART -- and a person-trip may be composed of several modal links. Clearly, different modes serve different functions. Another variation that has not been entered so far is differences in quality of service. Estimates of costs per vehicle mile implicitly assume that one vehicle mile represents a homogeneous uniform product, while in fact a BART seat is much more spacious and comfortable than a seat on one of Muni's trolleys. Reliability, safety, general availability of service, etc., have also been ignored. Future work will improve on this situation.

IV. CONSTRUCTING COSTS

With budget data from a single agency, we could break the costs down into variables and parameters that would allow the total costs for that agency to be reconstructed from the pieces. The structure of this breakdown would be almost entirely arbitrary -- with respect to the data -- and hence the structure would depend upon available theory and other guidelines. If comparable data for the same agency were available over time, then the account structure would have more internal consistency, but unique characteristics of the particular agency would not emerge as such.

Having two agencies gives us a new dimension of information; a structure that fits two different operating situations has considerably more validity. Utilizing more agencies provides more information, leading eventually to statistical cross-sectional cost functions. Since we have several agencies to work with, we can consider what characteristics we would like a general cost function to have and attempt to construct such a function. Two characteristics appear important:

(1) Consistency Under Varying Circumstances. A good cost function should work equally well under different output levels for the same firm and for different firms under similar output levels, as well as variations in both. This allows the function to be used to predict costs under conditions not directly observed, e.g., for planning purposes. The robustness of an hypothesized function can be tested by seeing how well it explains data for agencies not used to construct the function.

(2) Flexible Decomposition. Different levels of accuracy will be needed and different parameters will be critical for different purposes. A useful cost function would be one that could be broken down to the extent needed and in ways that would permit the function to be tailored to the specific question at hand (an alternative strategy would be to construct a completely disaggregated cost function that could be aggregated if desired).

Following these guidelines and using the data generated by analyzing the budgets of AC and Muni, we will construct -- piecemeal -- a cost function. The first form is simply,

$$\text{Total Cost} = \text{Cost/mile} \times \text{Total miles}$$

which introduces two issues. First, it assumes constant returns to scale over the relevant range, since the unit cost does not vary.[3] This is not as restrictive as it sounds, since unit costs will, in fact, be allowed to vary; in the long run, however, we are assuming that unit costs are not a function of mileage. The second issue is that total (vehicle) miles has been chosen because it is probably the easiest variable for the policy maker to estimate, not because it has theoretical or empirical content. A better basic output measure is vehicle hours, so

$$\text{Cost/mile} = \frac{\text{Cost/hour}}{\text{Miles/hour}}$$

which then focuses attention on the cost per hour.

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[3] According to Nelson in Wells, et. al., Economic Characteristics of the Urban Public Transportation Industry (Washington: US DOT, February 1972), "There do not appear to be economies or diseconomies of scale in bus transit. The major differences in unit costs that are observed between small and large operations are explained by differences in wage rates." (p. 4-3). Nelson bases his conclusions on an econometric model of roughly 45 firms at two points in time. Herbert Mohring, "Optimization and Scale Economies in Urban Bus Transportation," 62 (September 1972), pp. 591-604, has shown that certain kinds of scale economies exist if the value of the passengers time is taken into account.

From the budget data, we can hypothesize the structure and some of the parameters of a standard cost function. This will be done by major categories. An example of the results is shown in Table 5.

(1) Labor. The largest share of labor costs are in the form of drivers' wages, and the main component of this is the base pay rate. Fringe benefits, overtime, non-vehicle pay hours, supervisory, support, maintenance, and administration must be added on.

(a) Base wage rate: For Muni, wages and fringe are determined by the labor union, the Board of Supervisors, and the civil service commission. AC's labor contracts are handled directly between labor and management. Hence the base pay rate is a local factor subject to local conditions.

(b) Overtime and non-vehicle pay hours: Pay hours that do not go into vehicle hours depend upon a number of conditions that are either the same or average out between Muni and AC, since the factor for both is very close to 1.63. At some future time it may be worthwhile to separate excess driver time for supervisory time, since the two may be differentially affected by peaking characteristics.

(c) Administration and Maintenance: Factors for Muni and AC fall close to an average of 1.24, whether for functional reasons or by coincidence. The factor is applied to total driver and supervisory pay costs, not including fringe.

(d) Fringe benefits: A local factor similar to the base wage rate, fringe benefits are applied as a factor to total base labor costs.

