Development of a Bus Operating Cost Allocation Model Compatible with UMTA Urban Transportation Planning System Models

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Traditionally, bus operating cost models have been based on actual bus components or expenditures, and unit coefficients have been assigned to these based on actual or estimated costs. Such models are usually applied as linear models in which the unit coefficients are applied to such measures as vehicle miles and vehicle hours of service. The development of a cost-allocation model is documented here. The model differs from the traditional ones by separating costs into fixed and variable components and by using multiple-step functions that reflect the increments of costs or savings generated through changes in the number of employees required to operate the bus system. The model is based on an extensive analysis of the budget data of a large bus operator (the Southern California Rapid Transit System), and provides an example of how a model can be developed for any size of operation if records are maintained on a reasonably detailed budgeting level. The model was developed to be compatible with the UMTA Transportation Planning System (UTPS) models, and can be used both to assist in evaluating alternative long-range transit networks as well as an effective short-range planning and costing tool. The model is currently developed as a microcomputer model that runs on a database developed from the scheduling data of the system. A series of sensitivity tests that have been applied to the model to determine how it behaves under a variety of short-term conditions is also described. One of the major problems in testing a cost-allocation model is that costs are rarely compiled by an operator at the level of an individual line or small groups of lines. As a result, sensitivity can be judged against systemwide cost estimation and against reasonableness of the results and ranges of the results for subgroups of lines. The sensitivity tests documented in this paper comprise prediction to other recent years, with and without internal recalibration: comparison of calibrated and projected models for a 2-year time lapse, and tests on the ability of the model to project costs for a package of service changes. Each of the tests indicated satisfactory performance by the model and demonstrated the ability of the model to identify the sources of changes in costs resulting from changes in service.

To assess alternative transit policies and service changes, it is highly desirable and necessary [if federal capital or operating funding is sought (*1*)] to be able to forecast the annual operating costs of the alternative policies and service changes. Most transit properties possess some form of cost model that can be used to estimate current or near-future operating costs. Most of these models use coefficients that are fixed at a point in time close to the present and require the use of variables describing system operation that can be estimated for an immediately upcoming time period. For example, an operating cost model may include a variable such as the number of pull outs per day, which can be determined only after runs are cut and vehicle assignments made. In addition, most cost models do not distinguish between fixed and variable costs (except in the original cost-allocation procedure), and most treat all elements of cost as continuously variable.

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BACKGROUND

Before any analysis was attempted, current literature was researched and existing bus operating cost models were reviewed. There are three basic types of bus-operating cost models (2):

1. Type I—causal-factor models,
2. Type II—cost-allocation models, and
3. Type III—temporal-variation models.

Type I models break the cost into bus service, maintenance, and overhead components. Estimated quantities of these components required for bus operation are developed and multiplied by unit costs based on the actual or estimated market price of that component (e.g., drivers, buses, fuel, tires, etc.). These quantity estimates are multiplied by the appropriate unit costs, and the resulting products are summed to arrive at the transit cost. This process is similar to the budgeting process used to estimate costs in most industries. There are few examples of such models in practical use.

Type II models allocate the expenditures of each transit-system division based on aggregate measures of transit service, such as vehicle hours and vehicle miles. Unit costs are developed for these aggregate measures, which comprise the coefficients of the cost-allocation model. Most current models are of this type.

Type III models define cost as a function of time of day or day of week. The emphasis here is on differences in temporal labor costs and temporal vehicle costs that arise from differences in such items as deadheading, pullouts, use of part-time drivers, and so on. Few such models are currently used by transit agencies.

TABLE 1 EXAMPLES OF EXISTING BUS OPERATING COST MODELS

	Variables and Coefficients						
Source	Vehicle Hours	Vehicle Miles	Peak Vehicles	Revenue	Days	Passen-gers	Pull Outs
Chicago Transit Authority[a]	11.13	0.28	20,059.22	0.06	–	–	–
University of Oklahoma[b]	–	Yes	Yes	–	Yes	–	–
St. Louis Model	Yes	Yes	Yes	–	–	Yes	–
Minneapolis-St. Paul[c]	9.90	0.31	1,353	–	–	–	–
Cash Flow Model, Miami[d]	–	Yes	–	–	–	–	–
Bus Planning, Miami[e]	22.39	1.10	–	–	–	–	–
The Scatchard Model[f]	25.42	1.74	–	–	–	–	–
The Gephart Model[g]	40.98	–	–	–	–	–	173.37

[a]See (*3*,p.241).
[b]See (*4*).
[c]See (*5*).
[d]See (*6*).
[e]See (*7*).
[f]See (*8*).
[g]See (*9*).

In Table 1 (*3–9*) are examples of cost-allocation models currently used at transit properties. Although a number of other models exist, there are few practical examples of Type I and Type III models. Described in this paper is an attempt to develop a methodology and to construct a model of bus operating costs based on cost allocation, with variables available from UTPS forecasting procedures, so that the model can be used for long-range and short-range costing. A specific attempt was made in the calibration procedure to develop a model that would estimate costs in constant dollars and for which adjustments could be made to reflect a change in the base year for the constant dollars. Some attempt was also made to deal with differential inflation within transit property operations. The model was also developed to distinguish between fixed and variable costs and to treat costs as noncontinuous functions where appropriate.

This bus-operating cost model is designed to allow the calculation of the operating expenses for bus operation associated with either increases or decreases in service. The model generates these estimates from projections of annual bus operating statistics based on the quantity of service for the whole bus system—that is, a summation of the data for each specific route—and can also be used in a long-range version with linear coefficients applied to estimates of service-level variables generated from UTPS forecasts.

