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Scheduling-Based Marginal Cost-Estimating Procedure

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With changing policies regarding transit funding at all levels of government, transit planners will be required to more carefully monitor existing bus systems as well as intensively examine the net cost or savings of proposed service changes. In the past, research has focused on only one side of the equation—demand, hence revenue estimation. In the near future, more effort will be directed to operating-cost estimation and the underlying relationships that impact expenditures. Although a variety of cost-estimation techniques have been developed, there is little agreement as to which one best estimates cost. The purpose of this project was to develop a technique that is complex enough to capture the salient cost characteristics of a change in transit service. The cost model presented here is sensitive only to those line items that typically vary in response to changes in the scale or characteristics of fixed-route service. These are termed variable costs. A major variable cost component is driver cost, which is treated by the model in some detail. Driver cost is assumed to be a function of the number of drivers required to operate scheduled service, along with exceptions that normally occur in daily operations. These perturbations are captured through simulations of scheduling and dispatching processes. These are described as a set of calibrated ratios and percentages that assume no dramatic departure from the norm. Other variable costs (e.g., fuel and insurance) are estimated through a typical cost-allocation approach. This model is currently being tested along with several other prominent costing approaches. A variety of small service changes are being used as the basis for comparison. No results on the models' comparative performances are available at this time.

The current decade will represent a period of dramatic change for most transit agencies as they respond to an era of limited resources. Many systems, facing severe financial constraints, have already made substantial service changes to balance transit costs with available funds. This new direction in the transit industry will place greater demands on transit planners to forecast, with reasonable accuracy, the financial implications of service changes. Unfortunately, no single technique or procedure has been established that transit planners can readily use. Recognizing this deficiency, the Urban Mass Transportation Administration (UMTA) has commissioned a research effort to develop a bus-route costing procedure.

This study has consisted of several interrelated steps. The initial step was to review techniques now used in the industry as well as procedures identified in the technical literature. Following an assessment of these procedures and the requirements of transit planners, a proposed method was design-

ed. The current work element is the testing of the proposed procedure and other prominent models by using actual and hypothetical service changes in the Minneapolis-St. Paul (Twin Cities) urban area. Based on the test results, the proposed method will be modified as appropriate. The concluding step will be to document the proposed costing technique and prepare training materials to encourage its use throughout the transit industry.

MODEL OVERVIEW

The primary objective of the bus-costing procedure is to design a marginal cost model capable of estimating the operating-cost impacts of service changes. A review of available procedures indicates a wide range of techniques and capabilities (1). Simple procedures (e.g., average cost per mile or hour), although easily applied, are usually too coarse and insensitive to produce accurate results. More elaborate and sophisticated techniques that specifically address driver work assignments and benefit costs are normally too time-consuming for most planning applications. For this reason, the proposed model must strike a careful balance between simplicity and sensitivity to factors that influence bus operating costs.

One common feature of many cost analyses is the use of a cost-allocation model approach. Typically, the cost of providing transit services is related to different transit resource levels (e.g., vehicle hours, miles, and peak vehicles). With this approach, each expense item is assigned or allocated to a particular resource. This allocation process is normally logic-driven, although some statistical analysis has been performed to demonstrate the cost-resource relationships. For example, expenditures for tires, tubes, and fuel are logically a function of vehicle miles. An illustration of the cost-allocation approach is shown below based on the development and calculation of this procedure for the New York City Transit Authority surface operations (2):

Allocation Basis	Allocated Costs ($)	Percentage of Total Costs	Operating Statistic
Vehicle hours (H)	147 196	67.1	7 786 600
Vehicle miles (M)	54 006	24.6	66 108 000
Peak vehicles (V)	18 047	8.2	2 084
Total	219 249		

$$\text{Cost} = 18.90 * H + 0.82 * M + 8659.62 * V.$$

This three-variable model, although a commonly employed technique, overstates the cost of service changes when it includes fixed, or overhead, costs. An enhancement of the cost-allocation model is to segregate line-item costs into those affected by varying scales of service change. Most of the cost analysis performed in Great Britain, for instance, distinguishes between fixed and variable expenditures (3). Recent research efforts have been oriented to developing cost models that focus intensively on driver wages and benefits--the largest single cost of providing bus service. Although approaches differ, the intent is to incorporate procedures or variables that accurately reflect driver assignments and their associated costs. In view of the complex work rules and arrangements governing the computation of driver wages and benefits, this is no simple task.

