Again, INET's simple coding scheme and use of the highway network let planners test a variety of proposed service changes. Since changes are usually perturbations of existing service, INET's acceptance of known service schedules is an important feature.

After an alternative is selected, INET will make a first attempt at scheduling and estimate the resources required.

INET is merely a first link to operations planning. A major effort is underway to provide the special software needed for scheduling and operations analysis. Already INET allows the transit system to be further analyzed in UTPS according to system accessibility (UMATRIX, UMODEL) and station requirements (USTOS) (4).

EXPERIENCE WITH INET

Is INET as quick and easy as is claimed? Can these simple default models produce accurate transit-link times? The answer is an unequivocal and heartening "yes." The reassurance comes from research and development at UMTA, where INET is used with real-world data from the Washington, D.C., Metropolitan Council of Governments.

The most-complicated case has been the development of a network data base for existing transit service in the Shirley Highway Corridor. Of modest size, it includes 167 zones, 2700 links, 50 transit routes, and 2 subway lines. The time spent in coding the Shirley Corridor network is divided as follows:

1. Add data to highway-network file where necessary and check out and debug to obtain complete highway-system description to satisfy INET's requirements. Time: 24 person hours.
2. Code and debug route cards. Time: 45 person hours.
3. Run INET, analyze transit speeds, and update cruising-speed and dwell-time tables where necessary. Time: 20 person hours.

Thus, coding takes less than 90 person hours by a young, inexperienced engineer; the second time, he or she should take about half that length of time. Coding a new alternative by adding to or deleting from existing service would require less than one day.

As for INET's accuracy, the results were amazing. Because an existing service was coded, INET's estimates of transit travel times could be compared with printed schedules. Every estimated run time was within 5 percent of the schedule, many were precisely on the mark, and most were within 1 min.

Figure 6 is a route map that shows a bus route through 44 nodes, the middle 14 of which are on the exclusive HOV lane on Shirley Highway (Interstate 395). The remaining 30 nodes are roughly split between the Virginia suburbs and downtown Washington. When time checks were made on entering and exiting the exclusive lane and at the downtown end of the line, at all three points INET times coincided exactly with the scheduled times.

Figure 7 depicts a Washington, D.C., Metro subway line. Comparing Metro schedules with INET output shows that no INET time is more than 1 min different from Metro's. These concurrences are the rule rather than the exception and reinforce the satisfaction with INET's performance.

Those who wish more information on the INET program may obtain a book on the subject from UMTA (5).

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# Value of Urban Transit Operating-Cost Models as Forecasting Tools

**JAMES D. ORTNER**

**Eight urban transit operating-cost models were reviewed to determine their value as forecasting tools. The models were found to have structural problems. In the average-daily-cost model and annual-cost model, the association of inputs with outputs was assumed to have a strong positive correlation. Case-study transit system data were used to test these relationships. The findings indicate that these two models were not reliable because strong positive**

**correlations existed in too few of the expected relationships. The eight models were not designed to include variables that measure the influence of institutional factors on operating costs. The necessity to subsidize transit operations has led to increasing involvement of the public sector in transit operating decisions. Planners are advised to refrain from relying totally on any of the eight models for estimation of operating costs. Such additional techniques should be considered as developing probabilities of changes in cost categories and generating alternate scenarios of operating conditions.**

Traditionally, urban transit operating-cost models have been used in three ways--to explain and predict variation in expenditures among different public transit systems that operate similar services, to explain and estimate trends in expenditures of individual transit systems, and to compare costs of different modes (such as buses on freeways versus rail transit). This paper will examine only the first two uses of cost models. Examples of the third type can be found in studies by Boyd and others (1); Meyer, Kain, and Wohl (2); Vuchic and Stanger (3); and Lee (4), who refers to 23 articles on this particular subject.

Eight operating-cost models are presented in the following discussion: average-daily-cost model, annual-cost model, slowness model, urban-environment-cost model, Holthoff model, Merewitz model, cost-per-vehicle-hour model, and total-operating-cost model. These represent the recent thinking on the subject of measuring operating costs. This paper focuses on the value of these eight models as forecasting tools, which is an issue of current concern among transportation planners who are responsible for informing public officials of the future operating costs of proposed or on-going programs.

