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Multistage Approach for Estimating Transit Costs

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The need to improve estimates of the costs of operating specific routes and services is greater than ever given the current financial problems of the transit industry. Managers are increasingly relying on performance audits to evaluate the cost-effectiveness of different operations. A multistage technique for allocating systemwide transit cost estimates to more disaggregate levels and accounting for the unique features of an operation is presented. Cost centers and pay-hour adjustments are used in distilling the cost estimates of specific services for two California transit properties. Significant differences are found between the cost estimates generated by "aggregate" unit cost equations computed from systemwide data and those generated by the techniques presented. Finally, suggestions are made as to how unit cost estimates might be used in an ongoing transit planning effort.

Growing interest in line-by-line analyses of transit performance and the estimation of how much it costs to expand services has created the need for more refined methods of allocating systemwide transit costs. Attributing system costs to a specific route, time period, distance increment, or even individual passenger trip requires highly precise, disaggregate data as well as a strong theoretical foundation.

The ideal cost allocation process would causally attribute each and every operating and capital expense to the specific route directly responsible for its encumbrance. Daily cost estimates that reflect the individual characteristics of each route could then be divided further into time-of-day components. By prorating the resultant peak and off-peak cost estimates among the users of each route (on the basis of, say, passenger miles traveled), a reasonable approximation of incremental cost incurred in serving each patron could be derived. Several factors, however, impair the use of such an approach. For example, few expense items can be linked directly to a specific bus route much less to a particular time of day. Most transit cost records are kept at either a systemwide or divisional level, which precludes precise measurement. Moreover, detailed records of such important cost factors as drivers' wages, equipment, and general overhead expenses are not always maintained on a time-of-day basis. Even when such information is available, one is faced with the arduous task of "attributing" the effects of such factors as part-time work prohibitions and spread-time penalties to the costs of serving both peak- and base-period users. Just as important, however, is the fact that peak/off-peak cost allocation theory remains partial and fragmented. Although a growing body of literature has evolved over recent years that offers insights into the transit cost allocation problem, no widely applicable or universally accepted approaches have yet emerged.

This paper presents a multistage process for allocating transit costs to more disaggregate levels by using expense records from two California transit operators. Each stage seeks to refine original cost estimates to better reflect the expense characteristics of any bus operation under study. First, a systemwide unit cost allocation formula is presented for each transit property, and this is followed by a "cost-centers" refinement of the equation. The cost-centers model is then used to estimate the daily cost of operating specific routes. The daily cost for each route is further divided between the peak and base periods by using attribution procedures that account for the effects of labor prohibitions and peak demands on total costs. The paper concludes with suggestions on how detailed unit cost estimates might be used by transit planners.

UNIT COST ALLOCATION MODELS

Cost allocation models estimate operating expenses by associating them with certain output factors. The most commonly used technique is the unit cost method (1,2). Under this approach, expense items are segregated into subcategories such as labor, maintenance, and fuel. The subcategories are then stratified among several variables, such as vehicle hours or vehicle miles of service, which are considered causally linked to the encumbrance of expenses in each subcategory. A multivariable equation can then be derived by calculating a unit coefficient for each factor (e.g., by dividing the total cost of all subcategories by vehicle hours).

Under the unit cost method, subcategories of operating expenses have traditionally been linked with one of four factors: (a) vehicle miles, (b) vehicle hours, (c) revenue passengers, or (d) peak buses (3). Typically, the following associations are made. The costs of fuel, tires, maintenance, and repairs are related to vehicle miles. Driver

Table 1. SCRTD cost computations for FY 1978/79.

Cost Subcategory	Total Cost ($000s)	Share of Cost (%) In-Service Miles	In-Service Hours	Pull-Outs	Peak Vehicles
Maintenance					
Mechanics					
Labor	14 000	70	20	10	
Fringes	3 275	70	20	10	
Utilitymen					
Labor	6 700				100
Fringes	1 500				100
Supervision, clerical					
Wages	5 820	20			80
Fringes	1 330	20			80
Fuel, tires, etc.	19 000	70	20	10	
Indirect purchases	2 100				100
Operators					
Wages	85 000		88	7.5	4.5
Fringes	19 300		88	7.5	4.5
Supervision, clerical					
Wages	7 270				100
Fringes	1 620				100
Indirect purchases	1 000				100
Board, general manager, secretary	390				100
Legal, safety	725				
Operations, general	850			25	75
Building services	1 750				100
Print shop	880		70		
Schedules	2 800	25	25	25	25
Planning	1 460				100
Customer relations	3 300			20	80
Employee relations	1 500	20	40	20	20
Accounting, fiscal	3 000				100
Purchasing, stores	920				100
Administration	890				100
Bus facilities engineering	600	75	20	5	
Insurance					
Public liability and property damage	12 000	78	25		
Other	100				100
Local match, capital	9 900				100
Debt service	2 900				100
Marketing	2 400			25	75

Table 2. AC Transit cost computations for FY 1978/79.