Two interesting and contrasting approaches have been developed to gauge driver costs of service changes. The first technique, a peak-base model allocation, was developed as part of the I-35W Urban Corridor Demonstration Project to test the impact of freeway-ramp metering and expanded express-bus service (4). Within the overall framework of a cost-allocation model, the researchers quantified separate vehicle-hour unit-cost factors for peak and off-peak service. With this approach, two indices are computed, which are then used to adjust the standard cost model for both service periods. The first index (labor productivity) measures the relative ratio of pay hours and vehicle hours for peak- and off-peak service. The second index (service) measures the extent of peaking by comparing vehicle hours for both time periods. Both indices are developed by a calibration process in which recent payroll and operating data are used. The result of this process is the computation of two coefficients that adjust a systemwide cost per vehicle hour and that reflect peak and base differentials. The attractive feature of this approach is its simplicity and ease of use. This is accomplished at the expense of sensitivity to many diverse factors such as driver types, work assignments, and specific labor provisions. While the calibration measures the overall impact of these factors, it does not deal individually with each.

An alternative approach developed in England (5) and subsequently applied in Australia (6) differs markedly from the above model. It is somewhat more complex in that driver costs are estimated in a bottom-up approach rather than through cost allocation. One attractive feature of this work is the formulation of a driver-scheduling model that transcribes buses in service by time period into driver work assignments. In turn, various assignments are costed with respect to driver wages. The research also provides considerable insight as to how service is scheduled and the resulting cost implications by time of day and day of the week.

Although the two approaches briefly described above are only a sample drawn from the literature, they are instructive in that they contrast two different solutions to deal with the same problem. For this reason, the suggested approach attempts to incorporate attractive features of each without introducing undue complexity.

MODEL FRAMEWORK

The review of commonly employed costing methods yielded three guiding principles for the proposed model's development. First, only variable costs should be included. For many service changes, there is relatively little overhead, or fixed, cost incurred that would not have ordinarily been realized. Examples of fixed costs include administrative salaries, building maintenance, and some operations salaries such as that for the transportation manager. Second, driver cost must be computed with respect to the temporal service distribution. That is, it should be scheduling-based to the extent possible with a nonautomated approach. Third, nondriver costs should be estimated via cost allocation. Generally, these costs are affected only by service scale (e.g., net vehicle miles) and are not so sensitive to temporal characteristics as is driver cost.

The resulting model adheres to these principles. All cost categories included and excluded by the model were defined on the basis of the Section 15 accounting structure. Each function-code/object-code combination was used to identify all expense accounts. Consideration of the factors influencing a particular expense account plus the magnitude of expenditures was used in developing the suggested approach. The overall approach was to develop a

Table 1. Operating cost by major category.

Item	Amount ($)	Total Operating Costs (%)	Variable Operating Costs (%)
Variable costs			
Estimated by special analysis	32 946 460	51	60
Estimated by cost allocation			
Miles	19 179 677	29	35
Hours	2 419 229	4	5
Total	21 598 906	33	40
Total variable costs	54 545 366	84	
Fixed costs	10 636 972	16	-
Total operating costs	65 182 338		-

conventional cost-allocation model with only certain expenses subjected to special analysis. For this reason, only driver wages and fringe benefits are subject to special analysis. All other variable expenses relied on a traditional cost-allocation model. In the suggested procedure, only two variables are used--vehicle hours and miles. Peak vehicles was deleted as a variable since expenses allocated to this resource level are often fixed costs.

Initially, other expense items were considered for special analysis, particularly where variables other than miles or hours would affect variation in cost. For example, fuel economy and costs are a function of operating speed. From a research perspective, it would appear beneficial to develop a costing technique that could distinguish between local, central-business-district shuttle, and express-route service changes. However, it was felt that the additional effort to develop and apply a model with this capability would be burdensome. Further, the potential cost sensitivity would be relatively limited in comparison with other cost items (e.g., driver wages) and total system costs.

