

part of the authorization procedure. Signing restricted CCFL use to authorized vehicles, and sticker visibility, in addition to vehicle appearance, helped police enforcement and public recognition of violators.

3. Public attitudes--Although the CCFL was the first concurrent-flow freeway application in Houston, it was not the first preferential treatment project. North Freeway commuters were exposed to the contraflow concept over a 9.6-mile segment of the freeway in August 1979. The definition for authorized vehicles was not new to commuters. Many people, including the news media, called the CCFL an extension of the contraflow project. This sequence of staging the concurrent-flow experiment after contraflow may have improved the chances for public acceptance of the concept.

After three months of project operation, the general conclusion of the TSDHPT-MTA project management team, the users, and the public is that the North Freeway CCFL has proved successful. The level of use and its continued increase have met expectations. The fact that an additional 190 person-h are saved daily and 260 buses and vanpools have been afforded exclusive access around a congestion bottleneck has enhanced transit and vanpooling as a desired alternative to the automobile in the corridor. Both the CCFL and contraflow projects to date have accomplished a daily savings of 3300 person-h and removal of 4500 automobiles from peak-direction traffic, significantly impacting expectations for regional transitways on many of Houston's corridors in the future.

I hope that the information presented substantiates the initial conclusions drawn regarding the concurrent-flow application in Houston. The project will continue to be monitored and modified by the management team, as appropriate, until such time that a more permanent transitway facility can be incorporated into the North Freeway.

## REFERENCES

1. I-45 Contraflow Interim Report. Metropolitan Transit Authority, Houston, May 1980.
2. Manual on Uniform Traffic Control Devices. FHWA, 1978.
3. Addendum to Driver Training Manual. Metropolitan Transit Authority, Houston, March 1981.
4. Summary of Operations of the Concurrent Flow Lane. Texas Transportation Institute, Texas A&M Univ., College Station, Draft Rept., July 1981.
5. C.A. Fuhs and others. Operational Experience with Concurrent Flow Reserved Lanes. Texas Transportation Institute, Texas A&M Univ., College Station, Rept. 205-4, July 1977.
6. Beiswenger, Hoch, and Associates. Enforcement Requirements for High-Occupancy Vehicles. FHWA, Dec. 1978.
7. Beiswenger, Hoch, and Associates. Safety Evaluation of Priority Techniques for High-Occupancy Vehicles. FHWA, Feb. 1979.
8. H.J. Simkowitz. A Comparative Analysis of Results from Three Recent Non-Separated Concurrent Flow High-Occupancy Freeway Lane Projects: Boston, Santa Monica, and Miami. Cambridge Systematics, Inc., Transportation Systems Center, Cambridge, MA, Draft Rept., Jan. 1978.
9. Beiswenger, Hoch, and Associates; Texas Transportation Institute. Occupancy, Volume, and Park-and-Ride Surveys. Metropolitan Transit Authority, Houston, Jan. 1981.

*Publication of this paper sponsored by Committee on Bus Transit Systems.*

# Review of Bus Costing Procedures

WALTER CHERWONY, SUBHASH R. MUNDLE, BENJAMIN D. PORTER, AND GREGORY R. GLEICHMAN

With changing policies regarding transit funding at all levels of government, transit planners will be required to monitor more carefully existing bus systems as well as examine intensively proposed service changes. A key aspect of this responsibility will be an assessment of transit finances. During the past two decades, the focus of research has been placed on the estimation of demand and revenue. In the next few years, increasing efforts will be directed to the estimation of bus operating costs and the underlying relation that impacts expenditures. A discussion of various procedures and techniques that have been developed and applied in the past to estimate operating costs is presented. The methods have been grouped to form broad generic types, which in turn have been subdivided further by unique approaches. To illustrate the present state of the art, each approach has been illustrated by a single model. This cost-estimation review clearly indicates the evolutionary nature of cost-estimation procedures. The latest research efforts are typically more accurate and sensitive to drivers' wages and work rules that reflect the labor-intensive nature of bus transportation. It is anticipated that an understanding of the prevailing cost-estimation procedures will aid transit planners in their activities and enable them to contribute to the literature on costing procedures.

