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Bus Route Costing Procedures: A Review

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Prepared by
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FOREWORD

Many transit systems currently develop cost estimates as part of their bus service planning process. The systems use a wide variety of cost estimation techniques, but no single technique is accepted as more accurate or reliable than others. To assist these systems, UMTA's Office of Planning Assistance has initiated a study of cost estimation techniques for bus service planning. The purpose of this study is to develop a manual of costing procedures that will enable transit systems to accurately estimate the incremental change in overall system cost due to a planned bus service change.

This document is the first interim report from the study. It includes a review of existing cost estimation techniques and an evaluation of these techniques' applicability to the service planning process. We believe this "State-of-the-Art" review will be of value to transit systems in their efforts to accurately estimate the cost of proposed service changes.

Additional copies of this report are available from the National Technical Information Service (NTIS), Springfield, Virginia, 22161 at cost.

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We would also like to thank the members of the study review panel for their assistance and contributions. The panel members are:

- Joseph Berechman - University of California, Irvine, Institute of Transportation Studies, Irvine, California
- Ronald J. Hartman - Mass Transit Administration of Maryland, Baltimore, Maryland
- Gary D. Hufstedler - Dallas Transit System, Dallas, Texas
- Richard L. Oram - Greater Bridgeport Transit District, Bridgeport, Connecticut
- Lewis Polin - Orange County Transit District, Garden Grove, California
- Harris M. Schechtman - New York City Transit Authority, New York, New York
- Ronald J. Tober - Municipality of Metropolitan Seattle, Seattle, Washington
- Ron T. Fisher - Urban Mass Transportation Administration, Washington, D.C.
- Wendell Cox - Los Angeles County Transportation Commission, Los Angeles, California

Finally, we would like to thank Brian McCollom of UMTA for his comments and assistance in preparing this report.

C O N T E N T S

LIST OF EXHIBITS

LIST OF EXHIBITS
(Continued)

CHAPTER 1

INTRODUCTION

Almost every transit system today has established a mechanism to conduct bus service planning in a systematic fashion. The techniques and approaches used vary widely - some systems perform cursory reviews of their needs and others use sophisticated techniques to perform detailed operations and planning activities. Since most service changes impact the cost of providing service, there has been a need to estimate the resulting changes in operating cost. This need has become acute due to the limited financial resources of all public services, transit notwithstanding. 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 proposed small service changes.

Several approaches have been suggested and used in the past to estimate the cost of service changes, but no single technique or approach has been generally recognized to be more accurate than others. With varying degrees of reliability, the industry has used methods as gross as average costing (i.e., cost per mile or hour), to methods as detailed as preparing new schedules and driver assignments to estimate the cost of service changes. None of these methods have proven entirely satisfactory. Simple methods such as average costing often include expense components that would not change as a result of a service modificiation. Detailed methods such as making schedules are often either too expensive for routine use, or beyond the resources of many transit agencies. A cost estimation technique is needed that:

- identifies only those costs which change due to a service modification, and
- is relatively simple and easy to use.

Recognizing this need, UMTA contracted for the present study to be performed. The study's objective is to develop a uniform technique, or set of techniques, that will accurately estimate the incremental change in overall system cost due to planned, small scale, bus service changes. The technique should be technically sound, applicable to many types of service changes, and useable by all sizes of transit agencies.

The main elements of the study include reviewing and evaluating existing estimation techniques, developing and testing a proposed technique, revising the technique in light of test results, and preparing a manual of step-by-step procedures for applying the technique. Throughout the study, a review panel of persons active in the transit industry will critique the analysis and findings and provide comments. The review panel members represent a diverse group in terms of responsibilities, size of operations and number of modes (Exhibit 1-1).

This report presents the results of the initial review and evaluation tasks. The report includes a summary of the bus cost estimation state-of-the-art and an evaluation of the existing techniques' applicability to service planning. In the first portion of the report, existing techniques were identified, classified, and described. In the remaining part of the report, the techniques were evaluated against two tiers of criteria. The first tier screens out the techniques that can not effectively estimate cost for a broad range of service changes. The second tier qualitatively scores the techniques according to their ease of use and sensitivity.

Cost Concepts

An appreciation of key cost concepts is necessary to understand the techniques discussed in this report. These concepts include the distinctions between:

- capital and operating cost
- fixed and variable cost
- average and marginal cost
- incremental and fully allocated cost.

All costs to be considered in this study will be operating expenditures as opposed to capital costs. Capital costs refer to the expense associated with long term capital acquisitions, such as buses and maintenance facilities. In essence, capital items have a useful life extending over more than a single year. Operating costs are those expenditures that are consumed during a single year. For most bus systems, capital outlays are relatively modest in comparison to operating costs. From

EXHIBIT 1-1
REVIEW PANEL MEMBERS

TRANSIT OPERATORS
(Small)

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Greater Bridgeport Transit District

TRANSIT OPERATORS
(Medium to Large)

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Municipality of Metropolitan Seattle

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the perspective of the transit operator, this disparity is even greater since the federal government will assume 80 percent of capital costs but only up to a maximum of one-half the operating deficit (farebox revenue less operating costs).

Throughout the course of this report, reference will be made to four types of costs. These four types are 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; however, to facilitate a uniform nomenclature the following definitions are used:

- fixed costs - 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.

- variable costs - 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 Exhibit 1-2A.