DEVELOPING THE MODEL

The cost model described in this paper was developed to meet the following requirements:

1. To realistically reflect changes in the variable operating costs of a transit agency, while maintaining correct fixed costs for the operation;
2. To estimate both fully allocated and marginal costs for service and service changes;
3. To function with currently available UTPS data;
4. To use data readily available from an operator;
5. To function on a systemwide level; and
6. To provide line-by-line estimates of operating costs, irrespective of the accuracy of the underlying model.

The model described next was developed to satisfy the foregoing requirement and has been calibrated to data from the Southern California Rapid Transit District (SCRTD).

Most existing bus cost models are based on level-of-service variables primarily selected from vehicle hours, vehicle miles, passenger boardings, number of pullouts, peak-vehicle requirements, and revenue. The validity of using such variables has been established both through statistical analyses and conceptual argument. Cost-allocation models of this kind have led to the simple assumption that any budget item or expenditure line item can be set to vary with only one level-of-service variable. The model described here is no exception: the added complexity required for multiple-variable effects is not likely to be justified. This cost model is based on selecting a set of level-of-service variables that meet several criteria:

1. Variables are sufficient to forecast costs on all line items of the budget,
2. Variables provide responsiveness to different types of service that may be offered and to changes in service profile, and
3. Variables can be output or derived from standard urban transportation simulation procedures for long-range forecasting.

Criterion 1 is a judgment call, but seems to suggest that vehicle hours and vehicle miles alone are unlikely to be adequate. Criterion 2 also suggests use of additional variables that would provide some differentiation between services offered throughout the day and peak-period-only services. Criterion 3 leads to a rejection of a variable such as pull outs, which is not readily derived from long-range forecasting techniques.

Based on the foregoing criteria, the following four level-of-service measures were selected for the model: (*a*) annual vehicle miles, (*b*) annual service hours, (*c*) average weekday p.m. peak vehicles, and (*d*) annual passenger boardings. The model is a fixed/variable cost allocation model. Basically, the cost of each element of service is allocated to one of the level-of-service measures. The different elements of service are defined as the individual reported line items of expenditure, or small groupings of line items. Each line item is first defined as either variable—that is, the line item is expected to vary with changes in the service level measures—or fixed—that is, the line item should not change irrespective of service changes. Variable line items are then defined as varying either continuously with the selected service measure (e.g., fuel costs vary continuously with vehicle miles) or in steps (e.g., wage and fringe costs of transmission mechanics vary stepwise with vehicle miles; step size is defined as the annual cost of one transmission mechanic).

The stepwise element of the model is important because it reflects the fact that most positions in a transit agency are full-time positions and a change in cost will occur only when sufficient service is added or cut to trigger the addition or removal of an entire position. When part-time positions are available, the steps can be set to a half-time position cost, rather than a full-time position cost. Although it can be argued that service changes can occur during a fiscal year, potentially invalidating the stepwise concept, an agency is more commonly interested in the implications for a full year of operation instead of in the savings or costs for the balance of the year. Also, the stepwise characteristic is still valid in limiting cost changes to those resulting from a real capability to decrease the labor force or to operate increased service with the existing labor force.

When applied to the SCRTD, an additional refinement was built into the model that will also apply to any other multiple-division system. The SCRTD operates service out of multiple operating divisions, with minor maintenance undertaken at the operating divisions. Only major maintenance and repairs are undertaken at a central maintenance facility. Because it is not generally possible to assign an individual operator or service mechanic to more than one operating division, positions that exist at an operating/maintenance division can only change when service changes at the division are sufficient to add or delete a position. Therefore, each variable cost item is also identified as either division based or system based. If it is division based, then service changes must be estimated for this cost item at each division, and a determination made within each division of the changes in positions. System-based items are determined for the total of all changes within the entire system.

MODEL CALIBRATION

Procedure

To calibrate the model, it is necessary (*a*) to allocate each cost judgmentally to a service measure; and (*b*) to determine the budget lines, numbers of positions at each budget line, and the amounts of service for the calibration year. From these figures, the unit costs for each budget line item are calculated as follows.

When the costs are determined and allocated, the model can be used in two alternative ways. For short-range costing, the model has been constructed as a spreadsheet on which the individual budget items are preserved and costing is done by determining the number of steps triggered by the amounts of service under study. The costs of each step are then multiplied by the number of steps and the results summed to produce the total costs for the service. For long-range costing, a more conventional model application is undertaken because the detail for the line item costing is either not available or not sufficiently accurate to warrant this procedure. For the second application, coefficients (unit costs) are computed by summing the costs per vehicle mile, vehicle hour, peak bus, and passenger boarding, irrespective of step or continuous functions, to produce a model with the form

$$\text{Cost} = a_1 VMT + a_2 VHT + a_3 PKBS + a_4 PASS + FIX \quad (1)$$

where

VMT = annual vehicle miles of travel,
VHT = annual vehicle hours of travel,
$PKBS$ = average p.m. weekday peak bus requirement,
$PASS$ = annual passenger boardings, and
FIX = total annual fixed costs.

The model described in this paper was calibrated with data from the SCRTD FY 1986. SCRTD operates the majority of bus service for Los Angeles County, a region with a population of about 7.3 million. In 1983, SCRTD provided 331,500 daily service bus-miles and carried 1.47 million rides, which amounted to a total of 5.3 million passenger-miles. The SCRTD's total vehicle fleet is approximately 3,000, of which 2,500 vehicles are in active service (*9*). The bus operating costs in the FY 1986 model are based on the FY 1986 SCRTD organization, the SCRTD departments, and the projected account expenditures for FY 1986. The SCRTD annual budget for FY 1986 was used as the basic resource document. In addition, the June 1985 Revenue and Expense Statement (SCRTD) and inputs from the appropriate departments were used to subdivide some items of labor into more detailed components, and to provide estimates of the labor resources and costs for these. The projected operating statistics were supplied to SCRTD for the FY 1986 operations and are for 107,465,000 annual vehicle-miles, 7,585,000 annual vehicle-hours, 424,400,000 annual unlinked passenger trips, and an average weekday p.m. peak vehicle requirement of 1,987.