Almost every transit system today has established a mechanism to monitor existing bus service performance and conduct service planning in a systematic fashion. The techniques and approaches vary widely;

some systems perform cursory reviews of their needs and others use sophisticated techniques to perform detailed operations and planning activities. A key element of this analysis involves estimating the costs to provide present service as well as computing the cost impacts of proposed service changes. This need has become acute due to the limited financial resources of all public services, including public transportation. More than ever, transit managers are focusing their attention on improving the productivity, effectiveness, and efficiency of their transit systems. A key component of this new cost consciousness is a strong interest in developing a technique that accurately estimates the cost of present routes and the cost of proposed service changes.

Recognizing this need, the Urban Mass Transportation Administration (UMTA) has commissioned Booz, Allen and Hamilton to develop a uniform technique or set of techniques that will accurately reflect the cost of providing bus service. An initial step in this study is a review of cost-estimation techniques

that have been used previously in the transit industry. The objective of this paper is to present the results of this review and provide an overview of techniques and procedures that appear in the technical literature.

#### GENERIC TYPES OF COSTING MODELS

To provide an analytical framework for review, the various estimation techniques were catalogued into several generic types. Some techniques are combinations or hybrids of more than a single generic type. For purposes of this paper, each procedure has been designated as representative of a particular genre based on the model's concentration of effort. No simple classification system can account for the various permutations of cost models presented in the literature. However, three generic types of models are prevalent, as described below:

1. Causal factors: The causal-factors approach is similar in nature to the preparation of a bid estimate for a construction project. Various quantities required to provide bus service, such as drivers, buses, fuel, tires, etc., are estimated and multiplied by an appropriate unit-cost factor. The products of each quantity estimate and unit cost are summed to arrive at the transit cost.

2. Cost-allocation model: The cost-allocation technique appears widely in the literature as a means to disaggregate system costs into individual route expenditures. Unlike the causal-factors approach, transit costs are estimated on a top-down basis. The key assumption of this approach is that each operating expense item can be assigned or allocated to a specific operating statistic such as vehicle miles. Unit costs are developed that comprise the coefficients of the cost-allocation model.

3. Temporal variation: Many researchers have concentrated their analyses on the differences in costs for providing service by time of day or day of week. By analyzing the underlying relations that influence bus costs, an attempt is made to quantify the temporal variation in costs. Because the emphasis of this research is usually on drivers' wages, these techniques often embrace other generic types to estimate nondriver expenditures.

Regression models were reviewed in this study but are not fully described here. Typically, the regression approach has been applied to identify the underlying relations that influence transit costs rather than to compute the cost of existing routes or to determine the incremental cost associated with service changes.

A three-level hierarchy for classifying the models was developed to aid the following discussion. First, model groups are classified by their generic type. A generic type, as described above, is a grouping of approaches that all share one distinctive characteristic. Each of the next three sections of the paper covers a single generic type. Second, model groups are classified by their approach. An approach is a grouping of models that generally use a similar technique but vary at the detailed level. Finally, each model is discussed in the context of its generic type and approach. Models are distinct techniques developed by a single researcher or research team.

Another point to note is that transit operating expenditures can be described in four ways--fixed, variable, average, and marginal cost. For the most part, these cost categories and nomenclature are drawn from economics and accounting and are not unique to the transit industry. It should be recognized that some authors differ in their use of these

terms. To facilitate a uniform nomenclature, the following definitions are used:

1. Fixed costs: Fixed costs are those expenses that do not vary with the level of production. In bus systems, this means that these costs are unchanged with respect to the number of hours, miles, or buses operated. Fixed costs typically include costs such as general manager salary and maintenance expenses for buildings.

2. Variable costs: Variable costs are those costs that do vary with the amount of service provided. These expenses would include costs for fuel, drivers' wages, and a host of transit operating costs. The differences between fixed and variable costs are portrayed in Figure 1.

3. Average cost: As the name implies, average cost is merely the cost divided by the level of output. As shown in Figure 1, the average cost at output level  $O_1$  is merely the slope of the line from the origin ( $C_1/O_1$ ). Similarly, at output level  $O_2$ , the average cost is  $C_2/O_2$ .

4. Marginal cost: Sometimes referred to as incremental cost, marginal cost refers to the additional costs associated with an increase in the level of output. As shown in Figure 1, it is merely the change in costs ( $C_2 - C_1$ ) associated with a change in output level ( $O_2 - O_1$ ).