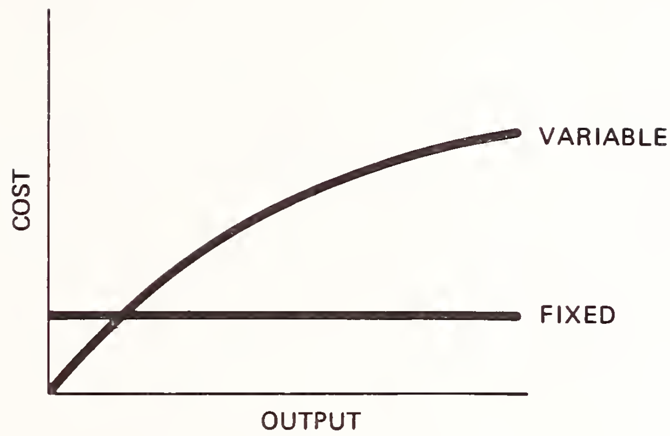
- average cost - As the name implies, this is merely the cost divided by the level of output. In Exhibit 1-2B, the average cost at output level O_1 is merely the slope of the line from the origin (C_1/O_1). Similarly, at output level O_2, the average cost is C_2/O_2.

- marginal cost - Sometimes referred to as incremental cost, this term refers to the additional costs associated with an increase in the level of output. As shown in Exhibit 1-2C, it is merely the change in costs (C_2-C_1) associated with a change in output level (O_2-O_1).

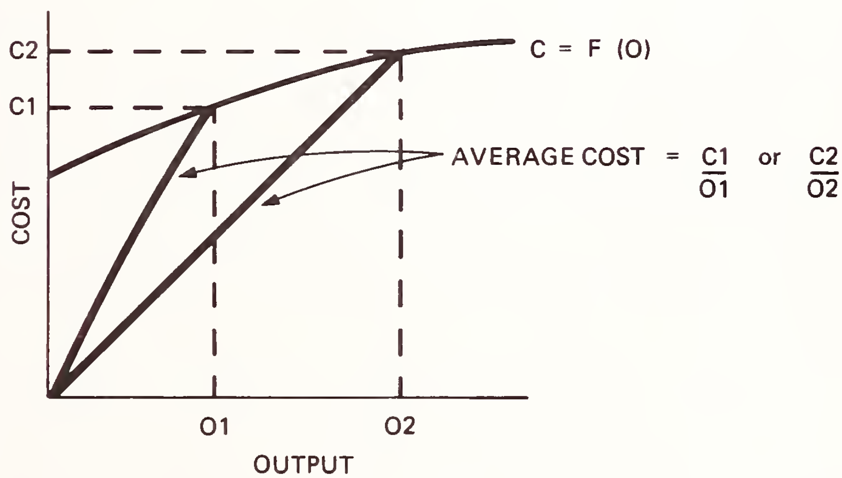
The focus of the present study is on the incremental (marginal) cost of a service change. In the context of a small service modification, some expenses can be expected to change in response to the modification while others will remain unchanged or change only under certain conditions.

EXHIBIT 1-2
COST DESCRIPTIONS

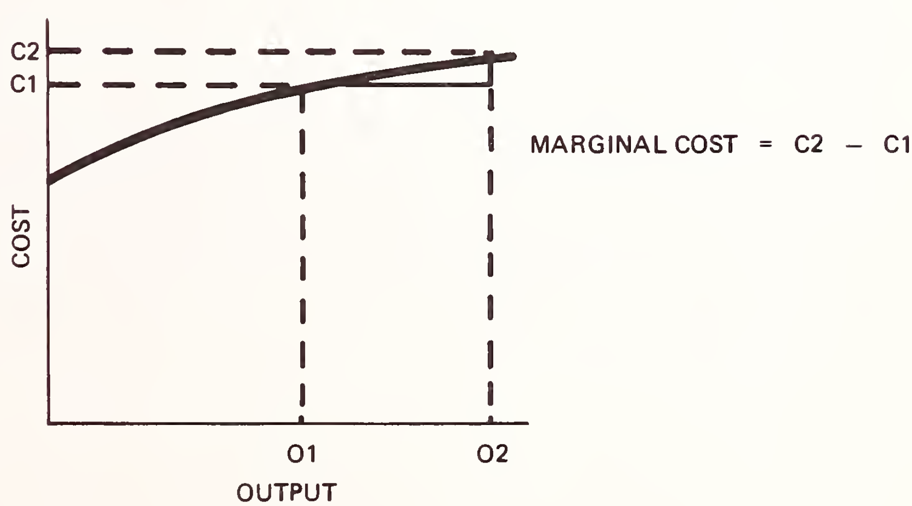
A. FIXED AND VARIABLE COST



B. AVERAGE COST



C. MARGINAL COST



Specifically, expenses such as fuel, oil, and tires will almost certainly change, and expenses such as garage utilities, general officers' salaries, administrative staff wages, and maintenance of service vehicles will not change.

In the middle range are a significant number of expenses whose likelihood to change depends on the size of the service modification. Driver wage expense is the most prominent of these expenses. If the service change is small enough that any extra operating time required can come from existing paid driver time, such as layover or guarantee time, the driver wage expenses will not change. If a larger amount of operating time is needed, the driver expense will change due to either the addition of overtime, the need to hire another driver, or some similar cause. The point is that for any service modification, the costs which do not change are fixed and should not be included in an estimate of the incremental cost of the modification.