The classification of transit-system expenses, as explained above, demonstrates the logic of the proposed model. By using the Metropolitan Transit Commission (Twin Cities) as an example, as shown in Table 1, it can be seen that one-half of total operating expenses and 60 percent of variable costs are attributed to driver wages and fringe benefits. This alone demonstrates the need for detailed scrutiny. The remaining variable costs can be allocated to either hours or miles; the resulting cost model is

$$C = 1.13 * H + 0.63 * M + \text{(special analysis)}.$$

DRIVER COST ESTIMATION

Driver cost is composed of two major components--wages and benefits. Both these components encompass a number of discrete cost categories, many of which are influenced by dissimilar causal (i.e., independent) variables. There are two problems with producing a reasonably accurate driver cost estimate. The first is in aggregating these categories into groups the cost of which is directly tied to a single causal variable. A second problem is in calibrating a value for that causal variable. For many cost categories, the causal variable is a product of the run-cutting process. Scheduled wages, for instance, are largely determined by the number of runs in a schedule. Because of the many decisions, both objective and subjective, encountered in the scheduling process, it is difficult to predict the results.

Most cost models developed to date avoid these problems by simplifying their approach. The most common solution is to use an average cost per platform hour to estimate driver wages and benefits. This is not without statistical justification because of the strong linear relationship existing between driver cost and platform hours. Some models go a step further by adjusting the cost per hour for differences in efficiency between peak and base periods. This approach is somewhat simpler than apportioning wage and benefit cost but is less complete.

Because there are so many variables affecting driver cost, there is some degree of noise in any estimation technique. Due to uncertainties in the creation and dispatching of driver assignments, it is impossible to estimate cost exactly. However, when one can identify the components of wages and benefits and then with reasonable accuracy and ease estimate the coefficients for the variables explaining their cost, it follows that the accuracy and resiliency of the resulting cost estimate are improved.

The technique described below is an attempt to incorporate the effects of scheduling and dispatching practices on the cost of a change in service. Its development proceeded from first identifying the variables that "drive" wage and benefit cost and then defining a process to estimate these independent variables' values. Cost estimation is then a simple process of applying these variables in a given formula.

Components of Driver Cost

Driver wages and benefits are merely the total of a number of identifiable cost categories. The key to accurately estimating their cost while retaining some degree of simplicity is to determine which categories can be aggregated without sacrificing the quality of the estimate.

Driver Wages

Wages represent about 70 percent of total driver cost. There are many categories of wages at any given transit agency, which relate to specific labor agreement clauses. However, because nearly all full-time drivers receive an eight-hour daily guarantee, wages fall neatly into two classifications--those paid as part of the guarantee and those paid exclusive of the guarantee. Any distinction between pay categories that contributes to the eight-hour guarantee can be ignored. It can then be assumed that each full-time driver who is working on a given day will receive at least eight hours of pay.

Wages paid exclusive of or in addition to the guarantee are generally composed of overtime and spread premiums. The latter is a premium paid when elapsed time at work exceeds some limit (e.g., 10.5 h). Either category can be contained in the schedule or can result from the way work is dispatched. For instance, an extraboard operator working short a.m. and p.m. assignments may receive a spread premium that was not contained in the schedule.

Driver Benefits

Benefits represent about 30 percent of driver cost. Like wages, benefits are composed of many categories, but these can be aggregated into three classifications. First, paid leave accounts for a substantial portion of benefit cost. This includes vacations, holidays, and sick leave and is a subset of total absences. Paid leave is a function of the number of drivers. Second, variable benefits is that portion of benefit cost that is relative to wages earned. These include Social Security and employer pension contributions. Variable benefits are usually paid as a percent of total wages and most

Figure 1. Use of cost model components.