#### CAUSAL FACTORS

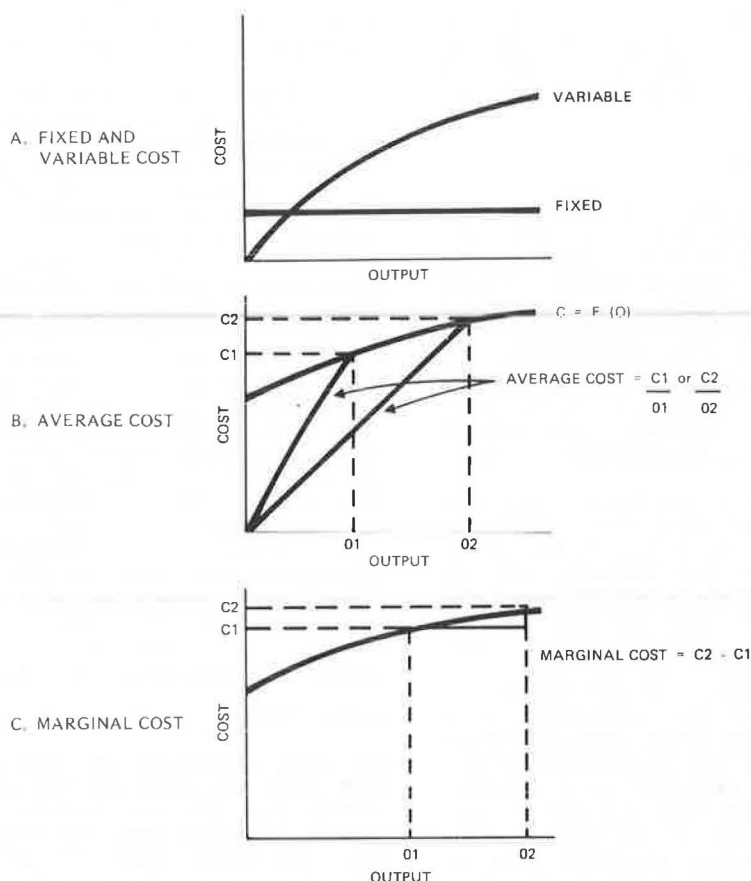
The idea underlying the causal-factors method is that total bus costs are the sum of the individual amounts paid for each resource item consumed. For example, resource items may include drivers' wages, tires and tubes, fuel, oil, and repair parts. The cost of each resource item is found by multiplying the quantity consumed by the unit price or unit cost of the item.

The causal-factors method, not being unique to bus costing, is well known and understood. The process is analogous to the cost-takeoff procedure used in the construction industry and is similar to the budgeting process used in almost all industries. The method is distinguished by the large number of resources included in the cost equation. Note that by selecting which cost items are included in the analysis, the issue of fixed and variable costs can be addressed as well as the incremental out-of-pocket expenses for a specific service change.

An example of this method for a single resource item can be illustrated with expenditures for drivers' wages. For example, a service change that requires an additional 80 vehicle-h daily would first be converted to hours paid based on productivity statistics. At a productivity rate of 1.5 h paid/vehicle-h, 120 pay-h would be required. Based on an average hourly wage of \$7.50/h, the driver cost of the service change would be \$900/day. In a similar manner, other expense items could be addressed with the causal-factor method.

Approaches that emphasize more accurate estimation of the driver labor resource requirement through detailed scheduling represent a subset of the causal-factors method. Schedule making may be facilitated through the use of computer programs such as RUCUS or other programs that offer simplifications of the driver assignment task. Once the labor requirement has been found by using one of these detailed approaches, the results are used as inputs to a cost model. Thus, detailed scheduling cannot stand alone as a cost-estimation method but can be regarded as an optional step within the causal-factors method.

Figure 1. Cost descriptions.



#### COST ALLOCATION

The basic concept underlying the cost-allocation method is that the cost of a route or service is a function of a few resource quantities. In the cost-allocation sense, resources are aggregate measures of transit service, such as vehicle miles, vehicle hours, and peak vehicles (1). For example, a commonly used cost-allocation model takes the following form:

$$C = U_H(VH) + U_M(VM) + U_V(PV) \quad (1)$$

where

$C$  = cost of route,  
 $U_H$  = unit cost per vehicle hour,  
 $VH$  = vehicle hours of route,  
 $U_M$  = unit cost per vehicle mile,  
 $VM$  = vehicle miles of route,  
 $U_V$  = unit cost per peak vehicle, and  
 $PV$  = peak vehicles used on route.