Cost Subcategory	Vehicle Miles	Vehicle Hours	Expansion Factor	Total Costs ($000)
Maintenance Department	1.00			11 907
Parts and supplies				
Fuel, oil, and tires				
Revenue equipment depreciation				
Transportation Department		1.00		28 902
Driver wages				
Driver fringes				
All other departments			1.00	12 161
Administration				
Supervision				
Insurance				
Marketing				
Services				

wages and fringe benefits are allocated to the vehicle-hour factor. The peak-vehicle factor usually encompasses expense items related to the size of the peak-period fleet (e.g., administrative overhead and storage), whereas the revenue-passenger factor accounts for expenses aasociated with accident payments and liability premiums. However, not all expenses can be cleanly tied to a single explanatory factor. For example, a case can be made for relating maintenance and repair expenses not only to the distance traveled but also to the vehicle-hour factor so as to reflect the effect of route congestion on equipment depreciation. Therefore, cost subcategories are sometimes apportioned among several explanatory factors to account for a multiplicity of influences.

FY 1978/79 expense records from the Southern California Rapid Transit District (SCRTD), which serves the Los Angeles area, and the Alameda-Contra Costa County Transit District (AC Transit), which serves the Oakland-East Bay area, were used in developing the multistage cost allocation procedures presented in this paper. Tables 1 and 2 present the cost subcategories and explanatory factors used by the two properties in deriving their respective formulas. The formulas themselves are presented in Table 3. By inserting into the appropriate formula the daily number of bus miles, hours, etc., generated by the operation of a particular bus line, a daily cost can be estimated for any route in question.

Differences in the accounting procedures and assignment approaches of the two agencies are quite evident in these tables. Although both included similar cost items, the classifications of expense subcategories varied markedly. SCRTD disaggregated expenses on a "cost item" basis whereas AC Transit broke them down according to internal departments. Another difference pertains to the way in which each agency handles expenses related to the depreciation of fixed capital. SCRTD lumped all depreciation for rolling stock, buildings, and equipment together under the expense categories of "depreciation" and "debt service" by using a declining-balance method. AC Transit, on the other hand, segregated depreciation of revenue equipment from that of overhead assets and opted for a straight-line approach to capital depreciation. Since these data predated Section 15 requirements (the Urban Mass Transportation Act of 1964, as amended) on uniform accounting standards, differences in the itemization of expenses could have been expected.

Table 3. Unit cost models for SCRTD and AC Transit.

Property	Variable	Column Cost ($000)	Percentage of Total Cost[a]	Parameter Total ($)	Formula Factor[b] ($)	Cost Allocation Model
SCRTD	VM	36 892	7.1	89 000 000	0.41	0.41(VM) + 16.44(VH) + 17.57(PO) + 107.77(PV)
	VH	101 225	48.2	6 340 000	16.44	
	PO	14 542	6.9	2 682	17.57	
	PV	60 460	28.0	1 781	107.77	
AC Transit	VM	11 907	22.4	25 014 817	0.476	[0.476(VM) + 13.58(VH)] x 1.298
	VH	28 902	54.6	2 128 299	13.58	
	EF	12 161	23.0		29.8[c]	

[a]Represents the share of the cost item attributed to the factor.
[b]Formula factor = column cost ÷ parameter total.
[c]Percentage.

Between the two agencies, four overall explanatory factors were used to estimate unit costs. Both attributed a large proportion, if not all, of their costs to the vehicle-mile and vehicle-hour variables. In the case of SCRTD, in-service data (i.e., exclusive of deadhead or nonrevenue miles and hours) were applied. AC Transit, by contrast, expressed the vehicle-mile factor in terms of scheduled (in-service) operations whereas the vehicle-hour data were on a total-platform (i.e., including nonrevenue) basis. In addition, SCRTD augmented its model by using peak-vehicle and "pull-out" variables. The peak-vehicle factor served to relate expenses incurred in scaling service levels to accommodate peak loads, and the pull-out variable reflected those costs associated with buses entering and leaving a divisional garage.

Rather than associating cost subcategories with a single factor, SCRTD prorated them among several variables by using a Delphi-type approach in which expert opinions were elicited from a committee of transit professionals. AC Transit, on the other hand, used an "all-or-nothing" approach that assigned 100 percent of each cost subcategory to one of the two formula factors. AC Transit also used an expansion factor (1.298) to adjust the operating-cost estimate of each route to account for general administrative and overhead expenses. One notable difference between these two models and those developed by other properties is the omission of a passenger-revenue factor. Rather than link liability insurance expenses to passenger revenues, such costs were incorporated into either the peak-vehicle or vehicle-mile factor. Another difference is the use by AC Transit of a simple two-factor equation.

COST-CENTERS REFINEMENTS

The unit cost approach represents an attempt to apportion transit operating expenses among all lines by using systemwide cost data. An implicit assumption of this "aggregate" approach is that driver wage levels, equipment qualities, maintenance practices, exogenous influences, and efficiency levels are the same throughout a transit system. Realistically, however, the cost characteristics of routes would be expected to differ as surrounding surface street congestion, frequency of passenger boarding and alighting, vehicle age, and similar factors varied among lines. An inner-city route that required frequent stopping to load and discharge passengers, for example, would be expected to experience higher maintenance expenses than a nonstop express service.

In contrast to the unit cost method, the direct assignment of driver wages, fuel, repairs, and other expenses to the particular routes on which they were incurred would improve the accuracy of operating cost estimates. This would obviously require a fairly elaborate accounting system. The marginal gains in accuracy, however, would probably be small in view of the additional accounting expenses. Ideally, what is called for is a cost allocation method that strikes a balance between the unit cost method and the direct assignment approach.

The concept of cost centers offers a compromise between the two extremes. Cost centers represent functional units within an organization that provide natural divisions for allocating costs (4,5). In the transit industry, these are best represented by operating divisions--facilities that operate groups of bus lines, give drivers specific route assignments, conduct maintenance activities, and maintain separate accounting records.