It is widely recognized in the transit industry that there are differences in costs for providing service by time of day or day of the week. In large measure, this reflects the nonuniformity in transit demand and supply by time period and day of the week. Transit demand peaking causes the operating staff and physical plant to be designed to accommodate the peak travel conditions, which constitute only a limited portion of the service span. In addition, collective bargaining agreements typically include penalties or prohibitions with respect to drivers' hours and wages related to bus system peaking. Rolling stock and other capital facilities are also underutilized because of the nonuniformity in bus supply. The temporal variation of cost due to peaking is a critical issue that will be raised frequently during the course of the study.

The incremental cost concept stands in contrast to the concept underlying the techniques typically used to evaluate the cost/revenue performance of existing bus routes. Most route performance evaluations begin with the total cost of a transit system. This total system cost is then divided and assigned to each individual route in the system. The cost is usually allocated proportionately based on the miles, vehicle hours, or peak vehicles associated with each route. Since the total system cost includes all expenses, including those that would not change due to a service change, a portion of these fixed expenses are allocated to each route. If such a route evaluation technique were used to estimate the cost of a service change, it would overstate the cost to the degree that fixed costs were included. Thus, the techniques commonly used for route performance evaluation are insufficient for the purposes of this study. Nonetheless, portions of these techniques may be adaptable to the planning task and, therefore, will be reviewed in this report.

Generic Types

To provide an analytical framework for review and evaluation, 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 the current analysis in presenting study findings, each procedure has been designated as representative of a particular generic type, recognizing that some procedures are not generically pure. No simple classification system can account for the various permutations of cost models presented in the literature. The four generic types used in the current analysis to catalogue and stratify cost estimation procedures are presented below:

- causal factors - This 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. For example, the driver cost can be found by estimating the number of driver pay-hours required and multiplying this value by the hourly wage rate. The products of each quantity estimate and unit cost are summed to arrive at the transit cost.

- cost allocation model - This 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 the basis of one or more key operating statistics, rather than numerous quantity estimates. Typically, two to four operating statistics are used in this kind of analysis, such as hours, miles, and vehicles. The key assumption of this approach is that each operating expense item can be assigned or allocated to a specific operating statistic. The costs allocated to each operating statistic are summed and then divided by the appropriate operating statistic to arrive at a unit cost. These unit costs then comprise the coefficients of the cost allocation model.

- regression - This generic type involves the use of statistical techniques to detemine costs and those factors that influence it. For the most part, this type of analysis has been used where cost relationships have been quantified for aggregate systemwide financial and operating data. Other applications involve statistical analysis of time series data for a single system. These studies typically estimate the cost behavior of a single bus system.

- temporal variation - Many researchers have concentrated their analyses on the differences in costs for providing service by time of day or day of the week. By analyzing the underlying relationships that influence bus costs, an attempt is made to quantify the temporal variation in costs. Since the emphasis of this research is usually on drivers' wages, these techniques often embrace other generic types to estimate other transit expenditures. Due to their unique approach to transit cost estimation, they are grouped as a specific generic type.

Report Framework

Each of the next four chapters covers a single generic type. A three level hierarchy was developed to aid the discussion:

- Generic type
- Approach
- Model

A generic type is a grouping of approaches which all share one distinctive characteristic. For example, all temporal variation approaches address cost variations by time of day, but have different ways of doing so. An approach is a grouping of models that generally use a similar technique but vary at the detailed level. For instance, all models within a certain approach may use the same procedure, but differ in the number of variables included. Models are distinct techniques developed by a single researcher or research team. Models are usually presented in a single report or monograph.

The techniques are discussed within a four-part system:

- Input - information needed for calibration and application of the technique.

- Algorithm - assumptions, procedures and formulae comprising the technique.

- Output - the form of the cost estimate and products of intermediate calculations.

- Applications - typical uses of the technique and a description of similar techniques or variations.

This rather rigourous reporting structure brings order to a rather complex subject and provides guideposts for readers not familiar with all of the techniques discussed.

An evaluation of the various techniques comprises the final chapter. A deliberate effort was made to keep the generic type chapters separate from evaluation comments to allow the reader an opportunity to independently form an opinion regarding each technique. Statements concerning the relative utility of the various techniques were reserved for the evaluation chapter.

CHAPTER 2

CAUSAL FACTORS METHOD

The idea underlying the causal factor 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 item's unit price or unit cost.

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, which can range from five to fifty. It should be noted that by selecting which costs 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.

The causal factors method, not being unique to bus costing, is well known and understood. As a result, the present chapter, while covering the method in sufficient detail, is relatively brief and has few references when compared to the subsequent chapters covering other costing methods.

Input

The inputs required for the causal factor method are relatively straightforward. They include values for unit costs and resource requirements. Unit cost values are assumed to be the prevailing market price for each resource item. Such values can be obtained from a simple survey or a comparison with other similar transit systems. Resource requirements are taken from estimates made for the service change. These estimates are derived from a number of methods, with varying degrees of detail and accuracy. Additional inputs are needed when detailed driver scheduling is performed within the causal factor method. Information regarding bus service requirements by time of day, labor agreement work rules, and driver assignment practices are typically required.

Algorithm

The first step is to determine the desired level of detail. This is accomplished by selecting the resource items to be considered in the analysis. A limited number of resources implies a coarse approach is desired, and a large number of resources corresponds to a detailed investigation. The number of resources included in the analysis varies from application to application. It can be as small as five or greater than fifty. Having defined the specific structure of the cost model, the values for unit cost and quantities consumed are multiplied. The summation is then performed to calculate cost.