For FY 1986, with unit costs in calendar 1985 dollars, the model is

$$\text{Cost} = 0.97{*}VMT + 25.82{*}VHT + 68088{*}PKBS + 0.1162{*}PASS \quad (2)$$

Step Sizes

Step sizes are defined for those expenditure categories where costs vary with the level-of-service variable by increments, rather than continuously. For example, wages and fringes for operators (drivers) are allocated to vehicle hours. However, each saving of a vehicle hour does not generate a saving of operator costs, given union and contract rules, and how operators are assigned to service. In the model, it is assumed that a cost saving or an additional cost outlay is involved each time the change amounts to the equivalent of one half-time operator for the year. This change, in FY 1986, is estimated to occur when there is an increment (up or down) of 853 vehicle-hours. If a change in vehicle hours smaller than this amount takes place, no change in operator cost will be obtained. If a change larger than 853 hours annually is projected, a change in cost is assumed to occur. The change is determined by dividing the total projected change in vehicle hours by 853, and truncating the result to an integer value. This integer value represents the number of half-time operators saved by the change in vehicle hours. The cost savings are estimated by multiplying this number by the step cost of operator wages and fringe benefits. Two numerical examples should serve to illustrate the process. (Note that operator wages and fringe benefits are determined to have a FY 1986 step cost of $21,064.)

1. Cost savings from a reduction of 500 vehicle-hours annually—This value falls below the step size of 853 hours and therefore is assumed to provide no savings in operator wages and fringe benefits.
2. Cost savings from a reduction of 10,000 vehicle-hours annually at one operating division—The value of 10,000 is divided by 853, yielding the result of 11.72. This is truncated to an integer value of 11, indicating that 11 half-time equivalent operators can be saved by this reduction. Further, 11 half-time operators work 9,383 vehicle-hours annually, which is the number of vehicle hours for which there will be a cost saving. Total cost savings from operator wages and fringe benefits are obtained by multiplying $21,064 by 11, for a savings estimate of $231,704 in wages and fringe benefits. It should be noted that the further reduction of 617 (10,000 – 9,383) hours produces no additional cost savings on operators. It should also be noted that, because operators are assigned to divisions, this computation is only correct if all 10,000 vehicle-hours are saved at one division. If the vehicle hours were saved as 5,000 at each of two divisions, the steps would be 5 at each division, totaling 10 steps for a savings of $210,640.

Step sizes are based on primary categories: (*a*) an employee, (*b*) an operating division, and (*c*) a bus facility. Because the number of employees at the SCRTD varies from department to department and from category to category, the step size (in miles, hours, buses, or passengers) also varies among departments and categories. The average size of both an operating division and a maintenance operating division in FY 1986 is 153 peak buses.

Directly Variable Items

Directly variable items are much simpler than stepwise variable items. These are expenditures that can be assumed to vary with every increment or decrement of the level-of-service variable to which they are allocated. For example, fuel is allocated to vehicle miles as a directly variable item with a unit cost of $0.2521 in FY 1986. By allocating fuel as a directly variable item, it is assumed that each change of a vehicle mile will produce a cost change of $0.2521. Thus, a decrease of 1,000 vehicle-miles will save $252.10, and an increase of 10,000 vehicle-miles will increase costs by $2,521. This computation is always systemwide. The model contains very few line items that are directly variable.

Fixed Items

All remaining budget line items are considered to be fixed costs, and these are allocated, for fully allocated costing at the line level, to one of the four variables used by the model. As for the other expenditure items, unit costs are computed for each line item defined as a fixed cost. If a change in service is examined, by definition there will be no changes to total fixed costs. Therefore, the unit cost of each fixed-cost item is recomputed, to yield the same total fixed cost as before the change in service. For example, wages for the general manager's office are assigned as a fixed cost to peak buses, with a FY 1986 unit cost of $179.67. If a service change reduces peak buses from the FY 1986 value of 1,987 to 1,968, the unit cost for wages for the general manager's office increases to $181.40.

SUMMARY OF UNIT COSTS

In Table 2 a summary is provided of the unit and step costs produced by the FY 1986 calibration for average daily p.m. peak buses, annual total vehicle hours, annual total vehicle miles, and annual passenger boardings. Unit costs in Table 2 are in end-of-calendar-year 1985 dollars, assuming 4 percent inflation from July 1985 through June 1986. The definition of annual scheduled vehicle hours and annual scheduled vehicle miles is consistent with the definitions used by the SCRTD in preparing Section 15 Reports (*10*). These unit costs can be used to estimate operating costs for alternative service-level scenarios and for individual bus lines of the SCRTD system, but are subject to the constraints discussed next. Broader error bounds apply here than would apply to a fully programmed model using these calibrations. The step functions in the model make it necessary to assign service changes to the specific operating divisions where they will occur.