The second stage of refinement involved reestimating the cost equations of each property by using division-level data. This resulted in the development of unique cost-centers equations for each property--11 for SCRTD and 4 for AC Transit. The formula factors calibrated for the operating divisions of each of the two properties are displayed in Tables 4 and 5 along with a sampling of bus lines from each division. (These sampled routes serve as data cases for the subsequent analysis of the cost models.)

A comparison of each property's systemwide (Table 3) and divisional (Table 4) factor coefficients reveals significant variations in unit costs. In the case of SCRTD, the divisional factor coefficients varied around the system's mean coefficients by 10-12 percent; the largest differential was in the pull-out factor and the smallest was in the vehicle-hour variable. The variability among divisions for the AC Transit factor coefficients was similar; the average differential of the vehicle-mile coefficients (around the mean) was 2.4 percent, and the vehicle-hour coefficients varied by slightly less.

An obvious attraction of the cost-centers approach is its ability to reflect the unique cost characteristics of bus lines according to division of operation. To the extent that factor coefficients vary when disaggregated at the divisional level, it can be argued that the accuracy of individual bus-line cost estimates is improved. However, it can also be argued that the cost-centers approach offers no real improvement over the systemwide unit cost formula if bus lines within divisions exhibit heterogeneous cost characteristics. In the case of both properties, however, bus operations were quite similar in terms of service types, rider composition, and geographic area of service. For example, SCRTD division 8 serves as the home base for primarily express and intercity services between downtown Los Angeles and suburban communities in the San Gabriel Valley. Table 4 indicates that the four factor coefficients for division 8 lie at or below the average system coefficients, which suggests certain economies in serving longer-distance trips. On the other hand, the bus routes of division 18 can

Table 4. Cost-centers refinements of SCRTD unit cost models.

Division	Lines	In-Service Vehicle Miles	Scheduled Vehicle Hours[a]	Pull-Outs	Peak Vehicles
1	3, 28, 801, 826	0.42	13.56	16.88	88.53
2	2, 22, 25, 29, 91, 95	0.51	14.48	16.18	97.76
3	6, 42, 47, 87, 435	0.42	14.56	20.08	99.05
5	73, 607, 828	0.40	14.13	16.50	87.32
6	873	0.41	13.36	13.84	87.16
7	3, 42, 89, 91	0.42	12.78	14.77	89.05
8	35, 144	0.41	13.16	14.65	86.70
9	480	0.37	15.41	16.47	87.91
12	33, 814	0.42	15.37	15.94	82.76
15	154	0.38	13.66	20.75	99.57
18	3, 29, 34, 114, 869, 873	0.45	14.76	18.17	106.22
System avg[b]		0.41	14.14	16.58	91.41

[a]Scheduled vehicle hours (including pull-out, pull-in, deadhead, layover, and off-route time) were used in lieu of in-service vehicle hours for the cost-center model due to the unavailability of in-service data at the division level.
[b]SCRTD systemwide factor coefficients differ somewhat from those displayed in Table 3 due to the use of cost data from different time periods as well as the replacement of the in-service vehicle-hour factor with a scheduled service variable.

Table 5. Cost-centers refinements of AC Transit unit cost models.

Division	Lines	Total Vehicle Miles	Total Vehicle Hours	Overhead Expansion Factor
2	A, 11, 51/58, 65, 72, 306	0.25	18.40	1.298
3	G, 31, 70	0.30	18.02	1.298
4	K/R, 46/87, 54, 79, 80/81, 82/83, 84, 90/92	0.29	18.62	1.298
6	U, 22/24, 32	0.21	18.93	1.298
System avg[a]		0.26	18.46	1.298

[a]AC Transit systemwide factor coefficients differ from those displayed in Table 3 due to the use of cost data from different time periods.

all be characterized as high-volume, inner-city operations that serve predominantly transit-dependent populations. The division 18 factor coefficients, by comparison, exceed the system averages, which perhaps indicates some relative diseconomies associated with these services. Thus, to the extent that relatively homogeneous operations characterize individual divisions, cost-centers refinements can effectively capture the unique cost features of each division's bus lines.

PEAK/OFF-PEAK COST APPORTIONMENTS

There are two primary differences between peak and off-peak operations that merit attention in the refinement of transit costs: (a) the fact that capital and overhead outlays are scaled to accommodate peak loads warrants the allocation of higher rates of fixed costs to peak time periods, and (b) labor costs, although paid at a standard hourly rate, effectively vary by time-of-day since peak work activities lead to more spread-time and overtime duties, which results in more pay hours per vehicle hour of operation.

Three steps were taken to attribute the full range of operating and capital costs for each property to either the peak or the base period:

1. First, the vehicle-hour coefficient of each cost-center allocation formula was adjusted to account for the relatively high proportion of pay hours during peak periods in comparison with those in the base.
2. Then systemwide capital costs were apportioned among time periods on a route-by-route basis.
3. Finally, unit cost factors (e.g., vehicle miles and vehicle hours) were assigned to either the peak or the base period so as to attain separate time-of-day cost estimates. Each refinement is discussed below.