A review of the eight models finds structural deficiencies that diminish their value as forecasting tools. The average-daily-cost and annual-cost models associate specific inputs with specific outputs. The rationale for this association is that correlations indicate strong positive relationships. However, an examination of correlations of data from several case-study transit systems indicates that these models are not reliable. Strong positive correlations existed in only a few of the relationships.

A major weakness of the other models reviewed in this paper is their failure to recognize the influence of institutional factors on operating costs. The changeover from private to public ownership of public transportation has brought local, regional, state, and federal officials into the process of determining the type and level of transit service. Quantifying the past actions of public officials is at best a difficult task. Forecasting their future behavior toward transit seems clearly impractical.

This paper concludes by suggesting that two other techniques for estimating future operating costs be researched further--development of probabilities of changes in cost categories and generation of scenarios of future operating conditions.

## MODELS OF INDIVIDUAL TRANSIT SYSTEM OPERATING COST

Two models are reviewed under this category--average daily cost and annual cost.

### Average-Daily-Cost Model

This model was developed by Ferreri (5). Unit operating costs for an entire system or route are illustrated as follows:

$$C = x_1 VM + x_2 VH + x_3 PR + x_4 PV \tag{1}$$

where

- $C$ = average daily operating cost of route or system (dollars);
- $x_1$ = expenses associated with the number of miles over which revenue vehicles operate, maintenance, and garaging;
- $x_2$ = expenses associated with the number of hours during which revenue vehicles operate, operator wages, and fringe benefits;
- $x_3$ = expenses associated with the amount of passenger revenue collected, accidents, and liability;
- $x_4$ = expenses associated with the size of the peak-period fleet, administration, and storage areas;
- VM = average daily vehicle miles of service of the specific route or system being analyzed;
- VH = average daily vehicle hours of service of the specific route or system being analyzed;
- PR = average daily revenue of specific route or system being analyzed (dollars); and
- PV = peak vehicle needs on specific route or system being analyzed.

Ferreri used Equation 1 to estimate the operating cost of each route as well as that of the overall Miami, Florida, transit system. He concluded from his research that (5)

> For long-range planning projections a simplified operating cost formula using only vehicle miles and vehicle hours is more than adequate and probably desirable because of the need to estimate only for miles and hours of service on each route. On the other hand, for short-range service improvements and fiscal planning, a more-accurate allocation formula such as the four-variable method is appropriate.

Contrary to Ferreri's conclusions, his model and the annual-cost model reviewed in the next section are not reliable forecasting tools.

### Annual-Cost Model

The format used in the annual-cost model was developed by W.C. Gilman and Company, Inc., and Alan M. Voorhees Associates (6) to project operating costs of the bus-system element of an integrated Washington, D.C., rail-bus system. Roess and others (7,8) extended this analysis to rail-transit systems.

As in the average-daily-cost model, inputs are associated with one of four outputs. Levine (9) notes that the annual-cost model has many similarities to the average-daily-cost model. Both models assume a linear equation and apply similar methodologies to the issues. One major difference is the use of annual revenue passengers rather than average daily passenger revenue.

Total operating cost is shown as follows:

$$C = x_1 VM + x_2 VH + x_3 PV + x_4 RP \tag{2}$$

where

- $C$ = annual operating expense,
- $x_1$ = unit cost of vehicle-mile-associated expenses,
- $x_2$ = unit cost of vehicle-hour-associated expenses;
- $x_3$ = unit cost of peak-period fleet-associated expenses,
- $x_4$ = unit cost of revenue-passenger-associated expenses,
- VM = annual system vehicle miles,

VH = annual system vehicle hours,
PV = size of peak-period fleet, and
RP = annual revenue passengers.

Both the average-daily-cost and the annual-cost models are based on the assumption that the specific inputs and outputs shown below have strong positive correlations (R = rail; B = bus):

| Input | Output and Mode |
|---|---|
| VM | Maintenance of way and structure (R) |
| | Maintenance of equipment (R) |
| | Maintenance (B) |
| | Power (R) |
| | Fuel (B) |
| VH | Direct operations (B,R, or both) |
| | Fringe benefits (B,R, or both) |
| | Social Security (B,R, or both) |
| PV | General and administrative costs (B,R, or both) |
| | Advertising (B,R, or both) |
| | Station (B,R, or both) |
| RP | Liability insurance (B,R, or both) |

Data from four case studies were analyzed to determine whether the relationships listed above could be verified empirically. The four transit districts used as case studies were Southern California Rapid Transit District (SCRTD); Alameda-Contra Costa Transit District (AC Transit); San Francisco Municipal Railway (Muni); and Chicago Transit Authority (CTA). The Statistical Package for the Social Sciences was used to calculate the correlations between input and output variables. Input data for the four case studies were correlated by using deflated 1967 dollars.

