Development of a Bus Operating Cost Model Based on Disaggregate Data

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ABSTRACT

As part of a major ongoing study to assess the efficiency and equity of the Southern California Rapid Transit District's current as well as proposed pricing policies, a set of models designed to estimate marginal line-by-line operating costs has been developed. Operating costs associated with different times of day (peak versus off-peak periods), different types of service (express versus local), and different days of operation (weekdays versus weekends) can be identified by these models. The approach taken in the design of the models is presented and the methods, assumptions, and results of the modeling process are described.

Traditionally, transit operating cost models were developed through a cost allocation procedure that attributed each and every operating and capital expense to the specific measurement of service that was believed to have primarily caused it. Under this unit cost approach, subcategories of operating expenses have typically been associated with one of four service variables: (a) vehicle-miles, (b) vehicle-hours, (c) revenue passengers, or (d) peak buses. Fuel, tire, maintenance, and repair costs, for example, have usually been associated with vehicle-miles. Driver wages and fringe benefits have usually been associated with vehicle-hours. Expense items related to the size of the peak fleet, on the other hand, have typically been related to a peak vehicle factor. Administrative overhead, clerical staff, and storage facilities are commonly attributed to the peak vehicle variable. The revenue passenger variable has usually been assumed to account for expenses associated with accident payment and liability premiums. Not all expenses, however, can be clearly tied to a single explanatory variable. Some transit agencies, for example, make the case that maintenance and repair expenses relate not only to the distance traveled but also to the vehicle-hour factor to reflect the effect of congestion along the route. To the degree that route congestion equates with greater numbers of vehicle stops, a close association between vehicle-hours and maintenance expenses can be inferred.

The unit cost approach represents an attempt to apportion transit operating expenses among all lines, using cost parameters generated from systemwide data. An implicit assumption of this aggregate approach is that neither driver labor agreements nor the distribution of an agency's services (between the peak and base periods) has any effect on the variations in estimated line costs. To the extent that these factors do not directly or indirectly vary among lines, the computation of line-by-line cost estimates from systemwide data appears to be reasonable. Realistically, however, the cost characteristics of lines should be expected to differ as the "peaking" of lines varies. An inner-city local route requiring a nearly equal spread of service throughout the day, for instance, would be expected to experience relatively lower unit costs compared to a peak-hour-only service, on the basis of the overtime and premium pay penalities stated in the labor agreements.

In contrast to the unit cost approach, direct assignments of driver wages, fuel, repairs, and so forth provide the optimal solution. Direct linkage of operating expenses to individual lines, nevertheless, necessitates an elaborate accounting system and would probably yield insufficient marginal gains in cost estimate accuracy to justify the additional accounting expenses. Ideally, a cost allocation method that strikes a balance between the unit cost and direct assignment approach is preferred.

COST CENTERS APPROACH

As part of a major ongoing study to assess the efficiency and equity of the Southern California Rapid Transit District's (SCRTD) pricing policies, a model that would address marginal line-by-line operating costs was desired. In an attempt to offer a better alternative to the unit cost and direct assignment modeling approaches, a disaggregate approach to identifying line-by-line operating costs was developed. Because the basic operating characteristics of various types of SCRTD services could be generally associated with the divisions (garages) from which the services originated, a disaggregate or "cost centers" modeling approach based on divisional data was chosen. To the extent that variations in divisional expenses could be explained by variations in divisional service, increases in the accuracy of line-by-line cost estimates were considered potentially significant.

In addition, because nearly half of SCRTD's expenses are incurred as operator labor costs, it was decided that an appropriate modeling objective would be to accurately identify the peak versus off-peak operator pay-hour differentials associated with the current labor agreement of SCRTD's United Transportation Union (UTU). Given that a cost centers approach could identify service-related expenses that differ from the system average expense, and given that divisional operator wages played an important role in explaining these differences, an increase in the model's accuracy in estimating line-by-line costs seemed possible.

The attraction of this approach is its ability to reflect the relative differences in the cost characteristics of service types on the basis of quantitative analysis of divisional expenses and service-related data. As opposed to the unit cost approach, where the selection of the model variables and their respective cost coefficients is subjective, the cost centers approach will allow the most appropriate model variables to be chosen objectively and will statistically determine each variable's appropriate cost coefficient. To avoid incorrect or artificial results, steps discussed in the following sections were incorporated into the modeling design.