SENSITIVITY TESTS

Description

The model described in this paper was calibrated for the FY 1986 projected budget. A second version of the model was created that was calibrated to actual data for FY 1984 (*11*). The objective of the first sensitivity test was to perform an internal calibration of the FY 1984 coefficients to FY 1985 service levels and to project FY 1985 expenditures in order to determine the ability of the model to respond to changes in SCRTD structure and service levels, and to provide guidance on the frequency with which full calibration to a new budget or financial statement will be needed. After the update to FY 1985 was completed, a further update was undertaken to FY 1986 in order to compare the results with the FY 1986 full calibration. Because the period from FY 1984 to FY 1986 covers a number

TABLE 2 UNIT COSTS FOR THE FY 1986 BUS OPERATING COST MODEL

Allocation		Step Basis	Unit/Step Cost ($)	Marginal	Level	Source
To	By					
Buses	Direct	1.0	75.4907	Yes	System	Facility maintenance supplies—radio
Buses	Fixed	1.0	43,640.6643	No	System	Most headquarter departments
Buses	Step	5.8	31,945	Yes	Division	Maintenance operating divisions—servicing
Buses	Step	31.5	42,645	Yes	System	Scheduling checkers
Buses	Step	33	31,771	Yes	Division	Maintenance operating divisions service—deep cleaning
Buses	Step	33.1	40,179	Yes	Division	Maintenance operating divisions—wheelchair service
Buses	Step	47	39,927	Yes	System	Facilities maintenance—electrical maintenance
Buses	Step	60.2	40,173	Yes	Division	Maintenance operating division—farebox maintenance
Buses	Step	110	40,025	Yes	Division	Maintenance operating divisions—special projects
Buses	Step	117	32,032	Yes	System	Central maintenance service
Buses	Step	142	275,925	Yes	System	Facilities maintenance—electrical, property, supplies
Buses	Step	142	50,168	Yes	System	Maintenance—general instruction
Buses	Step	153	750,139	Yes	Division	Transportation operating divisions
Buses	Step	153	44,121	Yes	System	Transportation services—radio dispatcher
Buses	Step	153	96,867	Yes	Division	Contracts and purchasing storekeeper
Buses	Step	153	729,656	Yes	Division	Maintenance operating divisions—miscellaneous supplies, additionals
Buses	Step	166	47,954	Yes	System	Central maintenance—central shop supplies
Hours	Fixed	1.0	0.1696	No	System	Transportation general—all
Hours	Fixed	1.0	0.3326	No	System	Transportation services—wages
Hours	Fixed	1.0	0.0079	No	System	Nondepartmental—fuel/lube, nonrevenue
Hours	Step	853	19,383	Yes	Division	Transportation operating divisions—operations
Hours	Step	853	1,681	Yes	Division	Nondepartmental—worker's compensation, operations
Hours	Step	216,714	34,400	Yes	System	Maintenance operating divisions—nonrevenue maintenance
Hours	Step	329,783	42,044	Yes	System	Scheduling—schedule makers
Hours	Step	421,400	44,002	Yes	System	Transportation services—street supervisors
Hours	Step	446,176	34,471	Yes	System	Police—transportation services inspections
Hours	Step	474,000	44,244	Yes	System	Transportation instructors, operator training
Hours	Step	632,083	31,084	Yes	System	Accounts and fiscal—payroll clerk
Miles	Direct	1.0	0.2366	Yes	System	Maintenance operating divisions—parts, lube, etc.
Miles	Direct	1.0	0.2703	Yes	System	Nondepartmental—fuel and taxes
Miles	Step	107,465	524	Yes	System	Nondepartmental expenses—expenses for property damage
Miles	Step	107,465	2,531	Yes	System	Nondepartmental expenses provided for property damage
Miles	Step	69,332	3,710	Yes	System	Nondepartmental worker's compensation, maintenance
Miles	Step	178,810	40,186	Yes	Division	Maintenance operating divisions—running repairs
Miles	Step	2,149,300	40,180	Yes	Division	Maintenance operating divisions—inspectors
Miles	Step	2,755,513	40,179	Yes	System	Central maintenance—running repairs
Miles	Step	2,904,459	40,189	Yes	System	Central maintenance—mechanical
Miles	Step	3,160,735	40,206	Yes	System	Central maintenance—electrical
Miles	Step	3,358,281	40,187	Yes	System	Central maintenance—body shop
Miles	Step	3,582,167	40,200	Yes	System	Central maintenance—transmissions
Miles	Step	3,960,185	39,984	Yes	System	Central maintenance—engine line
Miles	Step	4,477,708	40,209	Yes	System	Central maintenance—welding
Miles	Step	5,656,053	40,158	Yes	System	Central maintenance—cylinder head
Miles	Step	5,656,053	40,158	Yes	System	Central maintenance—paint shop
Miles	Step	7,676,071	40,215	Yes	System	Central maintenance—machine shop
Miles	Step	7,676,071	40,215	Yes	System	Central maintenance—sheet metal shop
Miles	Step	8,266,538	40,231	Yes	System	Central maintenance—frame shop
Miles	Step	8,266,538	40,231	Yes	System	Central maintenance—upholstery
Miles	Step	9,769,545	40,182	Yes	System	Central maintenance—systems
Miles	Step	13,433,125	40,125	Yes	System	Central maintenance—engine parts
Miles	Step	13,433,125	40,125	Yes	System	Central maintenance—engine teardown
Miles	Step	17,910,833	40,166	Yes	Division	Maintenance operating divisions—road failure
Miles	Step	21,493,000	40,033	Yes	System	Central maintenance—sign shop
Miles	Step	26,866,250	40,250	Yes	System	Central maintenance—tool and unit
Passenger	Direct	1.0	0.0011	Yes	System	Print shop—timetables
Passenger	Fixed	1.0	0.0070	No	System	Marketing and communication
Passenger	Fixed	1.0	0.0029	No	System	Customer relations (fixed)
Passenger	Step	163,231	524	Yes	System	Expenses for public liability
Passenger	Step	163,231	14,481	Yes	System	Provisions for uninsured public liability
Passenger	Step	4,715,555	29,678	Yes	System	Customer relations telephone clerks
Passenger	Step	12,482,353	34,470	Yes	System	Transit police passenger security
Passenger	Step	12,860,606	32,273	Yes	System	Accounting cash clerks
Passenger	Step	19,290,909	30,955	Yes	System	Marketing and communications ticket clerk

of organizational and service level changes, the procedure was believed to be quite a stringent test of the model's robustness.