(2) Materials and Supplies. Office supplies, spare parts, and all non-labor operating costs borne directly by the agencies are included in the category. It does not include, for example, materials used in

TABLE 5

SAMPLE COST CALCULATIONS

Cost category	Parameter	Standard Value	Local Values Muni	AC	
Labor	base wage		4.93	4.93	$/hr
	operating personnel factor	1.63			
	administration and maintenance factor	1.25			
	fringe benefits factor		1.33	1.15	
	(subtotal)		(13.36)	(11.55)	$/veh hr
Materials and Supplies		1.60/veh hr			
Accidents			1.11	.37	$/veh hr
Capital	discount rate	6%			
	asset value of vehicle	$42,000			
	vehicle life		8	15	yrs
	annual vehicle hours	2800			
	(subtotal)		(2.41)	(1.54)	$/veh hr
	structures	0			
	right-of-way	0			
TOTAL			18.48	15.06	$/veh hr
	average speed		10	15	mi/hr
			1.84	1.00	$/veh mi
	seats per vehicle	48	3.8	2.1	¢/seat mi

street repair, but it does include such items as tools, tickets, and schedules. A cost of $1.60 has been chosen as a compromise between Muni's $1.63 and AC's $1.40.

(3) Accidents. Costs of accidents and personnel claims differ enough between the two agencies to suggest that local influences affect this cost; congestion, drivers, vehicles, or other cause may be responsible, and efforts should be made to isolate these components. Both agencies self-insure, which requires for estimation purposes that actual costs to be smoothed over a period of a number of years.

(4) Capital Recovery Factor. On the capital side, the relationship used is

$$\text{Cost/vehicle hour} = \frac{\text{Asset Price} \times \text{Capital Recovery Factor}}{\text{Annual vehicle hours/vehicle}}$$

As described above, the capital recovery factor requires two parameters: an interest or discount rate, and an asset life. We have done our calculations using both 6% and 12% as discount rates, to cover a range of values, but those reported in the tables above are based on a 6% rate; hence they have a bias towards understating the capital cost. Vehicle lifetime varies considerably between agencies, but the range between Muni's 8 year life and AC's 15 probably covers a good part of the spectrum.

(5) Asset Price. Muni's 8 cylinder diesel motor coaches cost $39,000 each in 1969, are unacceptably noisy and are breaking down rapidly. For purposes of comparison, we have assumed a purchase price of $42,000 for a full-sized 48-seat motor coach, whoever buys it.

(6) Annual vehicle hours. Obviously, vehicle utilization is one of the most critical parameters in the entire cost structure, and summarizes a host of other factors. Annual vehicle hours is related to aggregate

demand, peaking characteristics of demand, service levels during peak and off-peak, and operating speeds, which in turn determine total fleet size and total hours operated. In the normal pattern, some buses in the fleet may be used as much as 6,000 hours per year (over 16 hours per day) and provide the basic overall service for the agency. At the other end, older equipment may make one round trip a day -- one way during each peak -- being stored at each end in much the same way a private auto is used for the journey to work.

(7) Way and Structures. Since the information available regarding capital and maintenance costs of way and structures is very sketchy, they have been ignored for purposes of comparison. Thus the network and related structures are assumed to exist and be in place, at no cost to the transit agencies. For long run calculations, these costs need to be entered more precisely, but they have been dropped in the illustrative computations shown in Table 5. Within a limited range of standard conditions, this methodology provides a rule-of-thumb accuracy in constructing vehicle hour costs in a specific situation. Total vehicle hours -- or vehicle miles and speed -- must be estimated separately to arrive at total costs.

V. THEORY AND CONCEPTS

A fundamental principle used in this study is that "cost" is a concept to be empirically estimated, rather than a set of data to be gathered. Variations in types of costs are a consequence of different cost concepts, not different acoounting procedures or data sources. The theoretical foundations of what constitute elements of costs and the operational definitions for empirical measurement are thus a central concern.

Marginal and Average Costs. At any given level of output, the incremental costs of providing one more unit of output are the marginal costs at that level of output. The concept is not symmetric, in that the avoidable costs of reducing output may not be the same as increasing by one unit, so the curves drawn in Figure 1 refer to expanding output only. Short run costs assume that at least one factor is fixed, while long run costs are constructed by allowing all costs to vary.