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

Approaches emphasizing more accurate estimation of the driver labor resource requirement through detailed scheduling represent a subset of the causal factor method. Schedule making may be facilitated through the use of computer programs such as RUCUS or other programs offering simplifications of the driver assignment task. Once the labor requirement has been found using one of these detailed approaches, the results are used as inputs to a cost model to derive service change cost estimates. Thus, detailed scheduling cannot stand alone as a cost estimation method, but can be regarded as an optional step within the causal factors method. In many cases, service planners perform this scheduling analysis in a subjective manner based on professional judgement.

Utilizing scheduling methods for cost estimation represents a use different from the normal application of the scheduling process. Usually driver scheduling is performed at infrequent intervals when required by seasonal schedule changes, a major increase or decrease in service, or changes resulting from adopting new labor rules. In such applications, the process ends when driver assignments are found. When used for planning purposes, the driver assignments are used as input to the costing model, either directly before or after some modifications. Thus, to use scheduling approaches for planning purposes, one proceeds as if the proposed change has already been selected for implementation.

Investigating labor resource requirements via manual scheduling, RUCUS or some other computer based method adds some steps to the basic causal factor algorithm. Under the manual procedure, the proposed change is first incorporated into the new service profile used as input to the scheduling procedures. Next, the service requirements are converted into trips. Then the trips are grouped and assigned to individual vehicles. Finally, drivers are assigned to operate each vehicle. To test several alternative planned service changes, the scheduling process must be repeated for each alternative. Scheduling is a complex, time consuming, and therefore expensive process, and the need for iteration limits its utility as a service planning tool.

The difficulties associated with this approach can be alleviated somewhat by automating the process. Computerization of the scheduling procedure, specifically the RUCUS program package, streamlines the process to some degree. Time and cost savings result from the substitution of a computer for the manual calculations. However, since considerable time is required to set up and run the program, RUCUS offers little advantage over manual methods when used in the context of planning service changes.

Output

The causal factors model produces the total cost of the service change under consideration as well as the various component costs that comprise this total amount. The associated operation may be a whole system, a route or an anticipated service change on an existing route. In addition to costs, the model also produces a list of resource quantity estimates.

Generally, no explicit distinction is made between fixed and variable costs or between average and marginal costs. However, since the method is typically performed at a highly disaggregate level, distinctions could be made during the selection of the resource requirements. For instance, the model can be defined to only include marginal costs, rather than including total costs.

Applications

The range of potential applications of the causal factor method is dictated by the level of detailed study undertaken. Relatively simple causal factor models, using perhaps five to eight resources, may be used for small service changes or preliminary comparisons among service changes of any size. Since few variables are included, the method may produce rather coarse estimates. As the number of variables increase, accuracy may increase, along with the expense and time required. Utilizing only a few resources makes application easier and less costly, but accuracy may suffer because some important resource items must be left out or aggregated at a less detailed level.

As a result of the expense involved in making accurate estimates with the causal factors method, it has been mostly applied to major service changes, particularly the introduction of new transit service to a previously unserved metropolitan area. Many systems utilize the causal factors method as a financial planning tool (as opposed to service planning) in preparation of annual or quarterly budgets.

FOOTNOTES - CHAPTER 2

(1) Bodin, Lawrence, Donald Rosenfeld and Andy Kydes, "UCOST: A Macro Approach to Transportation Planning Problem", Urban Analysis V (April 1978), pp. 47-69.

(2) Robert McGillivray, Michael Kemp and Michael Beesley, "Urban Bus Transit Costing", Working Paper 1200-72-1. Washington, (D.C.): The Urban Institute, September 1980, pp. 19-20.

CHAPTER 3

COST ALLOCATION METHOD

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, such as vehicle miles, vehicle hours and peak vehicles. For example, a commonly used cost allocation model takes the form:

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

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

PV = peak vehicles used on route

The unit costs are found by completing three tasks:

- Assigning each individual expense in the system's financial statement to one or more of the selected resources. Expenses may include driver wages, fuel, tires and tubes, maintenance wages, dispatcher wages, and a host of similar items.

- Summing the values assigned to each resource to obtain the overall cost assigned to the resource.

- Dividing the overall resource cost by the quantity of the resource used by the system. This calculation produces the unit cost of the resource.

The method received its name because it is commonly used to allocate total system costs to individual routes on a proportional basis.

The cost allocation method differs from the causal factor method in both the manner of calculating unit costs and in defining resources. In the causal factor approach, 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 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. This example illustrates the difference in defining resources between the two methods. The causal factor method defines "resources" as consumable input items, such as fuel, tires, paid driver hours, etc. The allocation method defines "resources" as aggregate measures of transit service, such as vehicle miles and vehicle hours. Strictly speaking, cost allocation resources are not resources at all, in the sense of being consumed in the production of transit service. Though some could be considered input measures, such as peak vehicles, others are more accurately termed output measures, such as vehicle miles. However, to maintain uniformity, the term "resources" will be used to identify the operating statistics utilized in the cost allocation method.

Each model falling within the generic type of "Cost Allocation Method" has its own distinctive characteristics. In the following sections, the cost allocation models have been grouped into two approaches. The fully allocated approach is discussed first because it is the basis of the other approach which is called fixed/variable. The fixed/variable models distinguish between fixed and variable costs. Cost allocation models which include detailed treatments of cost variations by time of day and day of week deserve classification as a separate generic type, and will be discussed more fully in the Temporal Variation chapter of this report.