Findings illustrated in Tables 1-4 reveal that the strong positive correlations assumed in the average-daily-cost and annual-cost models existed in only a few of the relationships. For example, for SCRTD over an 11-year period, vehicle hours had strong positive correlations with every input variable.

A major weakness of the models is their failure to consider systems such as Muni and CTA whose costs during the analysis period escalated while output declined. For Muni, the strongest positive relationship was between the input for power and fuel and revenue patronage (0.7083). For CTA, the strongest positive correlation was between injury-and-damage expenses and revenue patronage (0.3674). These findings suggest that the models are not reliable for forecasting expenditure trends.

An interesting finding from the correlation analyses is that direct operations correlates more strongly with vehicle mileage than with vehicle hours. Since most transit workers are paid hourly and work in direct operations, it would seem likely that changes in the value of direct operations would correlate more strongly with changes in vehicle hours than with changes in vehicle mileage.

## MODELS OF COST PER VEHICLE MILE

Four models of operating cost per vehicle mile are reviewed: the slowness, urban-environment-cost, Holthoff, and Merewitz models. All inputs are expressed in terms of cost per vehicle mile rather than in four categories as was the done with the two models just discussed, because (10)

> It is generally good practice to model costs or resources on a per-vehicle-mile or per-vehicle-hour basis in order to reduce the problem of unequal variation (heteroscedasticity) from one observation to the next. For example, the difference in dollar expenditures on vehicle maintenance between two large firms may be great in absolute terms but rather modest when expressed in cost per mile.

### Slowness Model

The slowness model was developed by Miller and Holden (11). It is based on the premise that vehicle miles operated and vehicle hours operated are the two most important determinants of operating costs. These two variables are combined by dividing vehicle hours by vehicle miles to form a ratio called slowness (vehicle hours/vehicle miles). Levine (9) comments that the slowness model is derived down from Ferreri's (5) average-daily-cost model. The variables in the Ferreri model that relate to peak vehicle needs and passenger revenue are dropped in the formulation of the slowness model because they are a function of the slowness variable. The final form of the slowness model becomes

$$C = a + bS \tag{3}$$

where

C = cost per vehicle mile,
a = those operating inputs associated with vehicle miles divided by total vehicle miles for the time period analyzed, and
S = total vehicle hours x 60 for the time period analyzed divided by total vehicle miles for the time period analyzed to yield minutes per vehicle mile--the slowness variable.

Can the slowness model be used to estimate future operating costs? It was noted earlier that two variables found in the average-daily-cost model--size of peak-period fleet and passenger revenue--are a function of the slowness variable. However, vehicle miles and vehicle hours remain in the function. Correlation analyses of output variables from the four case-study transit systems are illustrated in Tables 5-7. The findings highlight a strong positive correlation between vehicle miles and vehicle hours. The results could be severely distorted by forming a function of two variables that have a correlation greater than 0.95. This outcome casts doubt on the practice of calculating the slowness variable rather than expressing all costs as a function of either vehicle miles or vehicle hours. The slowness model is therefore not recommended for forecasting future operating costs.

### Urban-Environment-Cost Model

Miller (12,13) developed the urban-environment-cost model. It was later expanded by Foster (14) and Veatch (15).

Miller (13) hypothesized that managerial efficiency (controlling factor prices and output) alone does not account for the wide range in operating costs among different transit systems and that bus operating costs are a function of a city's setting (schedule speed, intensity, and city age) as shown in the following equation:

$$C = a + b_1 VM + (b_2 1/VM) + b_3 A + b_4 W + b_5 SS + b_6 I + b_7 CA + u \tag{4}$$

where

C = operating cost per vehicle mile,

VM = million vehicle miles per year,
1/VM = 1/million vehicle miles per year,
A = average age of bus fleet,
W = maximum wage rate,
SS = schedule speed (total annual vehicle miles/total vehicle hours),
I = intensity (total annual vehicle miles/number of route miles served), and
CA = city age (0 = old city, i.e., a city that did not meet conditions listed below, and 1 = new city, i.e., a city that had grown at least 200 percent in population from 1920 to 1960 and at least 68 percent from 1940 to 1960).