The first unresolvable problem is the measure of output. Many candidates can be proposed -- person trips, passenger miles, vehicle hours, seat miles, peak or maximum load point, etc. -- but no single measure is satisfactory for all purposes. Marginal cost, then, is first of all a function of the unit of output chosen; producing another seat mile may require different resources from producing another vehicle hour or another trip. At peak capacity, another passenger may require simply the time it takes to squeeze on one more standee, while another vehicle hour could be produced by reducing the number of vehicles out of service or racing one

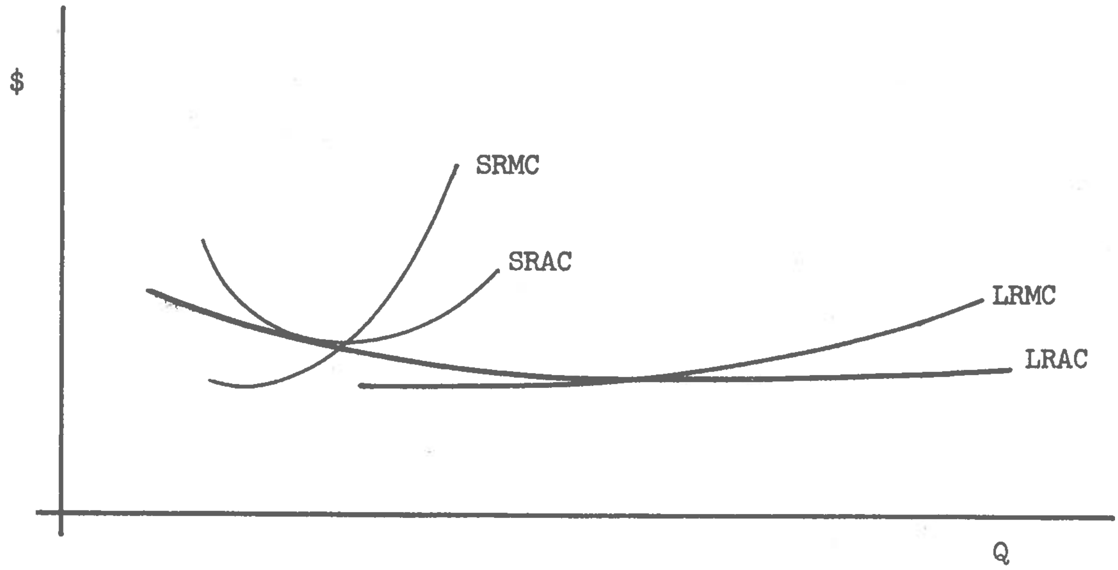

Figure 1. Short and Long Run Marginal and Average Costs

more bus back from the end of the line to make another peak direction trip. Ultimately, it might be cheaper in either case to purchase another bus and driver, and then the answer to marginal cost is simply whether the additional expenses are allocated to passenger trips or vehicle hours.

Marginal cost is also a function of what is considered to be the short run. A driver hired for the peak hour cannot be dismissed when the demand slackens, because his contract requires a certain number of contiguous hours in any work period; on the other hand, the place of a driver who fails to appear for work due to illness may or may not be replaced. Buses and cars can be sold in a matter of weeks once the decision to do so has been made, but getting rid of BART trains or highway bridges is unlikely to recover much of the initial investment. Over a period of decades the decision to replace structures can be regarded as a marginal or incremental cost, while at the same time the decision to retain right-of-way (which has an infinite asset life) incurs marginal opportunity costs of a much shorter run.

Another controversy related to marginal and average costs is whether economies or diseconomies of scale exist. Under constant returns to scale, long run marginal costs equal long run average costs; otherwise, they differ. The proposition underlying much of the work here is that long run costs operate under approximately constant returns, and short run costs may follow increasing or decreasing returns depending upon what factors are taken as fixed. Thus the estimates are for long run (continuation or expansion) costs, which can be rearranged to yield various versions of short run or marginal costs.

Decision Horizon. Considerations of marginal and average costs lead to a reorientation of cost definitions that is more suitable for policy purposes, by focusing on the time horizon of urban transportation decisions. Costs are defined as those costs which will be affected by a particular decision, i.e., costs are defined only in relation to a decision. From the information that is provided in our accounts, a wide range of decisions may be considered. For example, the decision to expand off-peak service should assume that the bus and driver are already paid for and deal only with costs of fuel, accidents, and vehicle maintenance. Maintaining a transit operation or a traffic control operation for another year must be based upon costs which include administration overhead. In general, the longer the decision horizon in time, the broader the scope of costs that are of interest.

Expenditures vs. Costs. The relationship between the dollars spent for something and the cost of that something is not necessarily a direct one, and the relationship between costs and items that appear as budget entries in the accounts of public agencies or private firms is even more obscure. The correct approach is to define the meaning of cost as applied to the particular context, and then seek information that can be used to make empirical estimates of the cost. A number of factors increase the difficulty of matching concepts with data:

(1) Prices. For a number of reasons, prices actually paid for inputs may not represent the correct value of those inputs. Political pressures or other market imperfections may distort the price from what would be optimal in the long run. Producers of transportation inputs may underprice in the short run in the hope of driving out competition and securing monopoly profits in the long run. Price and wage controls may create artificial prices and resulting black markets, shortages, and misallocations. Racial discrimination may allow some labor groups to be exploited at a lower-than-market wage, or labor may have an advantage or

disadvantage over management in bargaining. Short-sighted government policy may allow scarce resources to be wasted by underpricing.