The Fully Allocated Approach

The fully allocated approach received its name because all system expense items are assigned to the selected resources, and eventually allocated to each individual bus route. Thus, the total system cost is <u>fully allocated</u> to the routes.

Consequently, the sum of the individual route costs produced by the model will equal the total system cost. No distinction is made between fixed and variable cost. Fully allocated models are extensions of the average costing approach, where total system cost is converted into a single unit cost per some resource quantity. In the average costing approach, all expenses are assigned to a single resource, typically either vehicle miles, vehicle hours or peak vehicles. Fully allocated models merely extend this concept to include more than a single resource. The utilization of several resources requires an assignment process that associates the expenses with a particular resource.

Input

Two inputs are required for a fully allocated model. One input is a listing of total system costs for each expense account during the analysis period. The analysis period is often defined as one year. Thus, the value in a specific expense account represents the total cost of the quantity of that line item consumed by the system during the year. However, other applications of the fully allocated method have used monthly and weekly analysis periods. The second input requirement is a listing of resource operating statistics for the system. The statistics must correspond to the analysis period of the expense accounts.

Algorithm

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.(1) The Birmingham application used the model form presented in the introduction to this chapter.

The next step is assigning the expense accounts to the resources. Exhibit 3-1 shows the allocation of expenses for the Birmingham example. The following discussion illustrates the rationale used to make some of the assignments:

- 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. Supervision of

EXHIBIT 3-1
FULLY ALLOCATED APPROACH
EXAMPLE EXPENSE ASSIGNMENT

Expense Classification	Basis for Assignment: Vehicle Hours	Vehicle Miles	Peak Vehicles
Equipment Maintenance & Garage Expense			
... Supervision of Shop & Garage			100%
... Repairs — Shop & Garage Equipment			100%
... Operate & Maintain Service Equipment			100%
... Repairs — Shop & Garage Equipment			100%
... Light, Heat, Power & Water			100%
... Other Shop & Garage Expense			100%
... Repairs to Revenue Equipment		100%	
... ACC Repairs to Revenue Equipment		100%	
... Accident Repairs to Revenue Equipment		100%	
... Servicing of Revenue Equipment		100%	
... Tires & Tubes		100%	
Transportation Expense			
... Supervision	100%		
... Drivers' Wages	100%		
... Fuel — Diesel Oil		100%	
... Oil		100%	
... Other Transportation Expense	100%		
Traffic, Solicitation & Advertising			
... Salaries & Expenses			100%
... Tariffs & Schedules			100%
... Tickets & Baggage Checks			100%
... Advertising			100%
Insurance & Safety Expense			
... Public Liability & Property Damage Insurance		100%	
... Workmen's Compensation Insurance[(a)]	79%	17%	4%
... Other Insurance			100%
Administrative & General Expense			
... Expenses — General Officers			100%
... Salaries — General Office Employees			100%
... Expenses — General Office Employees			100%
... Law Expenses			100%
... General Office Supplies & Expenses			100%
... Communication Service			100%
... Outside Audit Expense			100%
... Employee Welfare Expense — Insurance[(a)]	79%	17%	4%
... Employee Welfare Expense — Pension[(a)]	79%	17%	4%
... Purchase & Stores Expense			100%
... Other General Expense			100%
... Uncollectible Revenue			100%
... Management Fee			100%
... Survey Fee			100%
Operating Taxes & Licenses			
... Fuel & Oil Taxes		100%	
... Vehicle & Registration Fees			100%
... Social Security Taxes[(a)]	79%	17%	4%
Interest			100%

(a) *Allocated on the basis of total employee compensation by major employment categories (e.g., maintenance, transportation, general office, etc.).*

Source: *Simpson & Curtin, "Birmingham Area Transportation Plan Re-Evaluation Study — Development of a Cost Allocation Model."*

transportation operations is directly related to the number of hours of service provided and this item has been assigned on the basis of vehicle hours. Other minor cost items related to operator wages are also assigned to the vehicle hour category.

- Vehicle Miles - Many costs are related directly to the miles of operation of each route. Expenses such as fuel, tires and maintenance of revenue equipment are a direct function of the number of miles operated. Expenses for vehicle bodies, brakes, engines, chassis and transmissions are also a function of exposure in terms of miles of service.

- Peak Vehicle Needs - Many individual expense items do not vary as functions of either of the foregoing parameters - vehicle miles or vehicle hours. For example, the cost resulting from providing storage facilities for vehicles is determined by the number of vehicles required to operate the system rather than the number of miles or hours of service provided. Total system expenses for maintenance of buildings, fixtures, grounds and garage, service car equipment and a number of broad overhead expenses will vary with the number of vehicles required to operate the system. Peak vehicles provide a reasonable measure to assess certain cost consequences of orienting the transit system to peak requirements of service.

Note that in the Birmingham model, most expense accounts are assigned on an "all-or-nothing" basis, i.e., one hundred percent of the account is assigned to a single resource. However, for some of the accounts, the expense is distributed among all three resources. Other model applications use an all-or-nothing assignment approach for all accounts while still other applications use a more complex distribution scheme than the Birmingham model. Similarly, other applications of the method may utilize different expense account definitions depending on the particular agency's accounting procedures such as ICC or Section 15 expense reports.

Unit costs are found through two simple computations.

- For each resource, the expenses allocated to the resources are summed to find the total systemwide cost allocated to the resource.