**Table 1. SCRTD correlation matrix for 1966-1976.**

| | VM | | VH | | PV | | RP | |
|---|---|---|---|---|---|---|---|---|
| Input | Coefficient | Significance Level | Coefficient | Significance Level | Coefficient | Significance Level | Coefficient | Significance Level |
| Maintenance | 0.9919 | 0.001 | 0.9899 | 0.001 | 0.9081 | 0.001 | 0.8946 | 0.001 |
| Fuel and oil | 0.9328 | 0.001 | 0.9366 | 0.001 | 0.6855 | 0.014 | 0.9786 | 0.001 |
| Direct operations | 0.9856 | 0.001 | 0.9745 | 0.001 | 0.9339 | 0.001 | 0.8438 | 0.001 |
| Pension and medical | 0.8723 | 0.001 | 0.8672 | 0.001 | 0.9744 | 0.001 | 0.6261 | 0.026 |
| Social Security | 0.9508 | 0.001 | 0.9288 | 0.001 | 0.9577 | 0.001 | 0.7758 | 0.004 |
| General and administrative costs | 0.9536 | 0.001 | 0.9531 | 0.001 | 0.9642 | 0.001 | 0.7908 | 0.003 |
| Advertising | 0.9157 | 0.001 | 0.8772 | 0.001 | 0.8781 | 0.001 | 0.7914 | 0.003 |
| Station | 0.9660 | 0.001 | 0.9456 | 0.001 | 0.9265 | 0.001 | 0.8081 | 0.002 |
| Insurance | 0.9456 | 0.001 | 0.9298 | 0.001 | 0.8946 | 0.001 | 0.8439 | 0.001 |

Note: VM, VH, PV, and RP are as defined in Equation 2; N = 10.

**Table 2. AC Transit correlation matrix for 1961-1977.**

| | VM | | VH | | PV | | RP | |
|---|---|---|---|---|---|---|---|---|
| Input | Coefficient | Significance Level | Coefficient | Significance Level | Coefficient | Significance Level | Coefficient | Significance Level |
| Maintenance | 0.9819 | 0.001 | 0.9203 | 0.001 | 0.8958 | 0.001 | 0.6955 | 0.001 |
| Fuel and oil | 0.8308 | 0.001 | 0.7908 | 0.001 | 0.7399 | 0.001 | 0.6169 | 0.004 |
| Direct operations | 0.9653 | 0.001 | 0.8733 | 0.001 | 0.9421 | 0.001 | 0.6091 | 0.001 |
| Welfare and pensions | 0.9315 | 0.001 | 0.8719 | 0.001 | 0.8759 | 0.001 | 0.6276 | 0.003 |
| Social Security | 0.7455 | 0.001 | 0.7211 | 0.001 | 0.6940 | 0.001 | 0.6173 | 0.004 |
| General and administrative costs | 0.8695 | 0.001 | 0.7495 | 0.001 | 0.8775 | 0.001 | 0.4576 | 0.032 |
| Station | 0.7170 | 0.001 | 0.5656 | 0.009 | 0.8615 | 0.001 | 0.2701 | 0.147 |
| Advertising | 0.7319 | 0.001 | 0.6516 | 0.002 | 0.8236 | 0.001 | 0.3986 | 0.056 |
| Insurance | 0.5492 | 0.011 | 0.5313 | 0.014 | 0.5634 | 0.009 | 0.2752 | 0.142 |

Note: N = 17.

**Table 3. Muni correlation matrix for 1960-1976.**

| | VM | | VH | | RP | |
|---|---|---|---|---|---|---|
| Input | Coefficient | Significance Level | Coefficient | Significance Level | Coefficient | Significance Level |
| Way and structure | 0.5516 | 0.011 | 0.4292 | 0.043 | 0.6987 | 0.001 |
| Maintenance | −0.3280 | 0.099 | −0.2526 | 0.164 | −0.1680 | 0.260 |
| Power and fuel | 0.5104 | 0.018 | 0.2919 | 0.128 | 0.7083 | 0.001 |
| Direct operations | −0.6748 | 0.001 | −0.4702 | 0.028 | −0.7648 | 0.001 |
| Fringe benefits | −0.7185 | 0.001 | −0.5254 | 0.015 | −0.8494 | 0.001 |
| Social Security | −0.5804 | 0.007 | −0.3531 | 0.082 | −0.7213 | 0.001 |
| General and administrative costs | 0.1539 | 0.278 | 0.3413 | 0.090 | 0.1009 | 0.350 |
| Accident claims | −0.3201 | 0.105 | −0.2759 | 0.142 | −0.3500 | 0.084 |

Note: N = 17.