To the extent that input prices are less than social costs and this underpricing is passed on to the consumer of the transportation service, an incentive is created to overuse modes which require relatively more of the underpriced inputs. Underpricing of gasoline encourages the overuse of automobiles, at the expense of less gasoline-intensive modes, and encourages the usage of large cars over small ones. The same is true if labor is underpriced: labor intensive modes are encouraged over capital intensive ones. In the past, wages in the transit industry were below social costs, but unionization has corrected that imbalance.

(2) Hidden Costs. Costs which appear in someone else's budget other than the nominally responsible agency are called hidden costs; non-market or external costs are treated below. An example of a hidden cost is the provision of power to the San Francisco Municipal Railway (Muni) by the Hetch-Hetchy Water utility at substantially less than costs. The actual costs include not only direct power but capital improvements in both power production and distribution (Hetch-Hetchy constructs and maintains the overhead wires for Muni, without charge). Hidden costs, of course, understate the true costs and tend (assuming that knowledge of these costs would make some difference) to encourage overconsumption and misallocation.

Another example of hidden costs are those borne by city agencies that are specifically for the benefit of users of a particular transportation mode, for which no compensation is paid. In an accident involving a Muni vehicle and a private vehicle, the City Attorney represents the Muni at the taxpayers expense while the lawyer representing the private party is paid through insurance premiums (unfortunately, the City Attorney usually loses, creating an offsetting and substantially larger bias). Traffic police are provided for the benefit of motor vehicles (pedestrians would not need traffic police if there were no vehicles), but paid out of the budget of the Police Department at the expense of the general taxpayer.

(3) Contributions to General Revenues. Aside from direct costs that can be assigned to a source, there are general overhead costs (e.g., basic education) that must be allocated on some equitable basis. One strategy would be to charge according to ability to pay (e.g., a progressive income tax for financing the "pure" portion of all public goods; another would be to charge everyone equally (a head tax). In practice, a complex multiplicity of instruments is used to collect revenues, and additionally complicated by redistributions, shifting, and intergovernmental transfers.

For transportation purposes, it is necessary to agree upon what constitutes the fair contribution for the sector and then allocate that total to users of the various modes. At present, there are some modes which withdraw from the general revenues (transit, automobiles) and others which contribute (railroads, through the property tax). The aggregate share paid by the transportation sector will affect the allocation between transportation and other goods -- the more paid by transportation the more costly it will become and the less of it will be consumed and hence demanded. Allocation between modes will be affected by how the aggregate share is distributed to modes. For this purpose, it does not matter what the total is so long as each mode carries its fair share.

The consequences for the measurement of costs are quite simple: either direct costs only should be estimated when comparing modes, or a consistent allocation of general costs should be assigned to each mode. It is thus incorrect to include property and other taxes as a cost for private transportation firms if there is no corresponding contribution from public agencies. In the accounts presented above, all sales, property, and other taxes have been removed, as well as bridge tolls.

(4) External Costs. If a transfer (income, utility) occurs between individuals in which the individuals cannot be uniquely identified and for which there is no market, the result is said to be an external cost or benefit (it does not involve a transfer of money). Air pollution from autos is a good example: users of automobiles generate pollution which is a disutility (reduces welfare, for health, aesthetic, or other reasons) for other persons whether they are users or not. Even if all air pollution were suffered only by persons generating it, the amount created would be greater than the socially desirable level because there is no market in which to set a price; hence, producers treat pollution as costless and ignore its effects, even though they may also suffer from the effects. If the externality is a benefit, then the lack of a market results in an underproduction of the benefit.

External costs are fairly easy to identify, but difficult to quantify. In transportation, air pollution, noise, fumes, congestion, excessively large vehicles for purposes of safety, the disruption of socially productive neighbors for right-of-way acquisition, and many others, can be regarded as external costs. The value of these costs to society are much harder to measure, but there are several approaches: (1) Estimate the aggregate damage caused by the externality (e.g., air pollution) and allocate it to those who generate it (e.g., through a gasoline tax); (2) Observe the revealed preference of individuals by comparing situations in which all characteristics are alike except for the externality and noting the difference in price paid (a quasi-market); and (3) Estimate what it would cost to neutralize the externality at its source. All of these methods have flaws, but they can be used to provide a good deal more information than is now available.