- The total system cost allocated to each resource is divided by the total system use of that resource to produce the unit cost of the resource.

Example calculations are displayed in Exhibit 3-2. The unit costs are then inserted into the algebraic equation shown above. This step produced the following calibrated equation:

$$C = 9.34\ (VH) + 0.32\ (VM) + 3{,}459\ (PV)$$

At this point, it should be noted that the example model includes a treatment of vehicle cost variation by time of day. Expenses attributed to peak vehicles will be charged to a route in proportion to the route's requirement for peak vehicles. A route offering no peak hour service will not be assigned any costs from the peak vehicle related expense accounts. Conversely, a route offering peak-only service will incur peak vehicle related expenses. Thus, the cost of a route will vary with the amount of peak period service provided, as a result of the time variation in the vehicle cost component <u>only</u>.

Cost variations due to the impact of peaking on driver labor costs are not treated by the fully allocated model. Time dependent driver cost variations are treated by the enhanced cost allocation models discussed in the Temporal Variation chapter.

Output

Output from a cost allocation model consists of a calibrated cost equation and supporting calculations, such as those shown in Exhibit 3-2. Additional output includes percentage of cost assigned to each resource variable, and the actual system cost assigned to the variables.

Applications

Fully allocated models are typically used to evaluate and compare the cost performance of individual routes comprising the transit system. This is far different from costing service changes alone. When the models are used for route performance

EXHIBIT 3-2
FULLY ALLOCATED APPROACH
EXAMPLE PARAMETER CALCULATION

Basis of Assignment	Total Cost Assigned	Percent of Total Cost	Total Operating Statistics	Unit Cost
Vehicle Hours	$3,406,452	62.8%	364,614	$ 9.34/Vehicle Hour
Vehicle Miles	$1,516,942	27.9%	4,808,759	$ 0.32/Vehicle Mile
Peak Vehicles	$ 505,039	9.3%	146	$ 3,459/Peak Vehicle (Annual)
				$ 14.00/Peak Vehicle (Daily)
Total	$5,428,433	100.0%		

Source: *Simpson & Curtin, "Birmingham Area Transportation Plan Re-Evaluation Study — Development of a Cost Allocation Model."*

evaluation, the resource requirements are readily available from existing operating statistics. However, actual operating statistics are not available for proposed service changes. Thus, an estimate of the resource requirements, such as hours, miles and vehicles, must be developed prior to applying a fully allocated model to a service change. Models within the fully allocated approach do not inherently address the task of making the resource requirement estimate. Descriptions of model applications to proposed service changes generally present the resource requirements as given; presumably estimated using some technique exogenous to the model. In constrast, the causal factor method includes estimates of consumable quantities such as gallons of fuel and driver pay hours.

Some fully allocated model applications have been directed towards studying the general nature of transit costs and the identifying factors influencing cost. These studies compare the results of model applications to several transit systems to draw conclusions.

Though the preceeding 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. Exhibit 3-3, showing six example cost formulae, indicates the variation in the type and number of resources used in the analysis. Most models include vehicle hours and vehicle miles, though occasionally revenue hours and/or revenue miles are substituted, as is the case for the SunTran model. Sometimes miles and hours are the only resources, but many models assign vehicle related costs to a third variable, most commonly peak vehicles. A fourth variable is occasionally added, usually representing passengers, revenue or vehicle pullouts. 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.

Fixed/Variable Approach

The approach discussed in this section involves cost allocation models that 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. Once classified, unit costs can be derived from the expense accounts in two dimensions:

EXHIBIT 3-3
EXAMPLES OF FULLY ALLOCATED MODELS

... SCRTD (Los Angeles)

C = .41*VM + 16.44*VH + 17.57*PO + 107.77*PV (Daily)

... SDTC (San Diego)

C = .43*VM + 20.76*VH

... CTA (Chicago)

C = .28*VM + 11.13*VH + 20,059*PV (Annual) + .06*R

... SUNTRAN (Albuquerque)

C = .44*RM + 10.48*RH + 15,667*PV (Annual)

... BJCTA (Birmingham)

C = .42*VM + 9.34*VH

... SORTA (Cincinnati)

C = 1.07*VM + 13.54*VH + 14,542*PV (Annual) + .01*P

Source:

SCRTD and SDTC: Cervero, et al, "Efficiency and Equity Implications of Alternative Fare Policies," June 1980.

CTA: Cherwony and McCollom, "Development of Multimodal Cost Allocation Models," 1976.

SUNTRAN: Simpson & Curtin, "Transit Development Study Final Report," prepared for the Department of Transportation, Albuquerque, New Mexico, December 1980.

BJCTA: Cherwony and Mundle, "Formulation of Transit Cost Allocation Models," ASCE Journal, *Fall 1979.*

SORTA: Southwest Ohio Regional Transit Authority, unpublished memorandum, June 12, 1980.

1) according to resource, as is done with the fully allocated approach; and

2) according to cost classification.

Several models are illustrative of the fixed/variable approach. In the interest of clarity, the discussion here will focus on a single model developed in Great Britain by the National Bus Company (NBC).(2) The other models are quite similar to the NBC cost model.

Input

The inputs to a fixed/variable model are the same as those required for a fully allocated model. These inputs include expense account amounts and operating statistics.