The unit costs are found by completing three tasks. First, each expense object (e.g., drivers' wages, fuel) is assigned to one or more resource variables (e.g., vehicle hours). Second, the expense objects assigned to each resource are summed to obtain the overall cost assigned to that resource. Third, unit costs (e.g., cost per vehicle hour) are derived by dividing the overall resource cost by the quantity of that resource. The method received its name because it is commonly used to allocate total system costs to individual routes on a proportional basis (2).

The cost-allocation method differs from the causal-factors method in that it is a top-down ap-

proach. In the causal-factors approach, for instance, unit costs are based on actual market prices for specific items. In contrast, the cost-allocation model derives unit costs from system expense-account data and operating statistics. Unit costs for the cost-allocation model, then, are not defined in terms of goods normally purchased. For example, transit systems do not buy vehicle hours in the same sense that they buy diesel fuel. Rather, unit costs represent the cost for providing some aggregate measure of transit service. Although some could be considered input measures, such as peak vehicles, others are more accurately termed output measures, such as vehicle miles.

Two approaches have been followed in the development and application of cost-allocation models. The first is denoted fully allocated in that all operating costs are included. Another approach, favored by British bus systems, is the fixed-variable procedure. In this latter approach, costs are stratified by whether they are fixed or variable.

#### Fully Allocated

The first step in applying the fully allocated approach is selecting the resource variables for inclusion in the model. This step effectively defines the number of terms in the model's equation. For illustrative purposes, the following discussion is based on the application of a three-variable cost-allocation model to the Birmingham-Jefferson County Transit Authority. The Birmingham application used the model form presented earlier.

The second step in this approach is to derive unit costs. As described previously, three tasks are involved. First, one must assign the expense accounts to the resources. The following discussion

illustrates the rationale used to make some of the assignments:

1. Vehicle hours: Employees engaged in operating the vehicles are, of course, paid on an hourly basis. Thus, the assignment of this wage expense is properly made on the basis of hours of service. Likewise, other expenses that are related to service hours, such as supervision of transportation operations, are assigned to this category.

2. Vehicle miles: Many costs are related directly to the miles of operation of each route. Expenses such as fuel, tires, parts, and maintenance of revenue equipment are a direct function of the number of miles operated.

3. Peak vehicle needs: Many individual expense items do not vary as functions of either of the foregoing parameters--vehicle miles or vehicle hours. Rather, many overhead expenses are related to the scale of the system. Peak vehicles provide a reasonable measure to assess certain cost consequences of orienting the transit system to peak requirements of service.

By summing the expenses assigned to each resource and then dividing by the appropriate operating statistic, the unit-cost coefficients of the model are determined. The calibrated model for the Birmingham example is as follows:

$$C = 9.34 (VH) + 0.32 (VM) + 3459 (PV) \quad (2)$$

Although the preceding discussion has centered on a three-variable model, other fully allocated models have used more or less variables. The resources used to define the variables also differ from model to model. No matter what number or type of resources are used, the basic algorithm for all fully allocated models is essentially the same as that described for the three-variable model. Only minor modifications are necessary to accommodate the additional (or deleted) variables. It should be noted that average costs, such as \$2.25/mile or \$23.50/h, represent the simplest cost-allocation model--one with a single variable.

#### Fixed-Variable Procedure

The fixed-variable cost-allocation models differentiate between fixed and variable costs. Such models modify the fully allocated approach by classifying each expense account as either a fixed or variable cost (3). Once classified, unit costs can be derived from the expense accounts in two dimensions: (a) according to resource, as is done with the fully allocated approach, and (b) according to cost classification.

As noted previously, this approach is typically employed by British bus systems. Frequently, the fixed costs have been stratified into two cost types--variable overhead and fixed overhead. An example (4) of a cost model for the Merseyside Bus Company is presented below:

	Cost Type		
	Direct	Variable Overhead	Fixed Overhead
Vehicle hours	1.08	0.39	0.82
Vehicle miles	0.03	0.04	--
Peak vehicles	--	53.53	22.35

One attractive feature of the fixed-variable cost-allocation-model approach is that it can be used to allocate existing bus route costs as well as estimate the incremental costs associated with proposed service changes.