EVALUATION OF DIVISIONS AS COST CENTERS

Operating cost models are typically constrained by the level at which expenses are accounted. Although operator wages, mechanic wages, fuel costs, and so forth are frequently incurred at less than the total system level (e.g., trip by trip), the accounting records of these expense items are usually maintained only at the system level. Although SCRTD also maintains system-level expense accounts, the origin of a majority of SCRTD's expenses is at the division level. Between 50 and 60 percent of SCRTD's total operating expenses are tallied among 12 operating divisions. The first step in the design of a disaggregate modeling approach, therefore, was to test whether SCRTD's divisional unit costs differed from the system average. If significant variations could be quantified, as well as subjectively explained, a statistical approach could be developed that would objectively explain the variations in divisional unit costs. Given that a number of service-related variables were found to closely correlate with variations in divisional expenses, the service variables with the "closest fit" could be used as the framework for the modeling process. However, if little or no variation between divisional unit costs could be quantified, justification for the use of a traditional unit cost model based on systemwide expenses (for line-by-line applications) would be confirmed.

To test the degree of variation between SCRTD's divisional unit costs, an analysis of SCRTD's cost per vehicle-mile and cost per vehicle-hour was made for each of the 12 operating divisions. Total expenses incurred and accounted for by division were divided by each division's respective total vehicle-miles and total vehicle-hours to produce the results given in Tables 1 and 2. A list of the expense accounts maintained for each division follows: An asterisk (*) indicates the expense accounts chosen for inclusion in the basic modeling design.

* UTU operator normal pay
* UTU operator nonwork pay
* UTU operator scheduled overtime and premium pay
* UTU operator unscheduled overtime and premium pay
* UTU operator part-time pay
UTU nonoperator normal pay
* UTU nonoperator nonwork pay
* Noncontract normal pay
* Noncontract nonwork pay
Noncontract overtime and premium pay
* Noncontract straight time and overtime pay
Contract working as noncontract pay
* Amalgamated Transit Union (ATU) revenue equipment mechanic normal pay
* ATU revenue equipment mechanic nonwork pay
* ATU revenue equipment mechanic overtime and premium pay
* ATU revenue equipment nonmechanic normal pay
* ATU revenue equipment nonmechanic nonwork pay
* ATU revenue equipment nonmechanic overtime and premium pay
ATU nonrevenue equipment mechanic normal pay
ATU nonrevenue equipment mechanic nonwork pay
ATU nonrevenue equipment mechanic overtime and premium pay
* Brotherhood of Railway, Airline and Steamship Clerks, Freight Handlers, Express and Station Employees (BRAC) employee normal pay
* BRAC employee nonwork pay
* BRAC employee overtime and premium pay
* Uniform and tool allowances
* Training programs
* Other fringe benefits
Professional and technical services
Contract maintenance services
Custodial services
Contract maintenance services of revenue vehicles
* Other services
* Fuel for revenue equipment
Fuel for nonrevenue equipment
* Lubricant for revenue equipment
Lubricant for nonrevenue equipment
* Tires and tubes for revenue equipment
Tires and tubes for nonrevenue equipment
* Other materials and supplies for revenue equipment
* Other materials and supplies for nonrevenue equipment
Buildings and grounds materials and supplies
* Office supplies and equipment
Promotional and informational materials
* Tools and expendable equipment
* Other materials and supplies
* Water
Gas (natural)

TABLE 1 SCRTD Mileage Unit Costs by Division (FY 1982-1983)

Division		Cost per Vehicle-Mile ($)
No.	Name	
9	El Monte	1.67
12	Long Beach	1.71
15	Sun Valley	1.79
8	Chatsworth	1.94
16	Pomona	2.02
1	Alameda	2.13
18	South Bay	2.23
5	South Central L.A.	2.25
3	Cypress Park	2.28
2	Los Angeles	2.32
6	Venice	2.46
7	West Hollywood	2.59
Mean		2.12
Standard deviation		0.29

TABLE 2 SCRTD Hourly Unit Costs by Division (FY 1982-1983)

Division		Cost per Vehicle-Hour ($)
No.	Name	
1	Alameda	26.65
2	Los Angeles	27.79
5	South Central L.A.	27.88
7	West Holywood	27.91
3	Cypress Park	27.98
9	El Monte	28.69
15	Sun Valley	29.01
6	Venice	30.21
12	Long Beach	30.39
18	South Bay	32.80
8	Chatsworth	32.90
16	Pomona	41.97
Mean		30.35
Standard deviation		4.16

- * Electricity
- Telephone and telegraph
- Other facilities
- * Vehicle license and registration fees
- * Fuel and lubrication taxes of revenue equipment
- Fuel and lubrication taxes of nonrevenue equipment
- Other taxes
- Dues and subscriptions
- Travel and meetings
- Schedule checkers travel expenses
- * Petty cash expenditures
- Other miscellaneous expenditures
- Passenger station leases and rentals
- Passenger parking facilities leases and rentals
- Service vehicle leases and rentals
- Operating yard and station leases and rentals
- Other general administration facilities leases and rentals
- Public liability

For each unit cost analysis, the audited expense accounts for FY 1982-1983 were used. That the total operating expenses maintained for the 12 operating divisions as a whole account for approximately 55 percent of SCRTD's total FY 1982-1983 operating budget is noteworthy.