Non-market benefits are hard to even identify, let alone measure. A reasonable approach would be to include only costs and benefits for which a strong case can be made and ignore those whose existence is in doubt. Since few, if any, external benefits can be identified, this policy would mean emphasizing the internalization and correction of external costs. Benefits would fall where they might. The danger here is that if external benefits are systematically and positively associated with external costs, then a cost-oriented pricing approach would be perverse. The argument can be made, but the conclusion would have to be to ignore what is known because it might be more than offset by what is not known. It is unlikely that public policy will be enhanced by such purposeful myopia; rather, progress is made by advancing in those areas where the path seems fairly clear. New information is gained in the process, and new policies can be generated to respond to the information.

Unfortunately, many external benefits are often cited as justification for subsidies or ignoring hidden costs. Downtown merchants are willing to provide parking and other subsidies for motorists on the impression that it improves the value of their property. This line of reasoning does not justify a consumption distortion in favor of either transportation in general or the automobile mode in particular, unless it can be shown that general benefits accrue to property served by transportation that are greater than the benefits that would accrue if transportation were correctly priced to the user.

Historical, Avoidable, and Replacement Costs. Several approaches can be used for operationalizing theoretical cost concepts. Historical costs are those expenditures that were used to create the present facilities at some time in the past; avoidable costs are those that could be recovered by going out of business and selling the facilities to the highest bidder; replacement costs are those which would be required to produce the same output at current prices.

If historical costs cover all factors (no hidden or external costs) and the prices were determined in a properly functioning market that confronted buyers with the true opportunity costs of alternative uses foregone, then the prices paid for facilities in the past reflect the true current value of the replacement value of the resources as long as there is a correction for price changes. This caveat, while theoretically feasible, has several practical difficulties: (1) Each component of the system under consideration must be inflated according to the appropriate index, which must account for changes in quality as well as price; (2) Error in any index (relative to the component being inflated) will be compounded over time, making data for several decades ago limited in usefulness; (3) If components have to be disaggregated, the reaggregated inflated figures assume that the original input mix is still optimal when in fact it is likely to have shifted in response to technology changes, relative price changes, and changes in the size of the market (for streetcars, for example). Despite these shortcomings, historical costs can be used to provide one set of estimates of current replacement costs if astutely inflated.

Avoidable costs are those which could be recovered if the enterprise were to go out of business in the short run; this includes the required maintenance or other costs that could be dropped, plus the salvage value of any capital equipment. Avoidable costs can also be thought of as opportunity costs, meaning the value of the resources used in their next best application. If the decision at issue is one that involves the possibility of reducing output or capacity, then avoidable costs are the correct ones to use.

For buses, there is a reasonably good second-hand market, so salvage value and replacement cost are not all that far apart. In the case of streetcars, there is little possibility of receiving more for one than its scrap value. Yet another form of capital is in paving and structures, where the materials could not be sold for the cost of carrying them away, let alone dismantling or detaching them from the right-of-way. There is, however, a substantial opportunity cost in the land occupied by streets -- particularly in downtown areas -- and present pricing and costing procedures ignore this cost.

Finally, replacement costs reflect the current value of resources that would have to be given up in order to recreate the service in question. Note that the purpose is not necessarily to reproduce in every detail a piece of rolling stock built many years ago (unless, of course, the rolling stock is something like a cable car or a New Orleans streetcar and has historic or tourist value worth reproducing), but, rather, to produce the qualities of service that are relevant to the price charged. The cost of producing a 1952 St. Louis PCC streetcar from scratch would presumably be much greater than the price charged by Boeing to build a current equivalent using present technology, materials, design, etc.

If the decision concerns the possibility of expansion, then replacement costs are most likely to reflect the long run costs of maintaining or expanding capacity. Under conditions of smoothly functioning markets and marginal changes in outputs, historical, avoidable, and replacement costs will tend to converge; but for many components of the transportation system, the resources cannot be easily adapted to another use and hence have little or no salvage value. In fact, they may have a salvage cost that impedes reuse of other resources, as in the case of the Embarcadero freeway in San Francisco. It has been generally agreed publicly that the structure should not have been built, but the problem now is to obtain the additional resources necessary to remove it. The most generally applicable situation, however, is where long run continuation of the system or expansion is assumed, and replacement costs are the preferrable concept to use for decisions made against that background.

Vehicle Capital Costs. Although rolling stock might appear on the surface to be sunk capital for the purposes of most decisions, a bus may be a relatively liquid form of asset; more flexible than, say, a labor contract. Buses can be bought and sold on the used market quite readily, and the technology does not change a great deal from year to year, so that historical costs, opportunity costs, avoidable costs, and replacement costs tend to coincide. If the issue is to determine how rapidly to shut down a bus operation, then the buses can be liquidated in short order; otherwise, the long run average cost in constant dollars is probably the most appropriate cost estimate to use.