#### TEMPORAL VARIATION

It is generally accepted in the transit industry that the cost of peak-period service is higher than the cost of base-period service. Costing models that specifically address this variation of peak and base costs have been termed temporal-variation models. Temporal cost variation arises from two sources: (a) the labor cost differential associated with labor agreement provisions that specify wages and work rules and (b) the vehicle cost differential associated with supporting peak-period vehicle requirements. All temporal-variation models focus on the first source, since labor costs are by far the single most significant component of operating cost. However, several models also treat the vehicle cost differential, although in a less complex manner.

The focus on labor costs takes the form of a detailed examination of productivity and wage costs for each period of the day and, in some cases, day of the week. Productivity is typically viewed in terms of the number of driver pay hours required to provide a platform hour of bus service. Generally, the ratio of pay hour to platform hour is higher for peak periods due to inefficiencies introduced by split shifts, spread penalties, guarantee time, and other labor agreement provisions. Wage cost variations result from bonuses, overtime rates, penalty pay rates, and other bonus or penalty provisions. Temporal-variation models use a variety of techniques to incorporate these types of cost differences into the cost-estimation procedure.

Temporal-variation models are all enhanced cost-allocation models that focus on time period cost variations. Typically, nondriver costs are handled within the traditional cost-allocation framework while special methods are reserved for driver and vehicle cost calculations. As a result, the subsequent discussion focuses on the unique features of the temporal models, i.e., their examination of labor and vehicle costs, and only briefly describes those aspects similar to the cost-allocation method described previously.

The models identified as belonging to the temporal-variation generic type have been classified as representing one of three approaches:

1. Cost-adjustment approach, in which vehicle hour unit cost is adjusted relative to peak and base labor productivity;
2. Statistical approach, in which sample data are used to determine the relative productivity of peak-period service and cost; and
3. Resource approach, in which labor assignment practices are used to estimate labor requirements that reflect time-of-day variations.

Models of the temporal-variation type are certainly the most complex and perhaps the most important in understanding relations that affect bus operating costs. Because of the evaluation and nature of research of transit cost, temporal-variation models represent the latest efforts in this field. Numerous models can be categorized into the three approaches described above. Because of space limitations, only a single representative model is described below for each approach.

#### Peak-Base Model: Cost Adjustment

The peak-base model modifies the standard three-variable cost-allocation model by defining two different vehicle hour unit-cost coefficients, one for vehicle hours operated during the peak period and another for vehicle hours operated during the base

period (5). The peak-period vehicle unit cost generally is higher than the base-period vehicle unit cost.

The two unit-cost coefficients are found by adjusting the standard allocation model's single vehicle hour coefficient. Two indices are used for the adjustment, one representing the relative productivity of labor and one representing the ratio of peak to base service. The indices are based on an audit of a sample month's data regarding vehicle hours and pay hours consumed during the peak and base periods. Vehicle mile unit cost is applied to both peak and base service. Peak vehicle unit cost is used for only the peak period.

The first step in the model is to assign the audit month's vehicle hours and pay hours to either the peak or base period. The labor productivity (i.e., ratio of pay hours to vehicle hours) is greater for the peak than base time period. Through various algebraic manipulations, it is shown that the new vehicle hour unit costs (peak and base) are calculated by the following formulas:

$$UC_p = [n(1+s)/(1+ns)] \cdot UC_s \quad (3)$$

$$UC_b = [(1+s)/(1+ns)] \cdot UC_s \quad (4)$$

where

$UC_s$  = vehicle hour unit cost (traditional allocation model),  
 $UC_p$  = peak-period vehicle hour unit cost,  
 $UC_b$  = base-period vehicle hour unit cost,  
 $n$  = relative labor productivity, and  
 $s$  = service index (ratio of peak to base vehicle hours).

Equations 3 and 4 represent the adjustment factors for the vehicle hour unit costs. The resulting cost-allocation model for the Minneapolis-St. Paul example is presented below:

Traditional:  $C = 9.90H + 0.31M + 1353V$

Peak:  $C = 10.57H + 0.31M + 1353V$

Base:  $C = 9.20H + 0.31M$

where  $C$  is cost,  $H$  is vehicle hours,  $M$  is vehicle miles, and  $V$  is peak vehicles.