From the data in Tables 1 and 2, significant variations in divisional costs per vehicle-mile and costs per vehicle-hour are apparent. Divisional costs per mile vary by as much as $0.92 (55 percent) per mile, whereas the divisional costs per hour vary by as much as $15.32 (58 percent) per hour. As expected, divisions that operate relatively more high-speed freeway service tend to accumulate lower costs per mile but, because of the nature of their services (generally peak period services with relatively higher operator pay-hour-to-vehicle-hour ratios), they also tend to have higher costs per hour. The statistics given in Tables 1 and 2 generally illustrate that divisions farthest from the Los Angeles central business district (CBD) have the lowest costs per mile and the highest costs per hour (Figure 1).

From a modeling perspective, the data in Tables 1 and 2 clearly show that system average unit costs do not present an accurate picture of SCRTD's variety of services. An operating cost model based on a division cost centers approach, therefore, can indeed improve the accuracy of line-by-line cost estimates.

DESIGN OF BASIC MODELING FRAMEWORK

To define the service-related variables that explain the variations in the divisional unit costs noted in Tables 1 and 2, a correlation matrix between divisional expense accounts and divisional service statistics was developed. The expense accounts that were thought to have "logical" relationships with various service-related variables were statistically analyzed using a Pearson Correlation Matrix. [The expense accounts that were chosen are noted by an asterisk (*) in the previous list.] The service-related statistics that were tested include

- Total vehicle-miles
- Revenue vehicle-miles,
- In-service vehicle-miles,
- Total vehicle-hours,
- Revenue vehicle-hours,
- In-service vehicle-hours,
- Number of bus pullouts, and
- Peak buses.

An analysis of the correlation matrix indicated that, of the eight service variables chosen, virtually all had relatively significant correlations with each of the tested expense accounts. In general, any one of the service variables would have made a good estimator of divisional expenses. On the other hand, various combinations of service variables appeared to provide even better explanations of division expenses, indicating that variations in divisional expenses can only be partly explained by one service variable. A combination of the total vehicle-hour and peak bus variables, for example, indicated a better correlation with the various expense accounts than either of the variables individ-

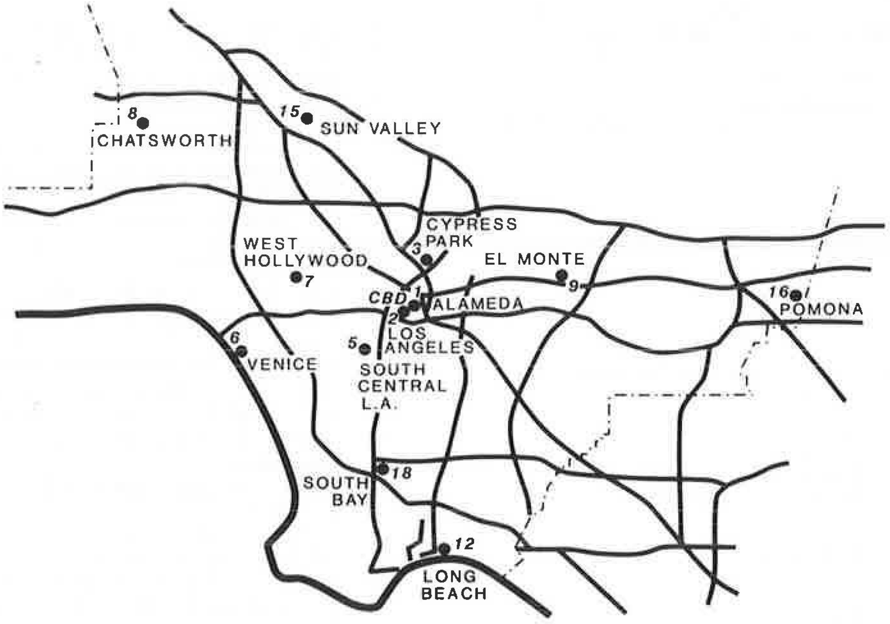

FIGURE 1 Division location map.

ually. A multivariate regression analysis, therefore, was used to define which variables in tandem produced the best estimate of divisional expenses. To avoid the development of a model with high intercorrelation between the independent variables (multicollinearity), and as an aid in identifying the specific variables that explain the variations in operating expenses, a nontraditional approach to multivariate modeling design was developed.