A 48-seat bus runs about $42,000; while half-size buses seem to cost less than half as much, they probably have shorter lifetimes. Selecting a discount rate and a lifetime (and a salvage value, if preferred), annual capital recovery factors can be generated and applied to whatever purchase price is contemplated. Table 6 shows the results for 6% and 12% discount rates and 8- and 15-year lifetimes.

TABLE 6

CAPITAL RECOVERY FACTORS

	6% discount rate factor[a]	6% discount rate amount[b]	12% discount rate factor	12% discount rate amount
8 year life	.161036	$ 6,763	.201303	$ 8,455
2400 hrs/yr[c]		2.82		3.52
2600		2.60		3.25
2800		2.41		3.02
15 year life	.102963	4,324	.146824	6,167
2400 hrs/yr		1.80		2.57
2600		1.66		2.37
2800		1.54		2.20

[a] capital recovery factor $= \frac{i}{(1+i)^n - 1} + i$, where i = discount rate and n = asset lifetime with no salvage value.

[b] annual payment over life of $42,000 asset.

[c] cost per vehicle hour, for given annual vehicle hours operated. (2400 hours/year = 6.6 hours/day; 2800 hours/year = 7.7 hours/day)

The next step is more difficult, since actual depreciation is a function of a large number of parameters, most of which are not directly related to output. Terrain, climate, congestion, hours operated, mileage, speed, number of passengers, maintenance, and driver training are a few of the conditions affecting wear on a bus. At the same time, it is seat miles or passenger miles that are of interest as performance measures, and they are largely unrelated to depreciation. The only resolution is to select a range of parameters that cover typical operating conditions and calculate unit costs on that basis.

(1) Discount Rate. The opportunity cost of resources tied up in one form as opposed to another is a subject of continuing debate; we have chosen 6% and 12% to represent the most likely range for numerical estimates.

(2) Lifetime. Muni operates its equipment over difficult terrain, under awkward conditions, uses no preventive maintenance, and writes a bus off in eight years; AC exercises preventive maintenance and can pamper its buses to a much greater extent, and so uses fifteen years as an average lifetime. These two cases represent our extremes.

(3) Vehicle Hours. Both Muni and AC have managed to achieve utilization levels of over 2800 hours per year per vehicle as an average for the fleet, in recent years. Currently, both average about 2400 hours per bus; this pattern seems to be suprisingly stable over time, although the trend at the moment is downward.

(4) Speed. Using vehicle hours as the basic performance measure allows mileage output to be calculated subsequently by applying an average speed. Muni runs roughly 10 miles per hour, overall, yielding a capital cost of rolling stock of $.28 per vehicle mile (6%, 2400 hours, and 8-yr. life). AC averages almost 15 miles per hour, yielding $.12 per vehicle

mile (2400 hours and a 15-yr. life). Hence the differences in costs between the two properties are largely a consequence of the combination of parameters used; production and cost functions may or may not be different for the two agencies. Capital cost calculations for some Bay Area rolling stock are given in Table 7.

Scale Economies. The existence of internal economies or economies of scale generally implies that there is some fixed factor which is being amortized over a larger and larger output, thus lowering unit costs with increased output. Three kinds of scale economies may be relevant to transportation: long-haul economies (greater distance implies lower cost per unit distance), large output economies (a higher volume of output reduces unit costs), and large capacity economies (more passengers on the system at the same time implies lower cost per person).

(1) Long Haul Economies. The fixed factor may operate in two ways to generate long distance economies: achieving the low unit costs may require a large capital investment to reach the optimal physical size, or the terminal costs may be very high relative to the line haul costs. The most efficient mode for long distance seems to be the airplane, which can reach costs of $.02 per seat mile flying coast to coast; both terminal and capital costs make the system inefficient for short hauls (forms such as V/STOL are being investigated for urban and metropolitan use, but these seem to be extremely high cost systems).

At some point the railroad may become cost competitive (although not necessarily time-competitive) with airline travel. Below that, the bus holds the cost advantage at $.03-.05 per seat mile. Thus each mode may enjoy increasing or constant returns to scale at various levels of output, but the envelope of those modes which are the least unit cost is a function with increasing returns. These considerations are generally