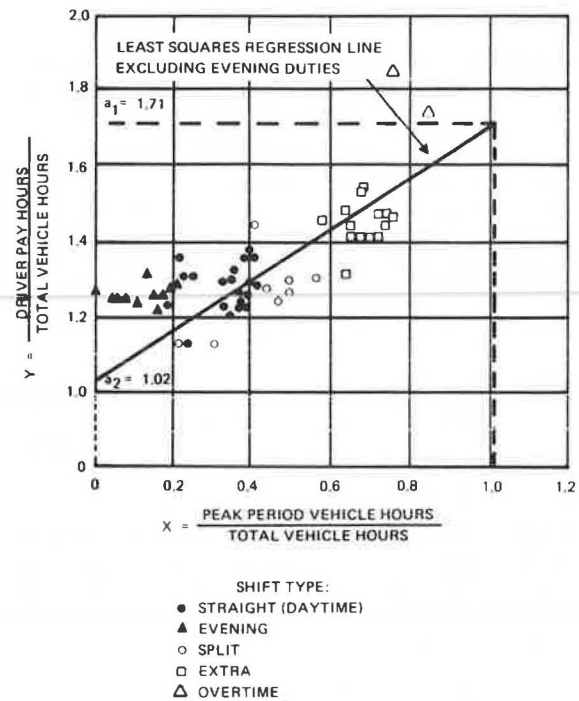
#### Arthur Andersen Model: Statistical

The Arthur Andersen model (6) is basically an enhanced fixed-variable cost-allocation model. Thus, the first step toward using the model is the development of the cost-allocation portion. Expense accounts are assigned to one of three cost types [i.e., direct costs, variable overheads (semifixed), and fixed costs] as well as three resources (i.e., vehicle hours, vehicle miles, and peak vehicles). Nine combinations are possible. Direct driver cost is included in the combination of vehicle hours and direct costs. Direct driver cost is analyzed in detail separately from the other combinations. Indirect driver cost and all other costs are estimated with the fixed-variable cost-allocation technique previously described.

To analyze driver costs, the initial step is to define the peak and base periods. Next, the sample shift data are used to estimate the coefficients of the following equation:

$$D_a = a_1(P) + a_2(B) \quad (5)$$

Figure 2. Arthur Andersen model—regression analysis example.



where

$D_a$  = total driver pay hours under the Andersen model,

$a_1$  = pay hours per peak-period vehicle hour,

$a_2$  = pay hours per base-period vehicle hour,

$P$  = peak-period vehicle hours, and

$B$  = base-period vehicle hours.

The coefficients  $a_1$  and  $a_2$  are found by plotting the sample data and fitting a curve. Each sample point is a shift that includes a combination of peak- and base-period vehicle hours ( $P$  and  $B$ ). The proportion of peak and base hours depends on the shift's type, as shown in Figure 2 (6, Figure 5; 7). Generally, split shifts will have a higher proportion of peak-period vehicle hours than straight shifts. Extra shifts have a higher ratio of pay hour to vehicle hour than split shifts. Overtime shifts have the highest ratio. Regression analysis is performed to find the curve that relates the ratio of peak-period vehicle hours to total vehicle hours to the ratio of driver pay hours to total vehicle hours.

Estimates of the coefficients  $a_1$  and  $a_2$  can be found from the graph of the regression analysis results (Figure 2). Coefficient  $a_1$  is the value on the vertical axis when the horizontal axis value is unity. The y-intercept of the graph gives the value of  $a_2$ . Once estimated, the parameters are converted to costs by multiplying them by the wage rate. As shown below, this calculation produces estimates of driver unit costs for peak and off-peak periods:

Item	Peak	Base
Pay hours per vehicle hour ( $a_1$ and $a_2$ )	1.71	1.02
Wage rate per pay hour (£)	2.00	2.00
Driver cost per vehicle hour (£)	3.42	2.04

Driver cost is combined with the results obtained from the fixed-variable cost-allocation model to produce total cost.

### Bradford Model: Resource Allocation

The Bradford cost model was developed by R. Travers Morgan and Partners for their cost analysis of the Bradford (England) bus system (8). In addition to the development of cost procedures, this research presents a lengthy discussion of factors that influence operating costs and the quantification of these costs impacts. Because of space limitations, only the salient dimensions of this research effort are presented here. Of interest are the cost variations by day of the week, time period within a typical weekday, and a scheduling algorithm to cost new services.