Instead of one model in which all expense accounts are correlated with each service variable at the same time, three separate models were developed. The expense accounts that consistently maintained a high correlation with each of the hourly service variables (total, revenue, and in-service hours) made up the dependent variable of the first model. Individual correlations between these hourly expenses and each of the three hourly service variables indicated which service variable was capable of making the best estimate of hourly expenses. The same process was used to define the "best" mileage and peak service variables. The resultant models took the following forms:

FY 1982-1983 divisional hourly expenses =
$507,639 (constant) + SIG T = .09
$14.50 (total vehicle-hours) SIG T = .00, $R^2 = .993$ (1)

FY 1982-1983 divisional mileage expenses =
$505,822 (constant) + SIG T = .12
$0.54 (revenue-miles) SIG T = .00, $R^2 = .958$ (2)

FY 1982-1983 divisional peak service expenses =
$691,704 (constant) + SIG T = .07
$45.89 (bus pullouts) SIG T = .00, $R^2 = .982$ (3)

Because each of these three models estimated a unique and separate share of divisional expenses, the three models together represented the best estimate of total divisional expenses. Through simple addition of the models, a multivariate model was prepared. The following equation represents the final, summed format of the initial modeling process:

FY 1982-1983 total divisional expenses =
$1,705,165 + $14.50 (total vehicle-hours)
+ 0.54 (revenue-miles)
+ 45.89 (bus pullouts) (4)

Of interest at this stage in the modeling process are the relationships that were found between a few of the more significant expense accounts and the resultant model variables. As expected, high correlations were developed between full-time and part-time operator pay and the number of vehicle-hours in each division. The longer an operator is assigned to a vehicle, the greater his pay. Also expected were the high correlations between fuel, lubricant, and tire costs of a division and the number of miles in each division. As a vehicle accumulates greater mileage, the costs associated with fuel, lubricant, and tires also increase. An unexpected result, however, was the relationship found between mechanic pay and the number of bus pullouts. Traditionally, mechanic pay has been associated with the number of miles in a division (or system). Nevertheless, at SCRTD, mechanic pay was found to have a higher correlation with the number of buses required for peak service (bus pullouts). Each of the three ATU mechanic expense categories (previous list) consistently correlated better with the number of divisional bus pullouts than with divisional mileage.

The apparent explanation of the greater proportion of mechanic time spent in preparation of each day's peak fleet on a bus-by-bus basis than on an accumulated mileage basis includes a number of peak-related issues. Most prominent is that daily vehicle assignments that have frequent bus pullouts are generally peak period (tripper) assignments that incur heavy passenger loads and, therefore, higher maintenance expenses due to their associated brake, transmission, and general "running gear" failures. In addition, assignments that have numerous pullouts tend to require the replacement of parts needed for each start-up (i.e., batteries, starters, and their associated electrical systems) more often than other assignments. Preventive maintenance expenditures based on accumulated vehicle-miles were thought to have a relatively small role in explaining daily mechanic expenses.

MODEL CALIBRATION

Thus far in the discussion of the modeling design, two important issues have not been addressed: (a) all remaining (nondivisional) operating expenses and (b) the significance of the nonvariable (constant) dollar values in Equations 1-4. With respect to the constant dollar values, the slopes of the lines in Equations 1-3 were "forced through the origin" to eliminate the constants so that the aggregate model would be more effective in estimating line-by-line costs. (Note the significance, SIG T, of each model constant.) It was assumed that if no service was provided at the line level, zero expenses would be incurred. With respect to the remaining nondivisional operating expenses, a method was developed to proportionally calibrate each variable's coefficient such that the resultant model was capable of estimating total (as opposed to divisional) FY 1982-1983 district operating expenses. The calibrated model is represented by the following equation:

FY 1982-1983 SCRTD (system) operating costs =
$28.35 (total vehicle-hours) +
$1.12 (revenue-miles) +
$104.22 (bus pullouts) (5)

DIFFERENTIATION BETWEEN LOCAL AND EXPRESS SERVICE OPERATING COSTS

The second step in the modeling process was to develop a procedure capable of differentiating SCRTD's operating costs by type of service. Because previous studies had indicated that the variations between local and express unit costs were significant, separate models sensitive to these variations were thought to be useful in enhancing the overall modeling process. The objective was to split the system model (Equation 5) into two distinct models, one capable of estimating local service operating costs and one capable of estimating express service operating costs.

A divisional cost centers approach, identical to the approach previously discussed, was used to identify the variations in local and express unit costs. However, to produce two distinct models that, when used in tandem, could also accurately estimate total system costs, individual cost center analyses were regenerated from local and express (as opposed to system) service and expense statistics. At the divisional level, local and express mile, hour, and peak-related service statistics were developed from actual measurements of SCRTD services. Mile, hour, and peak-related service statistics associated with the high-speed freeway increments of express lines were regarded as express service; all other services were regarded as local SCRTD service.