**Table 4. CTA correlation matrix for 1960-1976.**

| | VM | | PV | | RP | |
|---|---|---|---|---|---|---|
| Input | Coefficient | Significance Level | Coefficient | Significance Level | Coefficient | Significance Level |
| Materials and supplies | −0.3040 | 0.135 | −0.1348 | 0.316 | −0.4412 | 0.050 |
| Power and fuel | −0.5098 | 0.018 | −0.1720 | 0.255 | −0.2947 | 0.125 |
| Labor | −0.8185 | 0.001 | −0.0636 | 0.404 | −0.9470 | 0.001 |
| Pension | −0.8713 | 0.001 | −0.0178 | 0.473 | −0.9408 | 0.001 |
| Social Security | −0.8707 | 0.001 | −0.0909 | 0.364 | −0.8966 | 0.001 |
| Health | −0.8796 | 0.001 | −0.0217 | 0.467 | −0.9416 | 0.001 |
| Injuries and damages | 0.1789 | 0.246 | 0.3132 | 0.110 | 0.3674 | 0.073 |

Note: Data were available only for the total CTA system; N = 17.

Table 5. VM correlated with VH, PV, and RP.

| | | VM Correlated with | | | | | |
|---|---|---|---|---|---|---|---|
| | | VH | | PV | | RP | |
| Transit Property | N | Coeffi-cient | Significance Level | Coeffi-cient | Significance Level | Coeffi-cient | Significance Level |
| SCRTD | 10 | 0.9929 | 0.001 | 0.8940 | 0.001 | 0.9056 | 0.001 |
| AC Transit | 17 | 0.9544 | 0.001 | 0.8618 | 0.001 | 0.7553 | 0.001 |
| Muni | 17 | 0.9591 | 0.001 | NA | NA | 0.8666 | 0.001 |
| CTA bus | | NA | NA | 0.9749[a] | 0.001 | 0.9315[b] | 0.001 |
| CTA rail | | | | -0.6165[a] | 0.005 | -0.7176[b] | 0.001 |

[a]N = 16. [b]N = 17.

Table 6. VH correlated with PV and RP.

| | | VH Correlated with | | | |
|---|---|---|---|---|---|
| | | PV | | RP | |
| Transit Property | N | Coeffi-cient | Significance Level | Coeffi-cient | Significance Level |
| SCRTD | 10 | 0.8825 | 0.001 | 0.9102 | 0.001 |
| AC Transit | 17 | 0.7088 | 0.001 | 0.8806 | 0.001 |
| Muni | 17 | NA | NA | 0.7194 | 0.001 |

To test his hypothesis, Miller (13) examined 1963 transit data for 33 cities, 8 of which were new and 25 of which were old. Five of the variables were found to be statistically significant--annual vehicle mileage, wage rate, schedule speed, intensity, and city age. He concluded that city environment should be considered when operating costs of transit systems in different cities were explained (13):

> The importance of these results for resource allocation in urban transportation is two-fold. First, predictions obtained by using the method described should yield significantly better results for use in alternative modes of transport in an urban setting. Second, drawing attention to those "city descriptor" variables which are outside the control of the transit firm should help cities evaluate the costs and benefits that may result from, for example, a modification of traffic flow patterns to enable buses to achieve a higher schedule speed.

Foster (14) notes that the variables used by Miller (13) account for 80 percent of the variation in the dependent variable of cost per vehicle mile. In the Nelson (16) model discussed later in this paper, the variables account for virtually all the variance in the dependent variable of total cost, although the environmental variables used by Miller were ignored by Nelson. To determine which model was correct, Foster analyzed operating-cost data of case studies over an 11-year period and concluded (14):

> In the early years of the (1960-1970) period, city variables exerted a significant effect upon the costs of bus operations. In more recent years, however, costs are more a function of firm considerations (wage rate, operating speed, and frequency of service).