The model is basically a fixed-variable cost-allocation model with pay hours, bus hours, and peak vehicles as the resources and driver labor costs and direct operating and overhead expenses as the cost categories. Expense accounts are assigned to resource and cost categories. The peak vehicle cost calculation follows the traditional cost-allocation approach. The calculation of the unit costs per pay hour and per vehicle hour involve slightly different procedures.

Unit costs per pay hour are obtained exclusively from expense accounts classified as driver labor. The initial step is to calculate the wage cost per 40-h week. Next, the driver schedule audit month data are used to find the ratio of pay hours to worked hours. Results for the audit month, which reflect various premium and penalty provisions of the labor contract, are presented below:

Day of Week	Ratio
Monday-Friday	1.08
Saturday	1.55
Sunday	1.75
Total	1.20

In addition, the research focuses on labor costs by time period. Much of this work examines the ratio of pay hours to work hours by time period.

Another feature of the Bradford study is the estimation of daily vehicle costs for weekdays, Saturdays, and Sundays. This analysis is based on the number of days each bus operates. As shown below, the vehicle cost by day varies considerably, since the use of buses differs substantially during each day:

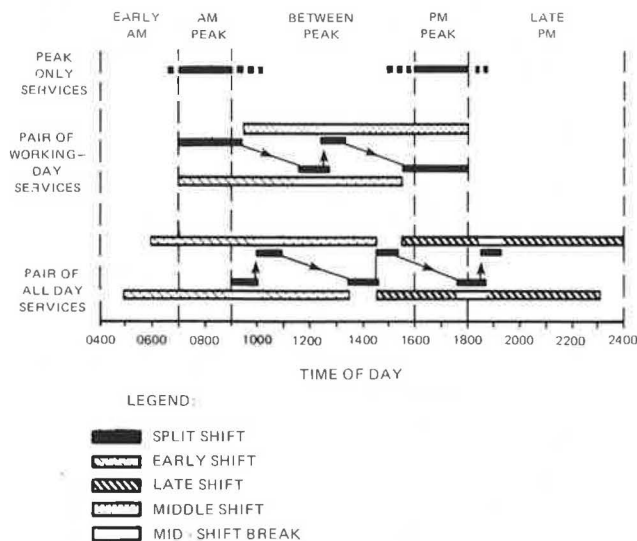
Day of Week	Vehicle Cost (£)
Monday-Friday	35.9
Saturday	32.5
Sunday	30.3

Another issue treated in the research is the vehicle cost variation by time period for weekday service. The examination is similar to the apportionment exercise carried out for the day-of-week variations. The analysis was performed for three layers of weekday service:

1. Peak only--Average duration is about 4 h, typically from 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m.;
2. Working day--Average duration is about 11 h, typically from 7:00 a.m. to 6:00 p.m.; and
3. All day--Average duration is about 18 h, typically having staggered starting times from 4:00 to 7:00 a.m. and finishing times from 11:00 p.m. to midnight.

By using these definitions, the values from various intermediate steps (not presented here) were summed to obtain the appropriate vehicle costs for each

Figure 3. Bradford model--driver scheduling model.



service layer. A summary of this vehicle cost analysis is presented below:

Layer	Hours	Avg Cost per Bus (£)
Peak only	4	22.2
Between peaks	7	16.0
Early morning, late evening	7	11.8

Total costs for each layer were found by adding the appropriate pay hour and vehicle hour cost components to the vehicle cost.

Another unique feature of the Bradford work was the development of a simple scheduling model to estimate the number of straight and split shifts required to implement service changes. The model is based on the labor scheduling practices prevailing at the transit property that typically reflect wage and work rule provisions of the labor agreement. As shown in Figure 3 (8, Figure 7.01), the model assumes that a single split shift staffs a peak-only service, that two straight shifts and one split shift staff a pair of working-day services, and four straight shifts and one split shift staff an all-day service.

### CONCLUSIONS

The previous discussion provides a brief overview of the various cost-estimation procedures that have been developed and applied in the past. They vary considerably in terms of their level of sophistication, ease of use, and sensitivity to various dimensions of the bus system. The most commonly used cost procedure is the allocation model, which can be used in cost analysis of existing systems as well as in estimation of cost impacts of service changes. The more recent research modifies and enhances this basic analytical framework. Some researchers have segregated costs into various categories of fixed and variable components. Not surprisingly, the latest research places a common focus on examining the major cost element of transit service: drivers' wages. Although these methods differ considerably, they all recognize the labor-intensive nature of transit operations.