The second sensitivity test aimed to determine the ability of the model to project costs for a package of service changes and to determine whether or not it is necessary to undertake an internal recalibration of the model whenever such a package of changes is examined. The test was also intended to provide a comparison between the existing cost model used by the SCRTD (*8*) (with costs reduced by 25 percent to account for fixed overhead costs) and the results from use of this model. The package of service changes was constructed by considering a potential list of service cuts that might be implemented with the goal of generating annual savings of $10 million in operating and maintenance costs.

Two sensitivity tests were designed to be executed for the procedure. First, determination of results of a simple application of the model was necessary, in which marginal costs were estimated and all step sizes were held the same as in calibration. This provided a comparison of the new cost model with the existing SCRTD model and also indicated what could be involved in application of the new cost model to small service changes. Second, the effect on the estimated cost savings if the model were internally recalibrated before completing the cost estimation needed to be determined. This test indicated the extent to which such recalibration may be necessary for short-range application of the model.

Application of the Procedures

Internal Recalibration of the Cost Model

The change in the Consumer Price Index (CPI) from the end of FY 1984 to the middle of FY 1986 was 4.6 percent for the Los Angeles standard metropolitan statistical area (SMSA) (*12*). FY 1984, FY 1985, and FY 1986 (projected) values of the level-of-service variables used in the cost model are given in Table 3, along with the final audited values for FY 1984—the calibration was done with actual data for the first three quarters of FY 1984 and projected data for the last quarter. The recalibration is unaffected by whether vehicle hours and vehicle miles are expressed as revenue, scheduled, or total values provided that the model is always applied with values consistent with the model calibration or recalibration.

In Table 4 the FY 1984 budgets are given for each type of variation for each service-level variable, along with the unit costs derived for FY 1984 for reference purposes. The CPI adjustment is then applied to determine the FY 1985 escalated budget, as given, and the budget values are then divided by the FY 1985 service-level values to obtain new unit costs. The latter two items are given in Table 4 as the escalated budget and the recalibrated unit costs. The same two calculations are also given for FY 1986, for which the CPI change from FY 1984 was determined to be 11.285 percent.

The result of the test, given in Table 4, is a model projection of total expenditure of $442,727,000 for FY 1985 compared with actual audited operating expenditures for FY 1985 of $439,903,899. The difference (overestimate) of $2,823,101 represents 0.64 percent of the FY 1985 actual expenditures. The same process for the FY 1986 estimated budget, using the FY 1986 estimated service level data used earlier to recalibrate the model, provides budget lines and coefficients that generate a total forecast budget of $481,256,000 compared with the SCRTD budget of $484,174,000. In this case, the difference (underestimate) is $2,918,000 and represents 0.60 percent of the SCRTD budget for FY 1986.

In Table 5 the final coefficients from Table 4 are summarized for the four service-level variables, and some shifting of cost between the service-level variables resulting from some internal reorganization of the SCRTD between FY 1984 and FY 1986 is shown. As a result, the match between the internally recalibrated figures and the actual calibration of FY 1986 is not as close as the overall budget projections would indicate. However, the results are encouraging in terms of the robustness of the model and the ability of the internal recalibration to produce sensible results.

Direct Model Application Without Recalibration

SCRTD planning staff identified a number of service cuts intended to total $10 million in terms of FY 1986 operating cost cuts for a full year. These service cuts were originally costed using a version of the SCRTD model (*8*) that had been adjusted to approximate marginal costs. In Table 6 the calculations for each line or period on a line are summarized and compared with the SCRTD cost model estimates of cost savings. The line costs in Table 6 do not reflect the potential savings within a division or across the entire SCRTD that would be achieved when the service cuts are summed together; these additional savings are as follows:

Division	*Operating Cost ($)*
1	25,100
3	349,800
5	69,400
6	479,100
7	48,200
8	333,800
9	685,500
10	319,200
12	603,700
15	62,000
16	687,500
18	827,200

Note that systemwide costs total $3,423,100, so that a total of systemwide and division costs is $7,913,600.

The full set of proposed service reductions is estimated at

TABLE 3 ACTUAL AND PROJECTED ANNUAL LEVELS OF SERVICE FOR FY 1984, 1985, AND 1986

	Value			
Variable	FY 1984 Calibrated	FY 1985 Actual	FY 1986 Estimated	FY 1984 Audited
P.M. peak buses	2,063	2,009	1,987	1,992
Vehicle hours	7,152,000	7,041,642	7,585,000[a]	7,062,585
Vehicle miles	95,122,000	91,959,736	107,465,000[a]	93,031,164
Passengers	465,400,000	497,158,321	424,400,000	465,637,732

[a]These are total miles and hours, while all other entries are revenue miles and hours.