Time-of-Day Specifications of Vehicle-Hour Coefficients

The models presented so far assume that unit costs are the same throughout the day. Accordingly, estimates produced by these models represent weighted averages of peak and base conditions. For three of the factors--vehicle miles, pull-outs, and peak vehicles--the use of weighted average coefficients presents no problems. Generally, unit costs associated with these three factors are independent of peak or base use. Maintenance costs associated with the vehicle-mile factor, for example, are essentially the same for peak and off-peak services, since the wear and tear of a bus is fairly constant for each mile of travel. Thus, there is no strong a priori justification for altering the coefficients of these factors in accounting for time-of-day cost differences.

By far, the largest cost difference between peak and base time periods relates to the labor component of the vehicle-hour factor. It is widely accepted that stipulations in most labor contracts that prohibit the hiring of part-time drivers and limit split shifts and spread-time duties have significantly increased the cost of providing transit services. The effects of these penalizing labor provisions are particularly important because transit is a highly labor-intensive industry. Since the size of the transit labor force is scaled to the level of peak demand, many attribute the cost of these labor restrictions to the peak period. Wagon and Baggaley (6) have estimated that, due to labor-union influences, crew costs per minute for London Transport's peak operations are approximately twice those of the base. In contrast, the AC Transit union agreement was estimated to have increased peak operating expenses only 20 percent above those for the base period (7).

Given such extremes in estimates of labor-union effects on transit cost differentials, it is important to clearly understand the components of labor contracts that affect transit financially before apportioning expenses between time periods. Generally, SCRTD and AC Transit operate under labor agreements that contain the following provisions: (a) straight-time duties guaranteed for a fixed percentage of peak-period drivers; (b) guaranteed time, which ensures a minimum of 40 h of pay irrespective of the number of hours worked; (c) combination time, which prescribes a full day's pay for drivers who work around a peak period for less than 8 h; (d) spread-time penalties, which impose premium pay for work performed beyond a fixed daily time span (e.g., time and a half pay for tripper duties over 8 h in an 11-h spread); (e) split-shift time limits, which restrict the time span between work assignments; (f)

Table 6. Specification of AC Transit peak and base vehicle-hour factors.

		Peak			Base							VH Factor		
Line	Division	PH (h:min)	VH (h:min)	PH/VH	PH (h:min)	VH (h:min)	PH/VH	n	s	Peak Factor[a]	Base Factor[b]	Daily Avg	Peak[c]	Base[d]
A	2	31:30	24:30	1.286	42:39	42:20	1.008	1.277	0.579	1.160	0.908	18.40	21.34	16.70
G	3	38:30	30:30	1.262	24	23:23	1.026	1.230	1.304	1.088	0.885	18.02	19.61	15.95
K/R	4	168:30	116:30	1.446	148:44	130:25	1.142	1.266	1.133	1.177	0.949	18.62	21.92	17.67
U	6	86	81	1.062	44	41	1.062	1.00	1.975	1.00	1.00	18.93	18.93	18.93
11	2	19	18	1.056	12:37	12	1.06	1.00	1.5	1.00	1.00	18.40	18.40	18.40
22/24	6	21:50	18	1.794	64:30	47:28	1.359	0.879	0.379	0.909	1.034	18.93	18.93	18.93
31	3	10:30	8	1.313	7:08	6:38	1.075	1.221	1.206	1.089	0.892	18.02	19.62	16.07
32	6	22	18	1.222	16	12	1.333	0.917	1.5	0.965	1.052	18.93	18.93	18.93
46/87	4	12:30	11	1.136	23:23	21	1.113	1.021	0.524	1.014	0.993	18.62	18.88	18.49
51/58	2	166	142	1.169	200:34	195:30	1.026	1.139	0.726	1.076	0.945	18.40	19.80	17.38
54	4	33:30	29:30	1.136	31:12	29	1.076	1.056	1.017	1.027	0.973	18.62	19.12	18.11
65	2	37:18	35:18	1.057	34:27	32:42	1.057	1.00	1.079	1.00	1.00	18.40	18.40	18.40
70	3	25:30	23:30	1.085	19:50	18:30	1.072	1.012	1.270	1.01	0.99	18.02	18.20	17.90
72	2	125:22	102	1.229	172:24	162:05	1.064	1.156	0.630	1.091	0.944	18.40	20.07	17.36
79	4	33:37	27:36	1.218	27:13	24:53	1.094	1.114	1.109	1.051	0.943	18.62	19.57	17.57
80/81	4	62:41	42:30	1.475	98:30	95:50	1.028	1.435	0.449	1.266	0.882	18.62	23.57	16.43
82/83	4	217	187	1.160	280:30	264:30	1.061	1.094	1.414	1.037	0.948	18.62	19.31	17.65
84	4	13	11	1.182	13:50	12:50	1.078	1.097	0.858	1.05	0.957	18.62	19.55	17.82
90/92	4	53	47	1.128	57:20	54:50	1.046	1.079	0.857	1.041	0.964	18.62	19.38	17.97
306	2	24:30	23:30	1.043	14:18	13:40	1.043	1.000	1.719	1.00	1.00	18.40	18.40	18.40
Sample avg		60:05	48:55	1.228	66:39	62:01	1.075	1.142	0.789	1.075	0.941	18.52	19.60	17.76

Note: PH = pay hours, VH = vehicle hours, n = relative labor productivity (ratio of peak to base pay hours/vehicle hours), and s = service index (ratio of peak to base vehicle hours of service).

[a] $n(1 + s)/(1 + ns)$.
[b] $(1 + s)/(1 + ns)$.
[c] $[n(1 + s)/(1 + ns)] \cdot$(daily vehicle-hour factor).
[d] $[(1 + s)/(1 + ns)] \cdot$(daily vehicle-hour factor).

overtime duties compensated at a bonus rate; and (g) a general prohibition of part-time work.