An important contribution of the Miller model is the recognition that many factors affect urban transit operating costs. Miller conducted his research on firms whose data represent a time period when transit operations were privately owned or received minimal, if any, subsidies. Recent trends examined by Ortner and Wachs (17) illustrate that factors such as political influence on operating decisions from officials who allocate subsidies are affecting operating costs. Miller (13) did not consider this factor as a variable in his model. The rapid change in the structure of the transit industry during the past 15 years would make comparisons by means of Miller's model difficult. This point was recognized by Miller (18).

## Holthoff Model

A third method that uses cost per vehicle mile was analyzed in a New York State Department of Transportation study (19). Inputs of rail and bus transit systems in New York State were expressed in terms of their unit cost per vehicle mile. Six input categories were used: wages and salaries, pensions, other employee-related benefits, fuel and power, materials and supplies, and miscellaneous.

The study revealed that employee-related inputs have been almost entirely responsible for past increases in operating costs. Increases in fuel, power, and other non-employee-related inputs were found to have little or no effect on operating-cost increases. Holthoff (19), like Miller (13), found differences in magnitude of operating cost per vehicle mile between transit systems to be attributable to differences in average vehicle speed, average employee earnings, and, in some cases, employee productivity.

Holthoff forecast operating costs through 1980 for New York State transit systems. His forecasting index was based on 1973 operating costs per vehicle mile of each system. In areas in which the operating environment remained unchanged, the model estimated operating costs within ±10 percent of the actual figure. However, when the operating environment changed, the total operating cost was estimated with a much larger error. For example, bus operations in Nassau County, New York, in 1974 changed from private to public ownership. The error in the estimate of total operating cost for 1974 was -35.8 percent and for 1975 it was -20.9 percent.

Holthoff's work has contributed significantly to operating-cost research. His format can structure simply but meaningfully whatever data are available on operating costs in terms of unit cost per vehicle mile or per revenue passenger. Forecasting of short-range operating-cost increases was shown to be possible, but the error of the estimate was still ±10 percent in what Holthoff considered to be a stable environment. Forecasting was shown to be highly inaccurate when major changes in the operating environment occurred, which suggests that another technique should be developed for planning purposes.

## Merewitz Model

Merewitz (20) used a regression format (y = a + bx)

**Table 7. PV correlated with RP.**

| Transit Property | N | PV Correlated with RP: Coefficient | PV Correlated with RP: Significance Level | Transit Property | N | PV Correlated with RP: Coefficient | PV Correlated with RP: Significance Level |
|---|---|---|---|---|---|---|---|
| SCRTD | 10 | 0.6827 | 0.015 | CTA bus | 16 | 0.9609 | 0.001 |
| AC Transit | 17 | 0.3597 | 0.078 | CTA rail | 16 | 0.7574 | 0.001 |

to model Bay Area Rapid Transit (BART) operating costs. The dependent variables were conduct of transportation, rolling-stock maintenance, support-facility maintenance, maintenance of way and structures, and power. The independent variable was vehicle miles traveled. One variable--station and construction costs--was dependent on the number of stations opened rather than on vehicle miles traveled. Administrative costs were assumed to be independent of vehicle miles traveled.

After calculating a regression formula for each operating-cost account, Merewitz estimated the annual operating cost of BART to be $60.1 million (1973 dollars), based on 25 million vehicle miles and 34 stations. [In fiscal year 1977, the total operating cost of BART was $45.7 million (1973 dollars) and total vehicle mileage was 22.9 million.]

The concern in this paper is whether Merewitz's methodology can be used to forecast future operating costs. He has used trend extrapolation to develop linear relationships. The principal criticism of this method is that during periods of rapid change in basic parameters, estimates often have large errors. Data highlighted by Ortner and Wachs (17) illustrate that constant-dollar factor prices have been changing rapidly during the past few years. Accurate trends have been difficult to develop. Therefore, an alternative to the Merewitz model would be preferable for forecasting future operating costs.

## MODEL OF COSTS PER VEHICLE HOUR

Lee (4,21) constructed a model of operating costs per vehicle hour. This model was developed in conjunction with a comparison of alternative transportation modes that could be operated in the I-66 Metro corridor west of Washington, D.C., in suburban Virginia.