TABLE 4 COMPUTATION OF RECALIBRATED COSTS AND ESCALATED BUDGETS

Variable	Type	FY 1984 Unit Cost ($)	FY 1984 Budget ($000)	FY 1985 Budget ($000)	FY 1985 Unit Cost ($)	FY 1986 Budget ($000)	FY 1986 Unit Cost ($)
Peak buses	Direct	79.01	163.0	170.3	82.57	181.4	87.93
	Fixed	33,279.69	68,656.0	71,745.5	35,712.06	76,403.8	38,451.85
	Step	22,497.33	46,412.0	48,500.5	24,141.63	51,649.6	25,993.76
Subtotal		55,856.03	115,231.0	120,412.0	59,936.26	128,228.0	64,533.54
Vehicle hours	Fixed	0.59	4,250.0	4,441.3	0.63	4,729.6	0.62
	Step	23.80	170,185.0	177,843.3	25.26	189,390.4	24.97
Subtotal		24.39	174,435.0	182,285.0	25.89	194,120.0	25.59
Vehicle miles	Direct	0.57	54,491.0	56,943.1	0.60	60,640.3	0.64
	Step	0.49	46,644.0	48,743.0	0.53	51,907.8	0.48
Subtotal		1.06	101,135.0	103,785.0	1.13	120,415.0	1.12
Passenger boardings	Direct	0.0011	490.0	512.1	0.0011	545.3	0.0012
	Fixed	0.01	4,078.0	4,261.5	0.0086	4,538.2	0.0107
	Step	0.06	30,065.0	31,417.9	0.06	33,457.8	0.0788
Subtotal		0.0711	34,633.0	36,245.0	0.0729	38,493.0	0.0907
Total cost/ budget ($)			425,434,000	442,727,000		481,256,000	

$7,913,600 by this operating cost model, instead of the $10,407,000 derived from the current SCRTD model (*8*). The estimate from the new model is approximately 24 percent lower than the SCRTD model. The model also shows that there are significant intra-division and systemwide economies possible in a group of service changes of this size, given that the difference between the line-by-line costs and the division/systemwide costs is about $1.5 million in a set of service changes initially costed at $6.4 million. Gross costs of these service changes are $10,412,900 with revenues of $2,499,200. An investigation of the detailed differences in the cost estimates revealed that most of the difference results from fractions of positions that could not be saved in reality and should not, therefore, be counted by any cost model.

The second notable element of this cost model is shown in Table 7, which gives the sources of the costs identified in Table 6 and indicates the cost attributable to each element. Of the gross costs for the service changes listed in these tables, approximately $2.8 million is derived from materials savings, such as fuel and parts, and from savings on property damage and public liability. These savings would be achieved without any other action on the part of the SCRTD than by cutting the service. All of the remaining $7.6 million in costs are from labor positions or labor-related costs. For example, $6.1 million in savings will accrue from the 144 operators used to operate the services in Table 6. However, if these operators are not laid off, only a small fraction of the savings would occur from reductions in hours paid.

Model Application With Recalibration

To determine the effects of internal recalibration of the model for a significant set of service changes, the changes used in the preceding section were reestimated using a single recalibration for the entire package. The primary effects of internal recalibration will be on the fixed costs, which were not included in the estimation of the service-change costs described in the previous section. However, some changes may occur in step sizes as a result of the service changes. These can be identified readily by using Table 7, which indicates those line items that are changed and which implicitly identifies all unchanged labor categories.

The internal recalibration was undertaken by recomputing each stepwise line item in the spreadsheets, which determined the change in FY 1986 cost, the change in the base, and the

TABLE 5 SUMMARY OF FINAL COEFFICIENTS FROM INTERNAL RECALIBRATION AND FULL CALIBRATION OF FY 1986

	Coefficient/Unit Cost ($)			
Variable	FY 1984 Calibrated	FY 1985 Internally Recalibrated	FY 1986 Internally Recalibrated	FY 1986 Calibrated
Peak buses	55,969	59,936	64,534	68,088
Vehicle hours	24.390	25.887	25.593	25.82
Vehicle miles	1.063	1.129	1.121	0.97
Passengers	0.0744	0.0729	0.0907	0.1162