A similar consequence of these prohibitions and penalties is that the transit labor force, the size of which relates to peak ridership, is maintained intact throughout much of the day whether or not there is sufficient off-peak demand to warrant such employment levels. The problem is compounded by the diurnal nature of commuting patterns: Peak loads occur during a 2- to 3-h time span in the morning and evening, and thus full-scale operations are required over a 12-h stretch of time. Although many of the excess wage expenditures occur during off-peak periods, a legitimate argument can be made for attributing them to the peak.

In addition to these union-related influences, other factors should be considered in assessing the "true" labor costs of peak operations. For example, labor efficiency tends to be relatively low during the peak, since considerable time is spent deadheading to additional runs. In general, the proportion of out-of-service to in-service pay hours is higher in the peak than in the base period due to these deadheading activities. Some have also speculated that the scale of the peak labor force possibly inflates the cost of transit service by the greater political clout it wields (8).

In attributing a larger proportion of total labor costs to peak operations, a procedure is needed to adjust the vehicle-hour factor--upward in the peak model and downward in the base model--since the weighted average vehicle-hour factor underestimates the costs of peak service and exaggerates those of the base. Ideally, what is called for is a cost allocation model that uses pay hours in lieu of vehicle hours. However, the scarcity of good pay-hour data has historically led to use of the vehicle-hour factor as a surrogate. Cherwony and Mundle (9) have developed an approach that ties these two indices together in the temporal apportionment of operating costs. The most salient feature of their approach is that the vehicle-hour coefficient is modified for the peak and off-peak periods based on a ratio comparison of pay hours to vehicle hours between respective times of day [details are given by Cherwony and Mundle (9) and at the bottom of Table 6].

Cherwony and Mundle's approach requires the analyst to attribute the pay hours for each route to either the peak or the base period. This is obviously a subjective task that relies on one's perception as to whether overtime pay hours, premium pay hours, etc., for a route were "caused" by demands in the peak or in the base or both. In order to reduce the possibility of biases in the attribution process, it is important to adopt assumptions a priori that can be applied consistently and universally.

The following "attribution rules" were agreed on for assigning vehicle hours and pay hours to SCRTD and AC Transit peak and base periods after discussions with the professional staff of each agency:

1. Vehicle hours were attributed to the peak and the base according to their occurrence (i.e., SCRTD vehicle hours occurring between 6:15 and 8:45 a.m. and 3:15 and 5:45 p.m. were assigned to the peak and all others to the base).
2. All deadhead, sign-on, sign-off, and elapse time was allotted to the base for straight runs and to the peak for split runs.
3. Overtime was attributed to the base for straight runs and to the peak for split runs.
4. Premium and combination pay hours provided for driver tours of less than 8 h were allocated solely to the peak under the premise that such pay represents compensation time revolving around peak loads for which insufficient off-peak demand exists.
5. All biddable and nonbiddable tripper time (including that for deadhead, sign-on, premium, etc.) was assigned to the peak except those portions extending into the base time period.
6. Overtime pay hours for biddable and nonbiddable trips that exceeded 8 h within an 11-h spread of time were allocated to the peak at a rate of time and a half.
7. Any extra operator pay hours spent driving trippers or sitting idle were assigned to the peak. Extra operator time spent substituting for regular drivers was prorated between the peak and the base according to time period of occurrence.

These attribution rules are similar to the ones used by Reilly (8) in his study of peak costs for the Albany Capital District Transit Commission. These assumptions, like Reilly's, are relatively conservative in that uncertainties are resolved by assigning those pay-hour allocations that are debatable to the base period. The second and third rules, in particular, favor lower peak-period pay-hour allocations.

The attribution of each property's vehicle hours and pay hours to either the peak or the base period was performed by applying the aforementioned rules to data from work assignment sheets maintained by the Scheduling and Planning Departments of both agencies. Table 6 presents the accumulated totals of pay hours and vehicle hours attributed to the peak and base periods of AC Transit's 20 sampled routes as well as the computed adjustments to the vehicle-hour factors from the AC Transit cost-centers equations. (Computations were similarly carried out for SCRTD's 30 sampled routes.) In averaging among all sampled routes, the AC Transit peak period was found to require 22.8 percent more pay hours than vehicle hours and the base period had only 7.5 percent more pay hours than vehicle hours, which yielded a labor productivity differential of 14.2 percent. For the SCRTD system, on the other hand, there were 39.3 percent more pay hours than vehicle hours in the peak yet only 7 percent more in the base, which produced a differential of more than 30 percent.

For cost estimation purposes, the vehicle-hour coefficients displayed in columns 14 and 15 of Table 6 are of primary importance, reflecting the unique scheduling, labor productivity, and service characteristics of each route. On average, these temporal adjustments resulted in a 28.3 percent differential in the SCRTD peak- and base-period vehicle-hour coefficients compared with only a 10.4 percent time-of-day difference in the AC Transit coefficients. These coefficient refinements are significant in view of the fact that more than 50 percent of the total operating expenses of each property is attributable to the vehicle-hour factor.