Algorithm

Generally, the fixed/variable approach follows the same computational framework as the fully allocated approach. There are, however, minor differences within each stage related to the extra task of classifying expense accounts by cost type. The initial step is selecting the resources to be included in the model. For example, the National Bus Company model employs the same three variables used in the Birmingham formula (Exhibit 3-4). The next steps are unique to the fixed/variable approach.

First, the cost categories must be selected. The NBC model includes variable costs, semi-variable costs and fixed costs. Second, each expense account must be assigned to one of the cost categories. The precise definition of these categories can be most easily understood from the model's classification of expense accounts.

Some generalizations concerning the definition of the cost categories can be made. Variable costs generally include vehicle operator, fuel, and maintenance accounts. Management, supervision, and marketing accounts fall in the semi-variable category. General administrative expenses are classified as fixed costs. It should be noted that differences exist among the three fixed/variable models described in this report regarding the classification of certain expenses. Classifying expenses by cost type is a subjective procedure and relies on professional judgement. Its intuitive nature accounts for the variation in classification among the three example models.

EXHIBIT 3-4

FIXED/VARIABLE APPROACH

EXAMPLE EXPENSE ASSIGNMENT

	Resource			Cost Type		
Expense	Bus Hours	Bus Miles	Peak Buses	Variable	Semi-Variable	Fixed
Crew Wages	X			X		
Vehicle Servicing	X			X		
Fuel		X		X		
Tires		X		X		
Insurance		X		X		
Traffic Staff	X				X	
Miscellaneous Traffic Expenses	X				X	
Maintenance Supervisors	X				X	
Vehicle Maintenance	X				X	
Workshop Expenses	X				X	
Tickets			X		X	
Publicity			X		X	
Vehicle Depreciation			X		X	
Licenses			X		X	
Vehicle Leasing			X		X	
Administrative Staff Costs	X					X
Rent			X			X
Building Maintenance			X			X
Building Utilities			X			X
Staff Cars			X			X
General Expenses			X			X

Source: *H.W. Taylor, "A Method of Bus Operations Costing Developed by NBC," in U.K.-T.R.R.L. Supplementary Report 180 UC.*

Once the expense accounts are classified, the algorithm returns to that used in the fully allocated procedure. Hence, the next step involves assigning the expense accounts to the resources. The assignment basis for the NBC model is shown in Exhibit 3-4. At the completion of this step, the expense accounts have been categorized in terms of two dimensions; one dimension being the resource items, the other the cost categories. Each expense account belongs to a particular resource/cost type combination. For example, crew wages expense belongs to the bus hours/variable cost combination. Administrative staff costs are assigned to the bus hour/fixed cost combination. Some resource/cost type combinations have no expense assigned to them, such as the peak vehicle/variable cost combination.

The next step involves summing the expense accounts within each resource/cost type combination. This calculation produces the total system cost for each combination. Then the unit cost of each combination is found by dividing the combination's cost by the relevant aggregate resource statistic. Thus, rather than creating the single unit cost per bus hour produced by a fully allocated model, the NBC model creates three different types of bus hour unit costs:

- variable bus hour unit cost,
- semi-variable bus hour unit cost, and
- fixed bus hour unit cost.

Bus mile and peak bus unit costs are also separated by cost type. As discussed below, other research projects conducted in Great Britain are similar to the NBC model. Presented below are the unit cost factors (Pounds) for the Merseyside Bus Company.(3)

	COST TYPE		
Cost Variable	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

A total of seven unit cost factors comprise the cost formula.

Output

The unit costs produced by fixed/variable models provide several alternative output formats. In addition to producing an estimate of the overall cost of potential service change, the model can produce the associated fixed, semi-variable and variable costs.

For example, an application could produce costs in five categories: variable, semi-variable, overall variable (variable plus semi-variable), fixed, and total (overall variable plus fixed). This example illustrates the many levels of detail possible within the fixed/variable approach. The fixed/variable model also produces the percentage of system and route costs that are variable, semi-variable and fixed.

Applications

The fixed/variable approach can be applied for the same purposes as other cost allocation models. However, the approach literally adds a new dimension to the process by making it possible to easily and rapidly include or exclude fixed and variable costs from the analysis. This ability facilitates an analysis of incremental costs associated with service changes.

The full implications of the differences between the traditional and fixed/variable allocation models regarding incremental costing can best be seen using a small service addition as an example. A fully allocated model would produce a total cost figure that included the change's proportional allocation of expenses such as general office, general officer salaries, and fire and theft insurance - expenses which probably would not increase as a result of a small service modification. In effect, a fully allocated model may overstate the cost of a small service addition. On the other hand, a fixed/variable model, while producing this total cost figure, also disaggregates the total cost into fixed and variable categories. Since the fixed costs may not change as a result of the service addition, they would not be included in the cost estimate used to analyze the addition. Thus, the fixed/variable approach makes it possible to include only the costs that change; i.e., the incremental or marginal cost resulting from a service modification.

Two other fixed/variable models are quite similar to the NBC model, with only minor differences in the expense account definitions, cost type definitions, cost type classification and assignment of expenses to resources. Despite these differences, all three models are nearly identical in concept and structure. One of these models was developed by Arthur Andersen, Inc. for application to the Merseyside (Great Britain) transit system and has been presented previously.[4] This model also includes a treatment of temporal labor cost variations. The entire model will be discussed in more detail in the chapter on temporal variation models. The other model was developed by Levinson and Conrad in the United States.[5] This model utilized pay hours and revenue vehicle miles as resources. Actual payroll was used in the model to describe driver wage expense, unlike other models that calculate a unit cost for driver costs.