TABLE 7

REPRESENTATIVE VEHICLE CAPITAL COSTS

Vehicle type	(a) Seat Cap.	(b) Price	Expected Life	Capital Recovery Factors @ 6%	Capital Recovery Factors @ 12%	Annual Cost @ 6%	Annual Cost @ 12%	(c) Hourly Cost @2400	(c) Hourly Cost @2800	(d) Oper. Speed	(e) ¢/ Vmi	(f) ¢/ Shr	(g) ¢/ Smi
Taxi	4	3,500	3	.374110	.416349	1,309	1,457	.55	.47	30	1.6	11.7	.39
Small DAV	20	16,000	5	.237396	.277410	3,798	4,439	1.58	1.36	25	5.4	6.8	.27
Motor Coach	48	42,000	8	.161036	.201303	6,763	8,455	2.82	2.41	10	24.1	5.0	.50
			15	.102963	.146824	4,324	6,167	1.80	1.54	15	10.3	3.2	.21
Trolley	48	75,000	20	.087185	.133879	6,539	10,041	2.72	2.33	10	23.3	4.9	.49
Streetcar	55	10,000	5	.237396	.277410	2,374	2,774	.99	.85	12	7.1	1.5	.13
		260,000	25	.078227	.127500	20,339	33,150	8.47	7.26	12	60.5	13.2	1.10
		325,000	25	"	"	25,424	41,437	10.59	9.08	15	60.5	13.3	.89
BART car	72	320,000	25	"	"	25,033	40,800	10.43	8.94	40	22.3	12.4	.31
Cable car	30	75,000	50	.063444	.120417	4,758	9,031	1.98	1.70	4	42.5	4.7	1.41

(a) Seating capacity.
(b) Price in 1972 dollars.
(c) Cost per hour assuming 2400 or 2800 vehicle hours per year, 6% discount rate.
(d) Average operating speed, in miles per hour.
(e) Cents per vehicle mile, @ 6% and 2800 hours.
(f) Cents per seat hour, " " .
(g) Cents per seat mile, " " .

relevant to intercity travel rather than urban, since distances within urban areas are not great enough to take advantage of long-haul economies.

(2) Large Output Economies. The most conventional concept of internal economy, large scale economies depend upon the size of the firm to reduce unit costs. In transit, economies might be achieved by centralizing maintenance or administration in specialized facilities, utilizing a unified fare structure with common equipment and transfers, and increasing the size of the network served. With the information presently available, it is hard to perceive the amount that would be gained from maximizing firm size by consolidating properties, although the gains might be large.

(3) Capacity Economies. More significant for urban transportation, increases in capacity may permit lower unit costs if the volume of travel can be aggregated on a large enough scale. Normally the scale economies are achieved through large investment in right-of-way, structures, and rolling stock. Operating costs are then similar per vehicle mile to operating costs of smaller capacity systems, but the larger system has the potential for spreading the costs over a much larger patronage. Whether enough additional passengers to eventually justify the difference in capital costs can be obtained depends upon the level of demand that can be generated for the larger system.

A simple way of looking at this problem is to determine cost per vehicle mile and then derive unit costs per person by dividing by passengers per vehicle. Formally,

(cost/passenger mile) = (cost/vehicle mile)/(passengers/vehicle)

For a given mode, the cost per vehicle mile is known or assumed, leaving cost per passenger mile as a function of passengers per vehicle mile. This function is linearized by taking logarithms of both sides, which means that it plots as a straight line on log-log graph paper. This has been done for several modes and alternatives in Figure 2. The intercept on the vertical azis is the vehicle mile cost (or cost per passenger for one passenger) and the slope is always minus one. For each mode, the maximum capacity per vehicle is marked, giving a minimum lower bound unit cost figure; various projected patronage or utilization rates are also indicated. The plots allow for easy comparison of break-even utilization rates for different pairs of modes.