Time-of-Day Allocation of Capital Costs

Several steps can be taken in apportioning the cost of owning and using capital to time periods. First, in order to compare transit capital expenses with operating costs, it is necessary to express the value of fixed assets on an annual basis. This is normally done by computing an annual depreciation estimate that accounts for the monetary value of using capital over a one-year time period. Generally, depreciation estimates reflect the annual decline in value of such physical assets as rolling stock, buildings, shop equipment, storage and maintenance facilities, and accessories (such as fareboxes). By convention, the "capital recovery factor" approach to the depreciation of assets is used. Under this approach, the net value of capital (i.e., original cost minus accumulated depreciation and scrap value) is amortized over the entire service life of an asset by using an interest rate that reflects the true opportunity cost of resources and that also attributes a larger proportion of depreciation expenses to future years. When the net worth of capital is multiplied by this factor, an annual depreciation estimate is derived that, when summed with interest over a specified period of time, would equal the amount to which the original expenditure would be expected to grow (with interest). By using net capital asset values from the balance sheets of the annual reports of each agency and assuming an 8 percent interest rate, the capital recovery factor method yielded an annual depreciation estimate of $7.91 million for SCRTD and $2.06 million for AC Transit.

Next, it is necessary to apportion annual depreciation expenses into peak and off-peak components. Peak-load theorists have long argued for charging the total costs of capital outlays to rush-hour users, since peak demand determines fleet size and overhead requirements (10,11). Precedents for assigning 100 percent of capital depreciation to the peak period have been established in a number of previous studies (7,8,12,13). Others, however, challenge this logic, arguing that the depreciation of transit assets should depend on use. Perhaps the most thorough analysis of the sharing of capital expenses is the simulation research of Boyd, Asher, and Wetzler (14), in which the authors estimated that 72-100 percent of transit capital costs should be allocated to the peak. An 85/15 percent split was recommended as a reasonable apportionment benchmark. Several precedents have been established in prorating capital costs between time periods within the range established by Boyd, Asher, and Wetzler (15-17). By applying the 85/15 percent proration, the following capital cost allocations were made: SCRTD, $6.72 million to the peak and $1.19 million to the base; AC Transit, $1.75 million to the peak and $0.31 million to the base.

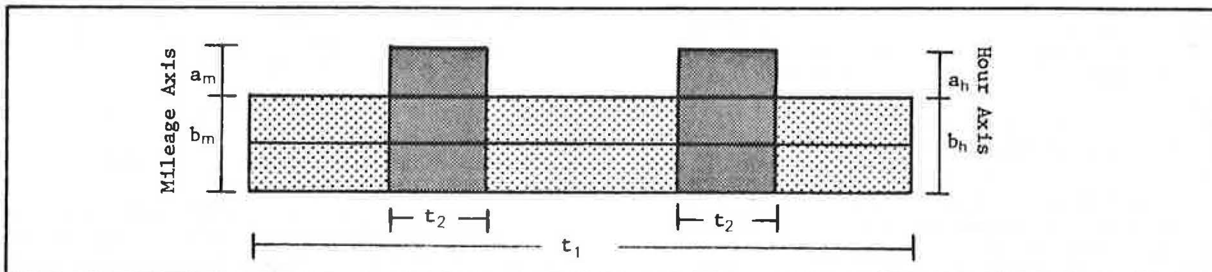
After the estimation of each agency's annual depreciation and subsequent 85/15 percent apportionment between peak and base, it is necessary to translate depreciation dollar allocations into the data inputs used in the unit cost models. For example, since SCRTD included annual depreciation costs in the peak-vehicle factor, a portion of peak vehicles had to be prorated between the two time periods for each route under study. This procedure was followed for each sample route of the two case-study operators.

Time-of-Day Cost Computations

Computation of the total cost of operating each sample route during the peak and off-peak periods entails inserting appropriate input data (on vehicle miles, vehicle hours, etc., for each time period) into the respective peak-adjusted and off-peak-adjusted cost models. The apportionment of each route's vehicle miles and vehicle hours between time periods is fairly straightforward. Figure 1 shows that bus miles and hours that accumulate during the span of time t_2 (minus those already assigned to account for capital depreciation) should be allocated solely to the peak and the residual should go to the base.

The allocation of SCRTD's two additional factor inputs--pull-outs and peak vehicles--was not quite as simple. The pull-out factor, it is recalled, measures the sum of morning and evening peak buses less the base volume of buses operating during the midday. It thus captures some of the incidental expenses related to buses going into and out of service. The peak-vehicle factor reflects expenses related to expanded operations by measuring the maximum number of buses in service during either the morning or the evening period (whichever is the greatest). The difficulty presented by these two factors, in contrast to vehicle miles and hours, is that there is no time continuum for causally assigning measures of pull-outs and peak vehicles between the peak and the base. Rather, both factors measure service intensity solely during the peak. In the absence of any strong theoretical basis for factoring these peak-related parameters into the base period, the following apportionment rule appeared reasonable: The increments of pull-outs and peak vehicles above the base level were allocated solely to the peak, and the residuals were prorated according to the vehicle hours for each time period.

Figure 1. Apportionment of vehicle-mile and vehicle-hour factors.