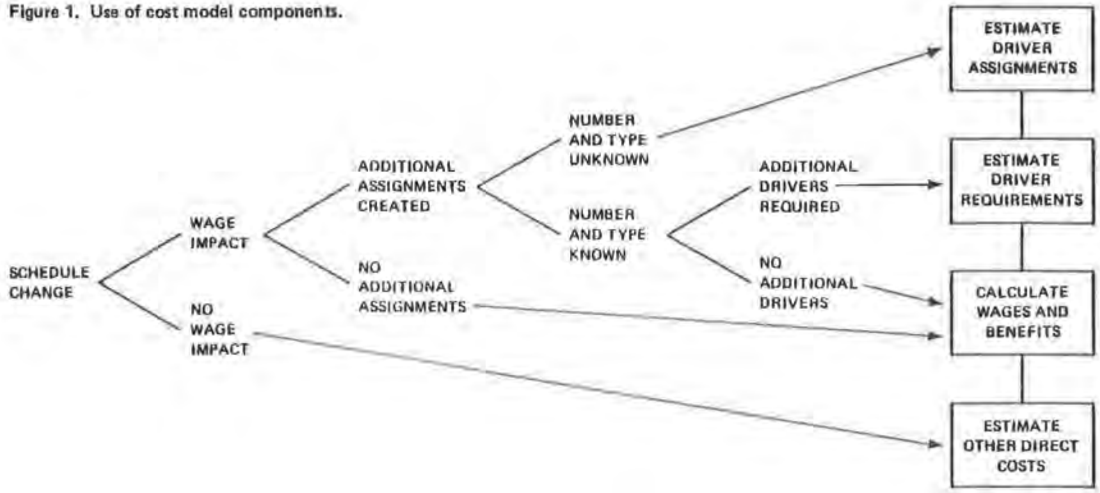
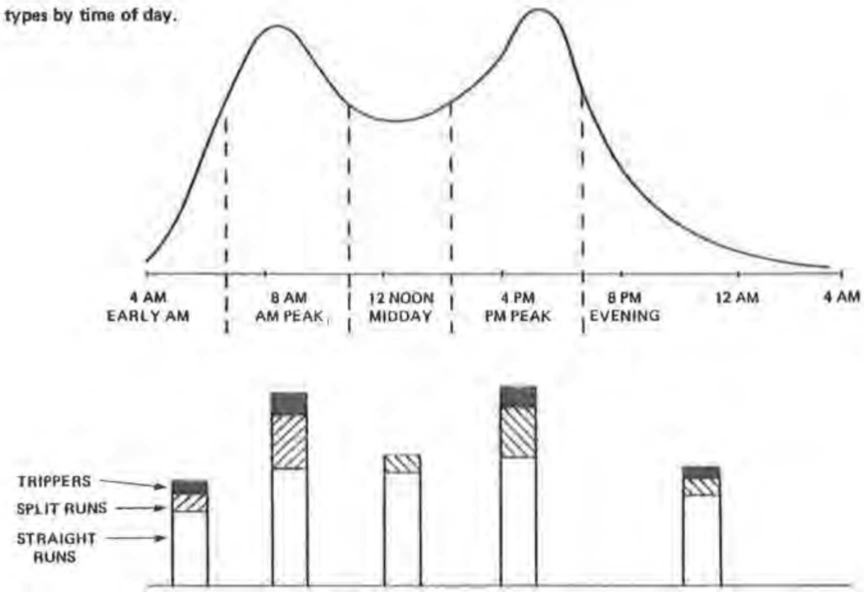


Figure 2. Assignment types by time of day.



paid absences. Third, fixed benefits include health plans, insurance plans, and uniforms. These are typically paid on a per-employee premium basis.

Model Description

Every service-planning decision has one of three driver cost impacts. First, the service change may fit within existing driver assignments so that no additional pay is required. An example of this is reducing layover time. Second, the service change may necessitate more or fewer driver assignments but may not require additional drivers. For instance, supplemental peak service could be added that is absorbed at overtime or with existing drivers. Third, the service change may require more or fewer drivers.

The structure of this cost model contains four components that relate to these potential outcomes (see Figure 1). The model is designed to conform to the level of information known about a proposed service change. If a rather large service change were proposed, for instance, the user may want to employ the full model. On the other hand, if a small change were being made and the run-cut impact known (e.g., deleting a tripper), the user may need only the wage and benefit components. Each of the components is explained more fully below.