The associated operating expenses, which were not available by service type, were proportionally allocated between local and express miles, hours, and so forth, on the basis of the relationships previously developed in the "system" Pearson Correlation Matrix. Operating expenses associated with the mileage variable of a division with 80 percent local service and 20 percent express service, for example, were allocated 80 and 20 percent, respectively. Because the percentage of local service ranged among the 12 divisions from 99.9 to 40.3 percent in hours of service and from 99.8 to 11.6 percent in miles of service, models with correlation coefficients and levels of significance similar to Equations 1-3 were produced. The resultant local and express models, which, in effect, are a weighted "split" of the FY 1982-1983 system cost model (Equation 5), are

$$\begin{aligned}\text{FY 1982-1983 local service operating costs} = {} & \$28.35\ (\text{total vehicle-hours}) + \\ & \$1.14\ (\text{revenue-miles}) + \\ & \$104.08\ (\text{bus pullouts})\end{aligned} \tag{6}$$

$$\begin{aligned}\text{FY 1982-1983 express service operating costs} = {} & \$31.00\ (\text{total vehicle-hours}) + \\ & \$0.99\ (\text{revenue-miles}) + \\ & \$134.57\ (\text{bus pullouts})\end{aligned} \tag{7}$$

As can be seen from a comparison of the system cost model (Equation 5) and the local cost model (Equation 6), the dominance of SCRTD local service throughout the system precludes any meaningful changes within the local model unit costs. All three of the coefficients in each equation are virtually the same. However, a comparison of the express model (Equation 7) and the system model (Equation 5) reveals that express service operating costs at SCRTD do indeed differ from the system average operating costs. More important, they vary in a manner that was not explained in the system cost centers approach. Express service hourly unit costs exceed the system average by 9 percent, express mileage unit costs fall below the system average by 12 percent, and express pullout unit costs exceed the system average by nearly 30 percent. In general, the variation between the express and the system average hourly unit costs can be attributed to the current operator work agreement that penalizes short (i.e., express) assignments, whereas the discrepancy between the express and the system average mileage unit costs can be attributed to the increased speed (i.e., efficiency) of the express assignments. The difference between the express and the system average pullout unit costs merely reinforces the finding that proportionally greater mechanic expenses can be associated with assignments that start up or pull out more times per day than does the average vehicle assignment.

DIFFERENTIATION BETWEEN PEAK AND OFF-PEAK OPERATING COSTS

The final step in the modeling design was to integrate the operator work rule stipulations that further explain variations in the estimates of line-by-line operating costs. Specifically, this involved an attempt to differentiate total weekday expenses between the peak and off-peak periods of service. Although the local and express models, as developed in the previous section, will, to some extent, address the issue of different time of day costs through the use of the bus pullout variable, the models will not account for the cost differences normally associated with the peak and off-peak time periods in which driver wages represent the largest single expenditure.

Because transit is a highly labor-intensive industry, stipulations in labor contracts, which limit the level of part-time drivers as well as the number of split shifts, have increased the costs of providing service. Because the size of an agency's operator labor force is scaled to the level of peak demand, many of these restrictions can be attributed to the peak period. A common consequence of the labor agreement penalties is that an agency's labor force must be 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 nature of daily commuting patterns in which peak loads occur during a 2- or 3-hr time span in the morning and evening, necessitating full-scale operations over a 12-hr stretch of time. Although many of these excess wage expenditures occur during off-peak periods, a legitimate argument can be made for attributing a portion of them to the peak periods.

In addition to the union-related influences, other factors should be considered when assessing the true labor costs incurred during the peak period. For example, labor "efficiency" tends to be relatively low under peak operations because considerable time is spent in nonrevenue service traveling to additional bus runs. In general, the proportion of out-of-service to in-service pay hours is higher in the peak than in the off-peak period due to these deadheading activities.

To attribute a larger proportion of total hour costs to peak operations, a procedure was developed by Cherwony and Mundle (1) to adjust the vehicle-hour coefficient in the system cost models upward for the peak period and downward for the off-peak period, because the weighted average vehicle-hour variable underestimates the costs of peak service and exaggerates those of off-peak. Ideally, a cost model that employs operator pay-hours in lieu of vehicle-hours is desired. However, the scarcity of adequate operator pay-hour data has historically led to the use of the vehicle-hour variable as a surrogate measure.

The approach developed by Cherwony and Mundle ties together vehicle-hour and operator pay-hour data into a time-apportioned index of operating costs. The most salient feature of their approach is that the system vehicle-hour coefficient is modified for the peak and off-peak periods on the basis of two factors: an index of relative peak and off-peak period operator productivity and an index of relative amounts of peak and off-peak period service. The operator labor productivity index adjusts the vehicle-hour unit cost coefficient by comparing the ratio of operator pay-hours to vehicle-hours in the peak versus the off-peak. The service index simply compares the number of vehicle-hours in the peak with those in the off-peak. Although the operator labor productivity index functions as a measure of the penalizing features of the operator labor agreement, the service index measures the relative amount of service offered in each peak and off-peak period. The equations developed by Cherwony and Mundle to adjust the vehicle-hour coefficients are

$$VH_p = \left\{[n(1 + s)]/(1 + ns)\right\} VH$$

and

$$VH_o = [(1 + s)/(1 + ns)]\ VH$$

where

VH_p = peak vehicle-hour coefficient,
VH_o = off-peak vehicle-hour coefficient,

VH = total vehicle-hour coefficient,
n = relative operator labor productivity (i.e., the ratio of peak pay-hour/vehicle-hour to off-peak pay-hour/vehicle-hour), and
s = relative service index (ratio of peak to off-peak vehicle-hours of service).