TABLE 6 SUMMARY OF COSTS FOR SPECIFIC LINE AND PERIOD SERVICE CUTS, BASED ON THE FY 1986 OPERATING COST MODEL

Line No.	Division No.	Service Day	Operating Cost ($)	Cumulative Cost ($)	SCRTD Operating Cost ($)	Cumulative SCRTD Cost ($)
203	3	Weekday	48,400	48,400	98,000	98,000
203	3	Saturday	1,000	49,400	19,000	117,000
203	3	Sunday	1,100	50,500	21,000	138,000
203	3	All	94,100	94,100	138,000	138,000
225/ 226	18	Saturday	134,400	228,500	233,000	371,000
208	3	Sunday	25,700	254,200	34,000	405,000
175	3	Saturday	24,200	278,400	55,000	460,000
175	3	Sunday	800	279,200	30,000	490,000
175	3	Saturday/ Sunday	46,000	300,200	85,000	490,000
208	3	Saturday	23,000	323,200	29,000	519,000
192/ 194	16	Weekday	427,700	750,900	636,000	1,155,000
250/ 253	10	Sunday	21,600	772,500	52,000	1,207,000
430	6	Weekday	44,400	816,900	83,000	1,290,000
130	12	Sunday	64,300	881,200	151,000	1,441,000
259	9	Sunday	42,100	923,300	103,000	1,544,000
236	8	Sunday	21,600	944,900	63,000	1,607,000
161	8	Weekday	181,600	1,126,500	333,000	1,940,000
205	12	Saturday	56,200	1,182,700	130,000	2,070,000
205	12	Sunday	14,500	1,197,200	52,000	2,122,000
205	12	Saturday/ Sunday	70,700	1,197,200	182,000	2,122,000
220	7	Sunday	40,800	1,238,000	91,000	2,213,000
487/ 491	9	Saturday	85,800	1,323,800	168,000	2,381,000
487/ 491	9	Sunday	40,100	1,363,900	115,000	2,496,000
487/ 491	9	Saturday/ Sunday	132,700	1,370,700	283,000	2,496,000
166/ 168	8	Sunday	42,300	1,413,000	129,000	2,625,000
208	3	Weekday	190,300	1,603,300	137,000	2,762,000
208	3	All	242,400	1,606,700	200,000	2,762,000
462	1	Sunday	41,400	1,648,100	92,000	2,854,000
236	8	Saturday	41,900	1,690,000	103,000	2,957,000
236	8	Saturday/ Sunday	84,500	1,711,000	166,000	2,957,000
293	16	Weekday	454,100	2,165,100	255,000	3,212,000
262	9	Sunday	38,800	2,203,900	114,000	3,326,000
225/ 226	18	Weekday	769,700	2,973,600	1,126,000	4,452,000
225/ 226	18	All	968,400	3,037,900	1,359,000	4,452,000
268	3	Sunday	39,900	3,077,800	97,000	4,549,000
130	12	Saturday	59,300	3,137,100	130,000	4,679,000
130	12	Saturday/ Sunday	148,400	3,161,900	281,000	4,679,000
250/ 253	10	Saturday	36,900	3,198,800	82,000	4,761,000
250/ 253	10	Saturday/ Sunday	79,600	3,219,900	134,000	4,761,000
271	12	Weekday	164,900	3,384,800	299,000	5,060,000
147	12	Saturday	16,800	3,401,600	44,000	5,104,000
147	12	Sunday	(4,900)	3,396,700	23,000	5,127,000
147	12	Saturday/ Sunday	33,000	3,417,800	67,000	5,127,000
488	9	Sunday	18,000	3,435,800	54,000	5,181,000
274/ 276	9	Weekday	495,200	3,931,000	767,000	5,948,000
42	18	Sunday	99,600	4,030,600	203,000	6,151,000
259	9	Saturday	37,100	4,067,700	88,000	6,239,000
259	9	Saturday/ Sunday	100,200	4,088,700	191,000	6,239,000

TABLE 6 *continued*

Line No.	Division No.	Service Day	Operating Cost ($)	Cumulative Cost ($)	SCRTD Operating Cost ($)	Cumulative SCRTD Cost ($)
434	6	Sunday	83,200	4,171,900	198,000	6,437,000
220	7	Saturday	36,500	4,208,400	77,000	6,514,000
220	7	Saturday/ Sunday	77,300	4,208,400	168,000	6,514,000
482	16	Sunday	38,200	4,246,600	123,000	6,637,000
267	9	Sunday	17,500	4,264,100	63,000	6,700,000
209	5	Sunday	54,200	4,318,300	110,000	6,810,000
493	9	Sunday	17,900	4,336,200	36,000	6,846,000
215	18	Saturday	15,900	4,352,100	57,000	6,903,000
262	9	Saturday	54,800	4,406,900	100,000	7,003,000
262	9	Saturday/ Sunday	118,400	4,431,700	214,000	7,003,000
434	6	Saturday	79,500	4,511,200	174,000	7,177,000
434	6	Saturday/ Sunday	180,700	4,529,200	372,000	7,177,000
158	15	Sunday	17,200	4,546,400	71,000	7,248,000
154	8	Sunday	36,200	4,582,600	86,000	7,334,000
183	15	Sunday	35,400	4,618,000	68,000	7,402,000
169	15	Saturday	35,400	4,653,400	100,000	7,502,000
423	8	Weekday	88,000	4,741,400	223,000	7,725,000
119/ 126	18	Saturday	52,100	4,793,500	108,000	7,833,000
438	18	Weekday	96,300	4,889,800	197,000	8,030,000
265/ 275	12	Weekday	374,400	5,264,200	588,000	8,618,000
211	5	Saturday	14,100	5,278,300	56,000	8,674,000
434	6	Weekday	638,400	5,916,700	993,000	9,667,000
434	6	All	883,600	5,981,200	1,365,000	9,667,000
256	10	Sunday	31,400	6,012,600	95,000	9,762,000
103	5	Sunday	14,900	6,027,500	44,000	9,806,000
255	10	Sunday	32,200	6,059,700	66,000	9,872,000
576	10	Weekday	361,500	6,421,200	535,000	10,407,000

change in the number of positions. This computation produced a new estimated step size for all steps. Using these new step sizes in the calculations for the division and systemwide costs of the service changes produced a revised estimate of net costs of $8,061,900, an increase of $148,300, or 2 percent of the original cost estimate. Based on this, it appears that internal recalibration of the model is unnecessary, at least for service changes on the order of 50 peak buses, and $10 million in gross costs.

LIMITATIONS ON THE MODEL APPLICATION

The primary limitation on the use of this cost model is that the step costs and unit costs are based on projected or reported labor and organization for the agency for the calibration year. Thus, the model cannot account for significant reorganization or changes in labor productivity or costs. Furthermore, if significant changes are proposed in service levels, the model should be recalibrated to adjust all step sizes and the unit costs for fixed costs to take into account the changes in the base over which the various costs are spread. Recalibration can potentially include a review of the allocation of certain cost items, together with the addition of any new line items introduced in a subsequent year's budget. Experience with this model to date indicates that it is quite robust under normal year-to-year changes, and may not require recalibration for a number of years as long as relatively small changes are made each year.

If service levels are increased, the bases of peak buses, vehicle hours, vehicle miles, and passenger boardings are likely to increase; unit costs of fixed budget items will decrease, and step sizes of stepwise variables will increase until a reorganization takes place. If service levels are decreased, each of these bases are also likely to decrease; unit costs of fixed budget items will increase, and step sizes of stepwise variables will decrease, again, until a reorganization takes place. When service changes are small, unit cost changes are unlikely to have a significant effect on the estimation of costs, as shown by the sensitivity tests reported in this paper. Major system changes, in excess of ±10 percent or more of current service, can be expected to significantly affect the accuracy of the estimated costs.