Factor	Daily Measure	Total Base	Total Peak	Peak Increment	Base Allocation	Peak Allocation
VEHICLE MILEAGE:	$b_m(t_1)+a_m(2t_2)$	$b_m(t_1)$	$(b_m+a_m)(2t_2)$	$a_m(2t_2)$	$b_m(t_1)-b_m(2t_2)$	$(a_m+b_m)\cdot(2t_2)$
VEHICLE HOUR:	$b_h(t_1)+a_h(2t_2)$	$b_h(t_1)$	$(b_h+a_h)(2t_2)$	$a_h(2t_2)$	$b_h(t_1)-b_h(2t_2)$	$(a_h+b_h)\cdot(2t_2)$

WHERE:

t_1 = 24 hour time period

t_2 = Total duration of each peak

a_m = Increment of Vehicle Miles above the base for each peak

b_m = Vehicle Miles during the base period

a_h = Increment of Vehicle Hours above the base for each peak

b_h = Vehicle Hours during the base period

Table 7. Comparison of daily route cost estimates.

		Unit Cost Model Estimate[a] ($)			Refined Cost Model Estimate[b] ($)		
Property	Route	Peak	Base	Total	Peak	Base	Total
SCRTD	814	0.41(307.3) + 14.14(22.6) + 16.58(7.08) + 91.41(7.0) = 1203	0.41(299.7) + 14.14(22.0) + 16.58(6.91) + 91.41(0) = 549	1752	0.42(307.3) + 21.24(22.6) + 15.94(7.08) + 82.76(7.0) = 1301	0.42(299.7) + 9.36(22.0) + 15.94(6.9) + 82.76(0) = 448	1749
AC Transit	80/81	[0.26(630) + 18.46(43.4)] x 1.298 = 1253	[0.26(1420) + 18.46(97.9)] x 1.298 = 2825	4078	[0.29(630) + 23.57(43.4)] x 1.298 = 1565	[0.29(1420) + 16.43(97.9)] x 1.298 = 2581	4146

[a]Unit cost models are of the form given in Table 3 but use the systemwide average factors given in Tables 4 and 5.
[b]Refined cost equations reflect cost-centers adjustments, vehicle hour coefficient adjustments, and capital depreciation characteristics of the particular route.

The application of these allocation principles resulted in 5 h of peak service for SCRTD and 4 h of peak service for AC Transit, which constituted 55.8 and 58.5 percent, respectively, of the total daily costs of each system. Thus, these estimation procedures led to the allocation of more than half of each property's total operating and capital costs to the peak period. Since the peak accounted for less than 50 percent of the daily ridership of each property, it appeared to be less "cost efficient" than other time periods. This finding suggests that peak-load pricing could prove more equitable than the current predominantly flat-fare structure of these systems.

ANALYSIS OF COST ESTIMATES

The procedures discussed in this paper produce individual time-of-day cost estimates for transit routes, refined to account for unique cost characteristics of each route's operating division, to incorporate depreciation expenses into the analysis, and to capture the influence of restrictive labor stipulations on the cost of peak operations. Such a procedure presents obvious advantages in conducting line-by-line performance audits, an increasingly popular means of monitoring the cost-effectiveness of routes. The advantage of this model can be demonstrated by comparing its estimates of route costs with those produced by the systemwide equations given in Table 7. For example, Table 7 gives peak, base, and daily (total) cost estimates produced by the systemwide formulas (from Tables 4 and 5) versus the estimate produced by the refined model presented in this paper for one sample route of each operator. For SCRTD route 814, an express intercity operation, the systemwide equation estimated a peak-period cost of $1203 and a base cost of $549, for a total daily estimate of $1752. In contrast, the refined equations led to peak and base estimates of $1301 and $448, respectively. Thus, the refined equations produced cost estimates that were 8.2 percent higher in the peak and 28.5 percent lower in the base for this particular route. For AC Transit route 80/81, an inner-city local operation, the refined model resulted in significantly higher peak cost estimates yet substantially lower base cost estimates. Similar cost-estimate differentials were generally found for other AC Transit and SCRTD routes under study. It is apparent that gross differences can emerge between estimates from a simple systemwide unit cost equation developed from aggregate data and those from a refined cost-centers approach that accounts for the unique temporal and operational characteristics of routes.

Another advantage of this refined approach is its ability to provide approximations of incremental costs. Dividing the peak-period cost estimate of a particular route by its respective revenue miles of service for that period, for example, provides an approximation of the marginal cost of expanding rush-hour service. Similarly, ratios of cost per passenger mile have been used in estimating the farebox recovery ratio of a particular trip on a certain route for a specific time of day (18). Such an exercise can give the transit planner some insight into how an efficient fare structure might be set. For example, distance-based price structures could be established by examining how daily cost estimates of routes (indexed on the basis of vehicle miles and passenger miles) vary as a function of distance. To the extent that unit costs decline with spatial measures of distance, a fare structure with declining distance steps would be in order.

Four regression relations established between two unit cost measures (cost per mile and cost per passenger mile) estimated for SCRTD's 30 sample routes and AC Transit's 20 sample routes and a number of distance-related independent variables are presented below (one route with outlier data was removed from the analysis for each system). The relations for SCRTD are as follows (N = 29):

$$C/M = 2.86 - \underset{(44.7)^{**}}{0.34(OWBM)} + \underset{(11.6)^{**}}{0.15(PASS)} \qquad R^2 = 0.82 \tag{1}$$

$$C/PM = 0.16 + \underset{(84.1)^{**}}{1.17(ADT)^{-2}} - \underset{(39.0)^{**}}{0.65(PASS)} + \underset{(5.2)^{*}}{10\,160(ABM)^{-2}} \qquad R^2 = 0.91 \tag{2}$$