Integration of the Cherwony and Mundle approach into the local and express operating models produced four distinct SCRTD cost models: two for estimating line-by-line peak period expenses (local and express) and two for estimating line-by-line off-peak period expenses (local and express). In addition, because the variations in the ratio of operator pay-hours to vehicle-hours differ significantly between weekdays and weekends (due to the differences in the peak-to-base vehicle ratios between weekdays and weekends), two system average weekend models were also developed to estimate the operating costs of local and express weekend service. No attempt was made to differentiate between peak and off-peak weekend operating costs because of the relatively "flat" demand for weekend service. The final model formats (FY 1982-1983) developed as a result of the entire modeling design are

$\text{Local } TC_p = \$30.34(THR_p) + \$1.14(RM_p) + \$104.08(PO)(APB/TB)$
$\text{Local } TC_o = \$27.16(THR_o) + \$1.14(RM_o) + \$104.08(PO)(BB/TB)$
$\text{Local } TC_w = \$28.35(THR_w) + \$1.14(RM_w) + \$104.08(PO_w)$
$\text{Express } TC_p = \$33.17(THR_p) + \$0.99(RM_p) + \$134.57(PO)(APB/TB)$
$\text{Express } TC_o = \$29.70(THR_o) + \$0.99(RM_o) + \$134.57(PO)(BB/TB)$
$\text{Express } TC_w = \$31.00(THR_w) + \$0.99(RM_w) + \$134.57(PO_w)$

where

TC_p = total cost of peak period weekday service, where peak period is defined as the sum of the a.m. peak (6:00 a.m. to 8:59 a.m.) plus the p.m. peak (3:00 p.m. to 5:59 p.m.),
TC_o = total cost of off-peak period weekday service, where off-peak period is defined as all weekday service minus the peak period service (see TC_p),
TC_w = total cost of weekend (24 hr) service (Saturday, Sunday, or holiday service),
THR_p = total peak period weekday vehicle-hours,
THR_o = total off-peak period weekday vehicle-hours,
THR_w = total weekend vehicle-hours,
RM_p = peak period weekday revenue-miles,
RM_o = off-peak period weekday revenue-miles,
RM_w = total weekend revenue-miles,
PO = number of weekday bus pullouts,
PO_w = number of weekend bus pullouts,
APB = average peak period buses (a.m. peak buses plus p.m. peak buses divided by 2),
BB = total base period buses (9:00 a.m. to 2:59 p.m.), and
TB = $APB + BB$.

As these equations indicate, the cost per hour of weekday peak period service (local or express) is marginally higher than the cost per hour of weekday off-peak period service. The cost per hour of weekend service is, essentially, the weighted average of the weekday peak and off-peak hourly unit costs. For all models, no attempt was made to differentiate between the peak and off-peak unit costs of the revenue-mile and pullout variables, nor was any attempt made to differentiate between the weekday and weekend unit costs of the revenue-mile and pullout variables. Nevertheless, so that a distinction could be made between the number of peak and off-peak bus pullouts at the line level, an index was developed to adjust the pullout variables of the peak and off-peak models on the basis of the relative number of peak and base period buses (see final model formats).

Throughout the modeling process the concept of having the "sum of the parts equal the whole" was maintained. Estimates of a line's peak period operating costs, therefore, must be added to the off-peak period operating costs to derive total daily operating costs. To estimate total system operating expenses, the system operating cost model (Equation 5) can be used or, through a series of line-by-line calculations, each line's peak period, off-peak period, and weekend operating costs can be added together to produce the same result.

SUMMARY

The final models were tested by comparing the daily peak and off-peak models with three traditional models currently in use throughout SCRTD. The models used for comparison were the 1984 Scatchard model, the 1984 Stopher (UTPS) model, and the 1980 Gephart model. The equations of each model, which have been calibrated to SCRTD's FY 1983-1984 operating budget, are

1984 Scatchard model

$TC = \$25.42(THR) + \$1.74(TMI)$

1984 Stopher (UTPS) model

$TC = \$44.00(RH) + \$0.57(RM)(PVR)$

1980 Gephart model

$TC = \$40.98(RH) + \$173.37(BPO)$

1984 Peak/off-peak models

$\text{Local } TC_p = \$30.27(THR_p) + \$1.14(RM_p)\ \$107.30(PO)(APB/TB)$
$\text{Local } TC_o = \$27.10(THR_o) + \$1.14(RM_o) + \$107.30(PO)(BB/TB)$
$\text{Local } TC_w = \$28.29(THR_w) + \$1.14(RM_w) + \$107.30(PO_w)$
$\text{Express } TC_p = \$33.09(THR_p) + \$0.99(RM_p) + \$138.73(PO)(APB/TB)$
$\text{Express } TC_o = \$29.63(THR_o) + \$0.99(RM_o) + \$138.73(PO)(BB/TB)$
$\text{Express } TC_w = \$30.93(THR_w) + \$0.99(RM_w) + \$138.73(PO_w)$

where

TC = total daily operating cost,
THR = total vehicle-hours,
TMI = total vehicle-miles,
RH = revenue vehicle-hours,
RM = revenue vehicle-miles,
PVR = a.m. peak-to-base vehicle ratio, and
BPO = number of bus pullouts.