The first calculation in the Lee model is to determine labor cost per vehicle hour by multiplying the following three operating inputs: the base wage, a ratio of total labor hours to vehicle hours (called the personnel factor), and a fringe-benefit factor. The personnel factor used by Lee was 2.0. This figure indicates that there are twice as many employee hours worked by transit personnel as there are vehicle hours of transit operation. This ratio allows for layovers, overtime, supervisors and inspectors, and maintenance and administrative personnel. To the labor cost per vehicle hour is added cost per vehicle hour of materials, fuel, and accidents to yield total operating cost per vehicle hour. For the I-66 Metro corridor, Lee (4) calculated bus operating costs as follows:

Base wage ($6.85/h) x personnel factor (2.00) x fringe-benefit factor (1.24) = total labor cost ($16.99/vehicle-h) + materials ($1.82) + fuel ($0.96) + accidents ($0.60) = total operating cost ($20.37/vehicle-h).

Although Lee (4,21) used his model in conjunction with a comparison of alternative modes, it has been described here because costs are expressed in terms of vehicle hours rather than vehicle miles. The use of the model as a forecasting tool is not recommended because the model suffers from the same basic problem as do the other models discussed earlier: It requires a stable operating environment for estimates to closely approximate actual figures. The model could serve a useful purpose if probabilities of changes in costs were used rather than forecasts of specific costs. With this technique it might be possible to develop different scenarios of transit finance.

## MODEL OF TOTAL OPERATING COST

Nelson (16) developed the total-operating-cost model to determine whether economies of scale exist for large bus firms, what the impacts of wage rates are on the cost of bus transit, and how fleet characteristics affect cost. Nelson illustrated the model as follows:

$$\ln C = a_0 + (a_1 \ln VM) + (a_2 \ln W) + (a_3 \ln VEL) + (a_4 A) + (a_5 S) + (a_6 PUB) + (a_7 G) \quad (5)$$

where

C = total operating costs (for the period specified),
VM = bus miles (for the period specified),
W = hourly wage rate for operating personnel,
VEL = bus miles per bus hour,
A = average age of bus fleet,
S = average seats per bus,
PUB = form of ownership (dummy variable: 1 = publicly owned, 2 = otherwise), and
G = proportion of fleet purchased with a capital grant.

Miller and Rea (22) comment that, unlike other operating-cost models, the Nelson model is a gross operating-cost model because it includes factors that reflect depreciation and debt service shown in the Nelson equation as variable A (which reflects fleet age) and variable G (which reflects the proportion of the fleet purchased with a capital grant). They also note that variable VEL (bus miles per bus hour) is the inverse of the Miller and Holden (11) slowness variable.

Merewitz (23,24) applied Nelson's cost function to the operations of three bus systems in the San Francisco Bay Area: Muni, AC Transit, and Golden Gate Transit. He found that only Muni's operations were more costly in its bus operations than would be expected. The significance of the Merewitz research is that it showed Nelson's cost function to be applicable as a descriptive model for comparing variations between systems and for noting system inefficiencies in system operations. However, a problem with the Nelson model is that it requires extensive data for determining depreciation and debt-service factors. Its use for estimating future operating costs would be a time-consuming endeavor.

## CONCLUSIONS

Eight operating-cost models have been reviewed. Structural problems limit their value for forecasting future operating costs. Case-study data illustrate that, since vehicle miles and vehicle hours are highly correlated, it does not make sense to use both variables in the same equation as was done in the models of average daily cost, annual cost, and slowness. In situations in which costs are rising and outputs are declining, the average-daily-cost and annual-cost models were shown to be unreliable.

The urban transit industry has been changing rapidly during the last 15 years. The ratio of expenditures to output is no longer predictable. One important reason is that political criteria, such as servicing all areas of a region with subsidized transit, have replaced efficiency criteria. This situation, which arose because of the need to subsidize operating deficits, allowed new actors (regional, state, and federal officials) to enter the urban transit policy-making environment.

The availability of data from reporting requirements of Section 15 of the Urban Mass Transportation Act of 1964, as amended, will present some interesting opportunities for cross-sectional analysis. Several of the operating-cost models, such as the urban-environment-cost and the cost-per-vehicle-hour models, could be applied to individual transit networks. For example, they could indicate which portions of a transit system could be altered or replaced by forms of privately owned and/or operated shared-ride systems. The California legislature has required that urban transit systems finance at least 20 percent of operating costs from fares. This requirement combined with the models discussed above could encourage better estimates of future operations and costs.