CONCLUSIONS

The cost-allocation model presented in this paper uses multiple-step functions related to specific positions in a transit operation. The model can provide accurate projections of short-range transit costs and is being used for projecting long-range

TABLE 7 SOURCES OF COSTS FOR THE SERVICE CHANGES IN TABLE 4

Source Level	Department	Item	Quantity	Allocated Cost ($)
Systemwide	Facilities maintenance	Supplies—radios	52	3,926
	Scheduling	Schedule checkers	1	42,645
	Facilities maintenance	Electronics maintenance	1	39,928
	Maintenance operating divisions	Nonrevenue maintenance	1	34,400
	Maintenance operating divisions	Parts, lubricants	–	1,030,705
	Nondepartmental expenses	Fuel and taxes	–	1,177,723
	Nondepartmental expenses	Workmen's compensation—maintenance	62	229,999
	Nondepartmental expenses	Expenses and provisions for property damage	40[a]	122,200
	Central maintenance	Running repairs mechanic	1	40,179
	Central maintenance	Mechanical maintenance, mechanic	1	40,189
	Central maintenance	Electrical maintenance, mechanic	1	40,206
	Central maintenance	Body shop mechanic	1	40,187
	Central maintenance	Transmission mechanic	1	40,200
	Central maintenance	Engine line mechanic	1	39,983
	Print shop	Timetable printing	–	5,769
	Nondepartmental expenses	Expenses for public liability	31[a]	16,239
	Nondepartmental expenses	Provisions for public liability	31[a]	448,904
	Customer relations	Telephone clerks	1	29,678
Division 1	Transportation operations division	Operators	1[b]	38,766
	Nondepartmental expenses	Workmen's compensation operations	1[b]	3,363
Division 3	Transportation operations division	Operators	9[b]	348,897
	Nondepartmental expenses	Workmen's compensation operations	9[b]	30,263
	Maintenance operating division	Running repairs mechanic	1	40,186
Division 5	Transportation operating divisions	Operators	3[b]	116,299
	Nondepartmental expenses	Workmen's compensation operations	3[b]	10,088
Division 6	Maintenance operating division	Service workers	1	31,945
	Transportation operating division	Operators	18[b]	697,794
	Nondepartmental expenses	Workmen's compensation operations	18[b]	60,525
	Maintenance operating division	Running repairs mechanic	3	120,559
Division 7	Transportation operations division	Operators	2[b]	77,533
	Nondepartmental expenses	Workmen's compensation operations	2[b]	6,725
Division 8	Transportation operating division	Operators	11[b]	426,430
	Nondepartmental expenses	Workmen's compensation operations	11[b]	36,988
	Maintenance operating division	Running repairs mechanic	2	80,373
Division 9	Transportation operating division	Operators	22.5[b]	872,243
	Nondepartmental expenses	Workmen's compensation operations	22.5[b]	75,657
	Maintenance operating divisions	Running repairs mechanic	3	120,559
Division 10	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating division	Operators	12[b]	465,196
	Nondepartmental expenses	Workmen's compensation operations	12[b]	40,350
	Maintenance operating divisions	Running repairs mechanic	1	40,186
Division 12	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating division	Operators	19.5[b]	755,944
	Nondepartmental expenses	Workmen's compensation operations	19.5[b]	65,569
	Maintenance operating divisions	Running repairs mechanic	3	120,559
Division 15	Transportation operating division	Operators	3[b]	116,299
	Nondepartmental expenses	Workmen's compensation operations	3[b]	10,088
Division 16	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating divisions	Operators	18[b]	697,794
	Nondepartmental expenses	Workmen's compensation operations	18[b]	60,525
	Maintenance operating divisions	Running repairs mechanic	2	80,373
Division 18	Maintenance operating divisions	Service workers	1	31,945
	Transportation operating division	Operators	25[b]	969,159
	Nondepartmental expenses	Workmen's compensation operations	25[b]	84,063
	Maintenance operating divisions	Running repairs mechanic	4	160,745

[a]Number of accidents involving property damage (average).
[b]Full-time equivalent positions.

costs. The model automatically ignores changes in service levels that are too small to generate cost increments or decrements and permits costs to be split between fixed and variable cost items. The model is therefore able to be used to produce both marginal allocated costs and fully allocated costs.

Sensitivity tests reveal that this bus cost model is a robust short-term model that produces acceptably accurate results (comparing systemwide costs) even under conditions of some significant amount of reorganization and service change. Changes of less than 10 percent in service levels do not require recalibration of the model, as shown by the documented sensitivity tests. The tests also indicate that, as should be expected, the model produces lower estimates of cost than are produced by a standard linear-in-coefficients model of bus costs.

An interesting side benefit of the short-range version of the model is that it provides identification of the specific budget items that contribute to a cost savings or cost increase. This property allows the model to provide additional information about the financial implications of alternative policies with respect to hiring and firing related to service changes and can readily reveal the consequences of different policies on the cost structure of transit service.

Overall, it appears that the cost allocation model tested here is appropriately sensitive, robust under fairly substantial organizational changes in a transit agency, able to provide new insights into the implications of service changes for both manpower and material supplies of a transit operation, and accurate to an acceptable level. However, the model is probably most exciting because of its basis in manpower and potential for future enhancements that could enable it to indicate changing relationships in an organization chart, changes in requirements for supervision and training, and changes in work rules and union contracts.

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