TC_p, TC_o, TC_w, THR_p, THR_o, THR_w, RM_p, RM_o, RM_w, PO, PO_w, APB, BB, and TB are as previously defined.

Because the service variables required as input to the peak and off-peak models were not readily available for every line in the system, three relatively small but distinctly different lines were used for the comparative analysis. The 495 line, which provides peak period express service between downtown Los Angeles and Diamond Bar, was chosen because it typifies a type of service that is generally thought to have relatively high unit operating costs. The 495 line is a park-and-ride service that runs from 5:12 a.m. to 8:54 a.m. and from 3:20 p.m. to 7:05 p.m. It does not have base period service (i.e., between 9:00 a.m. and 3:00 p.m.). The 602 line, on the other hand, was chosen because of its unique daily schedule that requires more buses in service during the off-peak period than during either of the peak periods. Unit cost estimates associated with the 602 line were thought to be less than average because of its nearly equal (and efficient) spread of service throughout the day. The 602 line is the (local) downtown Los Angeles minibus shuttle. The third line selected was the 262 line, which travels between South Gate and San Marino. The 262 line typifies one of the district's "average" lines in terms of the relative amounts of service scheduled during the peak and off-peak time periods. Unit cost estimates associated with the 262 line were thought to closely approximate SCRTD's average unit operating costs. The service variables required to compare each of the three test lines are given in Table 3. The results of the model comparisons are given in Table 4.

TABLE 3 Daily Operating Statistics for Lines 262, 495, and 602 (FY 1983-1984)

	Line 262	Line 495	Line 602
Bus requirements (a.m., base, p.m.)	5, 4, 6	10, 0, 10	7, 12, 9
Total vehicle-hours	79.6	49.8	98.3
Total peak period vehicle-hours	32.0	41.5	37.8
Total off-peak period vehicle-hours	47.6	8.3	60.5
Total revenue-hours	76.8	35.5	93.5
Total vehicle-miles	985	1,441	757
Total peak period revenue-miles	472	705	300
Total off-peak period revenue-miles	415	288	393
Total revenue-miles	887	993	693

In general, the statistics given in Table 4 suggest that, to some extent, all of the models consistently address line-by-line variations in unit operating costs. Each model, for example, indicates that the highest unit cost of the three test lines is indeed produced by line 495, the lowest unit cost by line 602, and the "median" unit cost by line 262. Given the nature of the service scheduled for each line (i.e., that line 495 provides peak period service only and that line 602 provides relatively little peak period service), the results are logical as well as consistent. Comparisons of the magnitude of each model's results, nevertheless, indicate that significant differences exist among the model designs.

Of the three models developed from system average expenses (i.e., the 1984 Scatchard model, the 1984 Stopher model, and the 1980 Gephart model), the model that explains the least variation in line cost estimation is the 1984 Stopher model. The Stopher model estimates a unit cost difference of only 22 percent between the highest cost line (line 495) and the lowest cost line (line 602). The 1980 Gephart model and the 1984 Scatchard model, on the other hand, estimate a unit cost differential of nearly 100 percent between the same two lines. Apparently, the Stopher model's overall purpose--as an input parameter to the UTPS modeling efforts of SCRTD--has, in effect, constrained the modeling design. Comparisons of the 1980 Gephart model and the 1984 Scatchard model indicate that, although both models track closely together, the 1980 Gephart model tends to associate somewhat higher operating expenses with lines that operate relatively more peak service than base service. The inclusion of a peak-related service variable (bus pullouts) in the 1980 Gephart model appears to account for the difference.

The results of the 1984 peak and off-peak models indicate an even greater disparity in operating cost estimates. From the unit cost estimates given in Table 4, the difference in peak versus off-peak period unit costs between the 495 line and the 602 line is 201 percent. Although the peak period cost model estimated a peak hour unit cost (for line 495) that was 18 percent greater than the highest average daily cost estimate of the other models, the off-peak period cost model estimated an off-peak period unit cost (for line 602) nearly equal to the lowest average daily cost estimate of the other models. As indicated by these results, the peak and off-peak models tend to address the marginal variations in SCRTD's services to a greater extent than do the traditional unit cost models that are based on system average expenditures.