The need to forecast operating costs remains an important part of planning. Research in this area should now be directed toward developing techniques that can build on the experiences gained from using the models reviewed in this paper. Two techniques are recommended for further research--developing probabilities of changes in cost categories and generating a set of alternate scenarios that focus on different operating environments and their impacts on operating costs. These techniques do not focus on a fixed future. Instead, as Vanston and others (25) note, they minimize the risk inherent in planning against a single, unforeseeable future.

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# Allocation of Bus Transit Service

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**To achieve an equitable distribution of its transit service, the Southern California Rapid Transit District intends to allocate service by formula to the communities it serves. The formula would have measures of ridership and population. Before a decision maker can set the relative weights of these two variables, the effect on service levels in the various constituencies must be determined. This paper describes a study that determined the formula that came closest to prescribing the existing levels of service. Data on population, service levels, and ridership were obtained from a system of area accounts, in which data are maintained at the census-tract level and then aggregated into larger areas as required. Regression was used to determine that the formula that best fit existing service levels would have weights of 48 percent on ridership and 52 percent on population. It was found that a better fit was obtained when service was measured in dollars expended rather than in bus kilometers.**

In any public enterprise, efficient operation is no more important than is the fair distribution of services. The inherent conflict between these two objectives can be dealt with in a transit service policy in which productivity is maximized within the constraints specified by a distribution policy. Total amounts of service for each subregion of a service area can be set and, given these amounts, the service within the subregions can be adjusted to be as productive as possible.

The question of distribution has previously been cast by Levine (1,2) as a problem in the allocation of transit operating deficits. Such an approach stems from the need to apportion deficits among tax-contributing political jurisdictions served by a single operator. In the case of Los Angeles, in which deficits are covered by tax funds collected on a geographic base broader than the area served (i.e., state and federal taxes), it is more appropriate to allocate the entire cost of service. Within that allocation, both deficits and user charges can be considered.

The Southern California Rapid Transit District (SCRTD) has been exploring the approach of formula allocation of service, which would function much like the formula used to distribute federal transit operating funds to urbanized areas. As with the federal formula, residential population would be one variable. The other variable, rather than population density, would be a measure of ridership.

A requisite for such an allocation formula is having a suitable data base. A system of area accounts was developed at SCRTD for this purpose. Maintained at the census-tract level, these accounts include transit service and use data in addition to the demographic data normally available by census tract. All transit data are attributed to bus stops and from there to the census tract in which the stop is located.

SCRTD obtains ridership data by bus stop for a number of purposes--scheduling, route planning, reporting as required by Section 15 of the Urban Mass Transportation Act of 1964, and area accounts. The cost of obtaining and processing the data is less than 1 percent of the operating budget, and the increment attributed to maintenance of the area accounts is a small fraction of that.

The question of distribution is inherently a political one and must be decided in a suitable manner. Before decision makers can or will make a decision on a formula, they must know how their constituencies will be affected. The subject of this paper is a study undertaken to determine the existing distribution of service in relation to a potential formula. By using multiple linear regression of the data provided by the area accounts, the level of service is estimated from explanatory variables such as ridership and population.

The SCRTD distributes its services over a broad and diverse geographic area. Although there has been no formal policy on allocation, the distribution is not random. The analysis reported here was undertaken in order to test an underlying (if unconscious) rationale. Questions of primary interest are

1. How closely is service level correlated with the combined factors of population and ridership within the local areas?
2. If we assume such a relationship, what is the relative emphasis on each of the two factors in the current distribution of service?
3. If a formula were adopted and adhered to, what would the effect be on service levels in the various geographic areas?

Some secondary questions were also addressed:

1. What happens if service level is defined by bus kilometers instead of by expenditure level?
2. Once variations in service level due to population and ridership are accounted for, what is the effect of a third variable that indicates transit dependency?

## ALLOCATION FORMULAS

Allocation is the splitting of a resource among the members of a group. Any allocation formula can be reduced to the form

$$y_i = \sum_j a_j x_{ij} \qquad (1)$$

where

$$\sum_i y_i = \sum_j a_j = \sum_i x_{ij} = 1$$

where

$y_i$ = fractional share of the resource that will go to the ith recipient,
$x_{ij}$ = fractional share of the jth variable associated with the ith recipient, and
$a_j$ = proportion of the total resource to be divided up according to the shares of the jth variable.