With greater emphasis on cost containment and resource allocation in the future, planners will need to understand the factors that influence bus

operating costs. This will mandate a knowledge of the prevailing state of the art in bus cost-estimation procedures. It is anticipated that with greater emphasis on this topic, further enhancements and innovative approaches to estimating transit costs will evolve.

#### ACKNOWLEDGMENT

This research was performed under the sponsorship of UMTA, U.S. Department of Transportation. The contents of this paper were prepared by the Simpson and Curtin Division of Booz, Allen and Hamilton, Inc., and do not necessarily reflect the official views or policies of the U.S. Department of Transportation or UMTA.

A more complete discussion of the concepts presented in this paper is available elsewhere (9).

#### REFERENCES

1. W. Cherwony and B.E. McCollom. Development of Multi-Modal Cost Allocation Models. Proc., Fourth Annual Intersociety Conference on Transportation, ASME, New York, 1976.
2. M.G. Ferreri. Development of Transit Cost Allocation Formula. HRB, Highway Research Record 285, 1969, pp. 1-9.
3. H.W. Taylor. A Method of Bus Operations Costing Developed by NBC. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1975, pp. 6-13.
4. J.S. McClenahan and D.R. Kaye. A Method of Bus Costing Developed by Arthur Andersen and Company. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1975, pp. 31-51.
5. W. Cherwony and S.R. Mundle. Peak-Base Cost Allocation Models. TRB, Transportation Research Record 663, 1978, pp. 52-56.
6. J.W. McClenahan, D. Nicholls, M. Elms, and P.H. Bly. Two Methods of Estimating the Crew Costs of Bus Service. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Supplementary Rept. 364, 1978.
7. Symposium on the Costing of Bus Operations. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Supplementary Rept. 180UC, 1975, p. 51.
8. R. Travers Morgan and Partners. Bradford Bus Study. West Yorkshire Metropolitan County Council and West Yorkshire Passenger Transport Executive, England, Final Rept., 1976.
9. Simpson and Curtin; Booz, Allen and Hamilton. Bus Route Costing Procedures: A Review. UMTA, Rept. UMTA-IT-09-9014-81-1, May 1981.

*Publication of this paper sponsored by Committee on Bus Transit Systems.*

## Potential Impacts of Transit Service Changes Based on Analytical Service Standards

GEORGE KOCUR

The results of a hypothetical case study of the Hartford, Connecticut, bus transit system in which service and fares are redesigned based on service standards derived from an analytical optimization model are presented. The key variables in the analysis are route spacing, headway, fare, and route length for both local and express routes. Three different sets of possible local objectives are treated, which place varying emphasis on profit (or deficit) and user benefits. Comparisons of the results with the existing system are made, and several policy issues are addressed. The analysis concludes that major increases in productivity are technically possible, based in large part on route restructuring and the introduction of substantial express service. Because relatively large changes from current operations are entailed, equity and political feasibility may be large issues in making the proposed changes.

The next decade promises to be a period of transition in urban transportation services. Urban public transportation was provided by private firms in most U.S. cities until the mid-1960s when most systems came under public management and subsidization. Few major changes in bus operating policies or system design have been made in this period of public ownership except for maintaining fares at a lower level than a private firm would have required. This strategy may be reassessed in many cities in the next decade for two major reasons. First, transit deficits have grown sharply over the levels originally anticipated when the systems became public operations. In 1965 the total U.S. transit deficit

was \$11 million and revenues covered 99 percent of expenses. However, in 1977 the U.S. transit deficit had risen to \$2 billion and the percentage of operating expenses covered by farebox revenues had dropped to 53 percent (1). Part of this rapid increase in deficits had been absorbed by the federal government, but already tight state and municipal budgets will be forced to absorb most of the additional operating losses that may occur. This is likely to lead to consideration of service reductions, fare increases, and means of increasing productivity at the local level.

A second major impetus to the analysis of bus systems is energy policy. Expansions in bus service may reduce urban transportation energy requirements, but the deficits of such service require that any expansion in service must be designed very carefully to maintain economic feasibility.

#### SUMMARY OF SERVICE AND FARE STANDARDS METHODOLOGY

In this case study, the Hartford, Connecticut, system was redesigned according to service standards based on three sets of goals (or objective functions), and the results were compared with current operations. The case study treats peak-hour service only for simplicity. The service standards are