Further, comparisons of the 1984 peak and offpeak models indicate that not only does line 495 produce the highest unit (hourly) operating cost of the three test lines, it also has the largest difference between peak and off-peak unit costs. The peak period unit cost for line 495 is 83 percent greater than the off-peak period unit cost. The peak-to-off-peak unit cost differentials for lines 495, 262, and 602 are 83, 39, and 13 percent, respectively (Table 4). Because the amount of variation between the peak and off-peak unit costs is a function of a line's peak-to-base operational efficiency, each line's peak-to-off-peak unit cost differential can be used as an indicator of potential passenger loading efficiency. Assuming fares are equal on a per passenger basis, the peak-to-off-peak unit cost differential indicates the percentage of peak period passengers required above the number of off-peak period passengers to offset the higher peak period operating costs. On an hourly unit cost basis, this would indicate that for line 495, 83 percent more

TABLE 4 Comparison of SCRTD Operating Cost Models for FY 1983-1984 ($)

	1984 Scatchard	1984 Stopher	1980 Gephart	1984 Peak/ Off-Peak
Line 262				
Total daily cost	3,737.00	4,011.00	4,361.00	4,020.00
Total daily cost/vehicle-hour	46.95	50.39	54.78	
Total peak cost/vehicle-hour				60.67
Total off-peak cost/vehicle-hour				43.68
Line 495				
Total daily cost	3,773.00	2,694.00	4,922.00	5,376.00
Total daily cost/vehicle-hour	75.76	54.10	98.84	
Total peak cost/vehicle-hour				116.77
Total off-peak cost/vehicle-hour				63.98
Line 602				
Total daily cost	3,816.00	4,344.00	4,525.00	4,002.00
Total daily cost/vehicle-hour	38.82	44.20	46.03	
Total peak cost/vehicle-hour				43.86
Total off-peak cost/vehicle-hour				38.76

passengers would be required to travel during the peak than off-peak period to offset the peak period operating costs. For lines 262 and 602, respectively, approximately 39 and 13 percent more passengers would be required to travel in the peak than the off-peak periods.

Clearly, a cost centers modeling approach, based on an understanding of the variations between local and express services as well as peak and off-peak operator pay-hours, has increased SCRTD's capability to estimate marginal line-by-line operating costs. Operating costs associated with different times of day, different types of service, and different days of operation can be identified. Given that even greater variations in divisional expenses are known to exist, sensitivity analyses by type of expense account can also be performed. Cost-effectiveness sensitivity analyses by bus type, for example, can be developed if differences in fuel, tire, and other expenses can be quantified. Although the development of six distinct models has increased the difficulty of the cost estimation process, the increases in accuracy appear to justify the disaggregate modeling design. Although significant modifications of SCRTD's labor agreements or service types, or both will influence the degree of accuracy of the peak and off-peak models, minor modifications can be absorbed in periodic calibrations of each model to the SCRTD operating budget.

REFERENCE

1. W. Cherwony and S. Mundle. Peak-Base Cost Allocation Models. In Transportation Research Record 663, TRB, National Research Council, Washington, D.C., 1978, pp. 52-56.

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Abridgment

Transit Routing and Scheduling Strategies for Heavy Demand Corridors

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ABSTRACT

Efficient routing and scheduling strategies for heavy-demand corridors are described. Examples are given. Four strategies pertain to local service: short-turning, restricted zonal service, semirestricted zonal service, and limited-stop zonal service. Zoning of express services and deadheading of both local and express service are also discussed. Advantages and disadvantages of the strategies, and conditions favoring their adoption, are discussed.

Transit service in radial corridors can often take advantage of a high level and concentration of demand by employing routing and scheduling strategies that are more efficient than the conventional local route. For the purposes of this paper, a corridor is the narrow area served by a single local route or by a set of routes operating on the same street, and a "heavy-demand corridor" is one in which peak passenger volume is roughly eight or more busloads per hour. Although service in such corridors will rarely be identified through service standards as substandard, it is nevertheless often possible to increase its productivity significantly through the use of routing and scheduling strategies tailored to the markets. Because of the large amount of service offered in these corridors, improved productivity here can lead to substantial operating cost reductions. Several of these strategies are described and their advantages and disadvantages are discussed. Proposed and actual examples of their applications are presented. A fuller description of these strategies is found in Furth et al. (1). Procedures for analysis and design are documented elsewhere (2-6).

ZONAL EXPRESS SERVICE

By separating the long-distance, central business district (CBD)-oriented market from the remainder of the transit market, the former can be more efficiently served with express service. Express routes are faster because they make fewer stops and can use high-speed roads for the express portion. If they can charge higher fares, they are all the more cost-effective. However, lower design load factors required on some express routes can lower their productivity.

If the demand for express service is at least six or eight busloads per hour (i.e., large enough to support at least two routes), express service can often be made more efficient by splitting the express service area into zones and serving each zone