Driver Assignments

This component uses existing run-cut information to project the number and type of driver assignments and scheduled premium hours existing after a service change. Four types of assignments (i.e., runs) are produced--straight runs, split runs, a.m. trippers, and p.m. trippers. In addition, the number of scheduled overtime and spread premium hours is forecast.

Runs are estimated by calculating the total platform hours allocated to a run type (e.g., straight run) for the day and dividing by that type's average platform time. The total platform hours allocated to one type of run are calibrated by examining the existing driver assignment data from the applicable operating base (i.e., depot, garage). The calibration calculates the proportion of hours allocated to one type of run for each of five periods in the day (see Figure 2).

Trippers are further defined based on the way in which they are usually assigned. The model is calibrated for the proportion of a.m. and p.m. trippers normally allocated to part-time drivers (if appli-

cable), assigned at overtime, or paired and assigned to the extraboard. Pay hours for both scheduled and unscheduled overtime and spread premium are calculated based on the average hours per type of assignment.

Driver Requirements

This component estimates the number of drivers working on a given day and the total number of drivers required for a week's schedule. A by-product of this process is the average number of absences.

A driver use ratio is the basis for determining driver requirements. It is computed to establish a relationship between the number of drivers required on a given day and the number of full-time assignments to be filled. In this case, full-time driver assignments include straight and split runs as well as tripper combinations assigned to the extraboard. Daily working drivers are calculated as the difference between total driver requirements and average absences. Weekly driver requirements are determined by summing the daily driver requirements for a week's time and then dividing by 5.

Driver Wages

Once daily premium pay hours and daily working drivers have been defined, driver wages are easily calculated with the following formula:

$$\sum_{i=1}^{3} [(D_i * 8) + P_i] * S_i * W \qquad (1)$$

where

- i = type of schedule (weekday, Saturday, Sunday),
- D = working drivers,
- P = premium hours,
- S = days of operation, and
- W = weighted average wage.

Driver Benefits

The costs of three benefit categories are calculated as shown below:

$$\text{Paid leave} = \left\{\left[\sum_{i=1}^{3} (A_i * PA)\right] + (TD * H)\right\} * 8 * W \qquad (2)$$

$$\text{Variable benefits} = (GW + PL) * VR \qquad (3)$$

$$\text{Fixed benefits} = TD * FR \qquad (4)$$

where

- A = absences,
- PA = proportion of absences paid,
- TD = weekly drivers required,
- H = scheduled and personal holidays,
- GW = gross wages,
- PL = paid leave,
- VR = variable benefit rate, and
- FR = fixed benefit rate.

MODEL APPLICATION

The formulas, calibration measures, and parameters defined above can be applied to service-change data to yield corresponding cost estimates. There are two basic steps--nondriver cost estimation and driver cost estimation.

Nondriver costs are estimated by applying the cost-allocation model defined earlier. This simply involves calculating the net vehicle hours and vehicle miles resulting from a proposed service change.

Driver cost estimation is somewhat different in that net costs are estimated by comparison with a baseline. This baseline is established by applying the model to existing data. For transit systems with multiple operating bases, it is advisable that this procedure be repeated for each base. Post-service-change costs are then estimated based on the entirety of service hours existing after the service change occurs. This is because driver assignments are usually created for the whole of an operating base. Therefore, examining the net change alone, particularly on a route basis, may not yield appropriate results.

CONCLUSIONS

The previous discussion has provided an overview of the need for and previous research in cost-estimating procedures. A brief description of a proposed approach has been presented. Some key conclusions from this analysis are as follows:

1. The suggested method must balance ease of use with requirements for accuracy and sensitivity.
2. A traditional cost-allocation model appears well suited to estimate all variable operating costs, excluding driver wages and benefits.
3. Driver costs associated with service changes require a two-step process--calibration and application.
4. A calibration approach can measure various indices and statistics that influence wages and benefits.
5. The model will not accurately respond to conditions that could produce significantly different run-cut results.
6. The various calibration measures are organized in such a manner and related to causal factors to permit a modular approach in which part or all of the model can be used.
7. The proposed approach is sufficiently flexible to be applied to any unique site-specific situation.
8. Because a calibration approach is used and applied to future service changes, the model does not optimize but rather reflects continuation of previous practices.

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