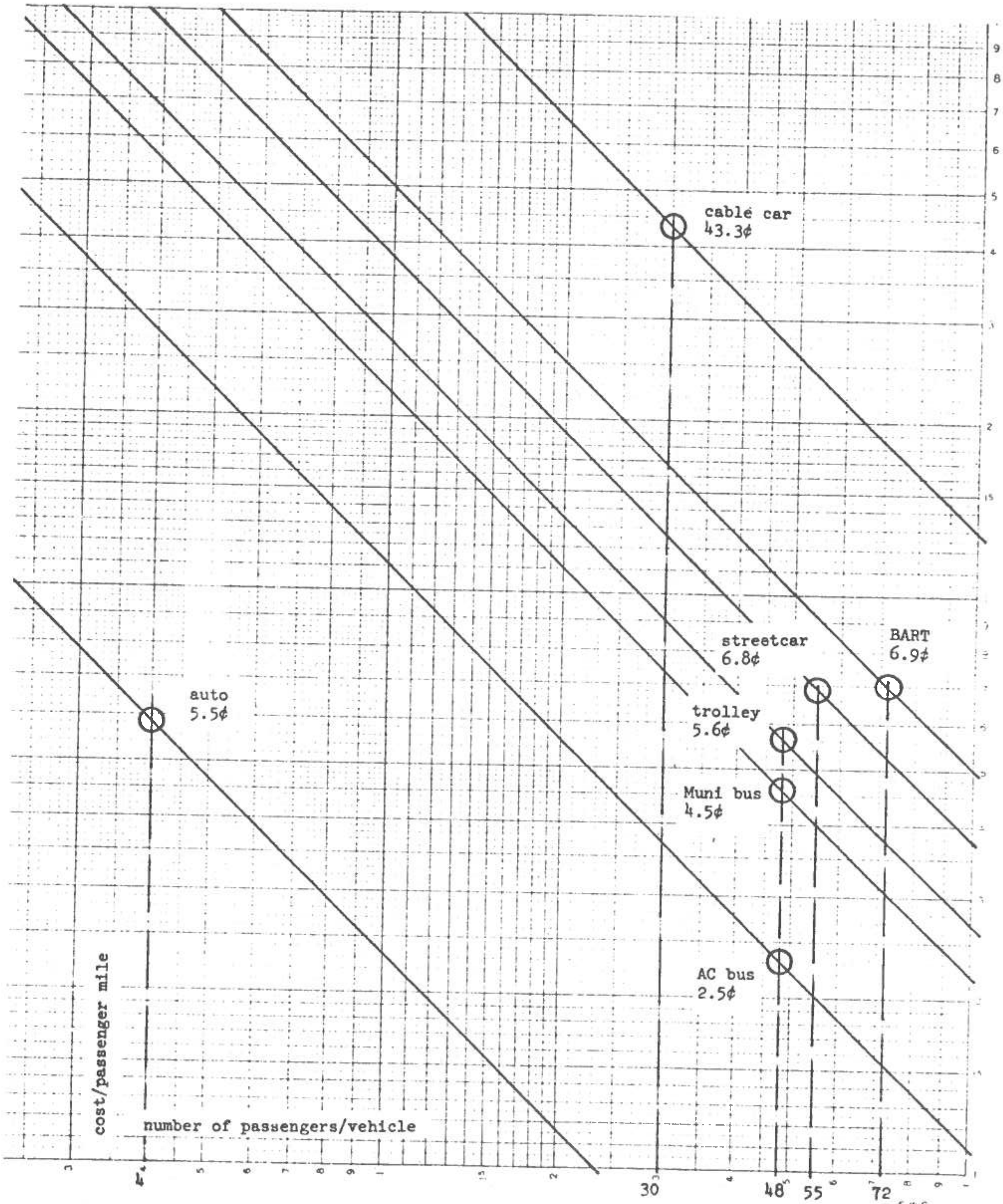

Figure 2. Unit Costs Versus Capacity for Urban Transportation Modes

VI. FUTURE WORK

Current efforts can be expanded in several directions. One is to construct more detail in the cost functions, separating out peak from off-peak, and relating quality of service to costs and also the characteristics of the service areas. Another direction is to include more agencies and more modes, to test the robustness of the costing methodology and the variation in experience within the Bay Area. Automobile cost analysis accomplished to date does not appear in this report, and there is a great deal of room for improving the state of information about the variety of social costs at least partially attributable to this mode. A third direction is in the refinement of statistical cost functions, delving for economies or diseconomies of scale and other types of non-linearities and interaction effects.

Some specific projects in progress or contemplated include:

(1) Disaggregated maintenance costs for the highway system based upon actual experience; type of road, urban vs. rural, and other factors are being considered.

(2) Application of the transit costing methodology to the Golden Gate Bridge, Highway and Transportation District.

(3) Methodology and empirical testing for measuring and evaluating the effects of peaking characteristics. This problem has come up frequently and already received a good deal of our attention, but has not been satisfactorily resolved.

(4) Design of experiments and data collection to isolate the sources of observed cost differences in comparable categories. An example is to what extent can accidents and vehicle wear be assigned to terrain, congestion, driver behavior, or other causal factors.

(5) Identification and measurement of service levels. Up to this point, all output has been considered of homogeneous, uniform quality; in fact, similarity in costs may hide real differences that are revealed as contrasting service qualities.

(6) Treatment of special issues. Certain important conceptual and empirical questions have emerged from the work accomplished so far, such as the advantages and disadvantages of shared versus exclusive right-of-ways.

(7) Computer programs for routine bookkeeping functions. The format for cost analysis has been standardized sufficiently through application to the cases already considered that it appears to be worthwhile to construct computer routines that will carry out these tasks. Cost categories, rearrangement of published costs, alternative price correction factors, alternative discount rates, vehicle lifetimes, base wage rates, fringe benefit factors, etc., can be programmed so as to accomplish more testing with the same level of effort.

(8) Construction of statistical cost functions. Some exploratory work has begun on the fitting of cost models by statistical means.