The AC Transit relations are as follows (N = 19):

$$C/M = 2.16 - \underset{(13.7)^{**}}{0.53(EC)} + \underset{(5.9)^{**}}{0.66(ATD)^{-2}} \qquad R^2 = 0.68 \tag{3}$$

$$C/PM = 0.62 - \underset{(10.1)^{**}}{0.66(LF)} + \underset{(10.0)^{**}}{0.79(ATD)^{-2}} \qquad R^2 = 0.64 \tag{4}$$

where

C/M = cost per vehicle mile ($);
C/PM = cost per passenger mile ($);
OWBM = one-way bus miles, which measures the unidirectional distance between route terminals;
PASS = daily passengers (in thousands) over an average 24-h period, a proxy for the relative service density of a route as well as the level of boarding and alighting activity it experiences (000s);
ATD = average trip distance, computed as the mean trip length of route daily ridership (miles);
ABM = average daily in-service bus miles, the total mileage covered on a route during a typical weekday while serving revenue passengers;
EC = express dummy code, where express routes are assigned the value 1 and all other routes are assigned 0 [express routes were defined as those operations in which at least 25 percent of in-service bus miles was on nonstop (or freeway) links];
LF = load factor, computed by dividing route average ridership at maximum load point by the seating capacity of vehicles assigned to the route (the load factor represents a proxy measure of route densities and volume intensities);
** = t-statistic significant at the 0.01 level; and
* = t-statistic significant at the 0.05 level.

Equation 1 indicates that SCRTD cost per mile declines linearly with longer route structures and lower passenger volumes. Equation 2 suggests that cost per passenger mile declines at a decreasing rate as average trip lengths become longer and total in-service miles increase at a linear rate as passenger volumes rise. The inference to be drawn is that SCRTD unit costs tend to decrease with longer trip lengths and route structures and that passengers are positively related to costs on a per-mile basis (although negatively related in terms of passenger miles). For AC Transit, unit costs decline in a rectangular hyperbolic manner with average trip length in both equations: Routes serving short-distance trips experience high cost ratios whereas those with medium- to long-distance trips incur relatively low unit costs. These findings suggest that price structures with distance steps that increase logarithmically with distance could best capture the unit costs of SCRTD and AC Transit operations. It is important to emphasize, however, that the validity of such an analysis hinges on the accuracy of the cost estimates used. Clearly, more refined estimates of transit costs offer a stronger, more palpable basis for evaluating route performance, assessing the feasibility of route expansions, and examining the efficiency implications of alternative fare structures.

SUMMARY

A multistage process for refining transit cost estimates has been presented, one that apportions operating and capital expenses between time periods based on the unique features of any service under study. Initially, systemwide models were presented for two California transit operators that linked operating expenses to specific causal factors. These systemwide models were then respecified in terms of cost-centers models that captured individual cost characteristics of the divisions from which sample routes operated. Next, the vehicle-hour coefficients of each agency's cost models were recalibrated to account for the relatively higher wage levels emanating from peak operations and restrictive labor agreements. For all routes studied, vehicle-hour coefficients were raised in the peak and lowered in the base. Both capital depreciation and operating expenses were then apportioned into time periods based on analyses of cost responsibility. After allocating factor units among time periods, it was possible to compute daily peak- and base-period cost estimates for all sample routes by using the adjusted cost-centers models. The usefulness of this approach lies in its ability to provide reasonably accurate cost estimates, disaggregated at the level of the analyst's choice. The approach appears particularly well suited to performance audits of route cost-effectiveness and the evaluation of transit pricing options.

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Transit Operating Costs and Fare Requirements Forecasting by Using Regression Modeling

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Because of increasing operating costs and a reduction in federal operating assistance, transit operators are faced with the reality of increasing fares over the foreseeable future. The traditional approach of holding off on any fare increase and cutting service for as long as possible, then needing to increase fares more than is politically acceptable will result in a new cycle of increasing fares, reduced services, and declining ridership. An approach to intermediate-term forecasting of fare and revenue requirements by using simple regression models is described, and examples are given for alternative fare and service questions that might be raised. Such a procedure will be useful to transit operators in planning for staged changes in fare and service levels so as to avoid drastic and unanticipated ones.

During the decade of the 1970s, a major emphasis in public transportation policy was fare stabilization. In 1974 federal policy joined with local efforts in this regard by providing direct operating subsidy funds through Section 5 of the Urban Mass Transportation Act of 1964, as amended. By 1981, however, increasing operating costs, both real and inflationary, and an apparent reversal of federal policy intended to result in reduction and termination of Section 5 funding are forcing a rethinking of policies to maintain fares at artificially low levels. Today's environment requires transportation operators to deal with the reality of increasing fares over the foreseeable future.

The traditional approach to increasing fares is to defer any action as long as possible, reducing costs as much as possible even to the point of seriously impairing service, and in the end still facing increases that are too large to be politically acceptable. The result is frequently a fare increase that is not large enough to restore or even maintain service but that has a negative psychological effect in the community.

From economic and competitive aspects, transit fares probably should be increased. However, it is important that these increases be made in a rational, well-planned manner and not in the traditional fashion: long-deferred, large-increment increases coming only after the level of operations has been reduced to the point that some segments of the transit market have been denied service at any price and other existing and potential market segments are angry and resentful. Rational and well-planned fare and service policies require anticipation of revenue requirements and a staging of fare increases in (relatively) small increments, matching fare increments to increasing costs of services provided and increased costs for alternative modes. Such policies, however, require some sort of intermediate-term forecasting capacity for both operating costs and revenues.

This paper discusses a very simple approach to