(1) Simpson & Curtin, "Birmingham Area Transportation Plan Re-evaluation Study - Development of A Cost Allocation Model," January, 1977.

(2) H.W. Taylor, "A Method of Bus Operations Costing Developed by NBC," in U.K. Transport and Road Research Laboratory, 1975, pp. 6-13.

(3) J.S. McClenahan and D.R. Kaye, "A Method of Bus Route Costing Developed by Arthur Andersen and Company," in U.K. Transport and Road Research Laboratory, 1975, pp. 31-51.

(4) ibid.

(5) Herbert S. Levinson and Paul E. Conrad, "How to Allocate Bus Route Costs," Transit Journal, Fall 1979, pp. 39-48.

CHAPTER 4

REGRESSION METHOD

Since statistical techniques have been widely employed in a variety of transportation analyses, it is not surprising to find that quite a number of the articles appearing in the bus cost estimation literature include regression methods. For the purposes of the present review the "regression method" has been broadly defined to include all models which use sample data to estimate parameters influencing costs. In contrast to the regression method's use of sample data, most other methods rely on a complete set of data for the system under study.

The data base for the regression method consists of either cross sectional data for several systems at one point in time, or time series information which describes changes in a single system over time. In terms of the regression variables, there are substantial differences. Overall, researchers have concentrated their efforts in defining relationships between four key variables -- total costs, component costs, resource levels and unit costs. The objective of most of the research was directed at identifying the underlying relationships that influence transit costs, rather than the current study's objective to compute incremental cost associated with service changes.

The definition of regression models as those that use sample data is by no means clear cut or pure. Several models are so centrally based on regression techniques that there is no question that they are of the regression generic type. Other models include regression techniques, but also have other, more distinctive characteristics that categorize them as belonging to some other generic type. For example, several temporal variation models contain applications of regression analysis. Such models are discussed in detail Chapter 5; however, for completeness, the regression characteristics of these models will be covered in this chapter.

Input

The major inputs to a regression model are the resources and costs for each case in the sample. Since this data will be used to estimate the parameters in the assumed equation, the specific resources and costs required depend on the model structure selected. The data required also depend on whether a cross sectional or a time series analysis is to be performed. Cross sectional analyses typically use aggregate system data where each case in the sample is a transit system. Time series studies generally use data based on a single system.

Algorithm

Regression-type models assume some particular functional relationship between key variables exists. For example, Nelson[1] developed the following equation to study factors influencing the costs of a bus system:

$$C = a_o + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + a_7x_7$$

where:

c	=	total cost
x_1	=	bus miles
x_2	=	hourly drivers' wage
x_3	=	operating speed
x_4	=	average fleet age
x_5	=	average seats per bus
x_6	=	ownership (0 = non-public, 1 = public)
x_7	=	proportion of fleet purchased with capital grant
a_o	=	constant
a_i	=	estimated coefficient of variable i

As can be seen in the equation, the key variables are total costs, component costs, resource levels, unit costs or some combination.

The parameters of the assumed relationship are estimated by applying statistical analysis to a set of sample historical data. This statistical analysis can be accomplished at varying levels of sophistication. At the simplest level national averages can be calculated. A higher level is reached by plotting scatter diagrams of the costs and resources to which a curve can be fitted using simple regression. The most sophisticated analysis is achieved with computer assisted multiple regression, which is the foundation of most regression models. Nelson used multiple regression to calibrate his equation.

Once the parameters have been estimated, by whatever analysis method, the assumed relationship is calibrated. Most regression models are not intended for the use as predictive devices, but are used to examine cost behavior at the systemwide level. As such, they are too coarse to provide meaningful estimates regarding the cost of a proposed service change.

Output

An estimated functional relationship is the primary output of a regression model. The relationship is comprised of cost coefficients associated with each variable. Secondary outputs may include statistical measures, such as mean, variance, and standard error, developed in the course of the statistical analysis to measure how well the estimated relationship fits the data. In many cases the individual coefficients of the estimated function are of more interest than the cost function itself. This is particularly true when the method is used to study cost behavior at a system level.

Applications

All statistical methods rely on generalization to provide estimates faster and easier than more direct methods such as causal factors. However, speed and simplicity are gained at the loss of sensitivity to unique local conditions. The assumption inherent in applying any method based on statistical analysis is that the real situation is similar to the average condition of the sample. The more the real situation differs from the sample average, the greater the loss of accuracy.

One group of models, rooted in economic theory, use aggregate system data to estimate a single cost function applicable to any transit property. An example is Nelson's bus cost function presented above. This and other so-called "econometric" models(2) have been used to compare the total and component costs of several transit properties, estimate the cost of totally new systems, and investigate the cost structure of providing transit service. The cost structure investigations addressed questions of scale economies, density economies (i.e., the impact of using fixed facilities more intensively), average cost, and marginal cost. For the most part, research in this area has been more concerned with examining the size and sign of the estimated cost function coefficients than in making predictions for planning.

In most regression equations, the resources are the independent variables, and the total cost is the dependent variable. However, a model developed by Quillian, Hillegass and Zimmerman(3) defines resources as the dependent variable, and other resource items as the independent variables. Unit costs are found by some method exogenous to the model. This model is composed of four scatter diagrams which relate two resources types to four other resource items. The required resource quantities are found from graphs of:

- peak buses and operators required
- peak buses and other employees required
- bus miles and gallons of fuel required
- bus miles and other expenses required

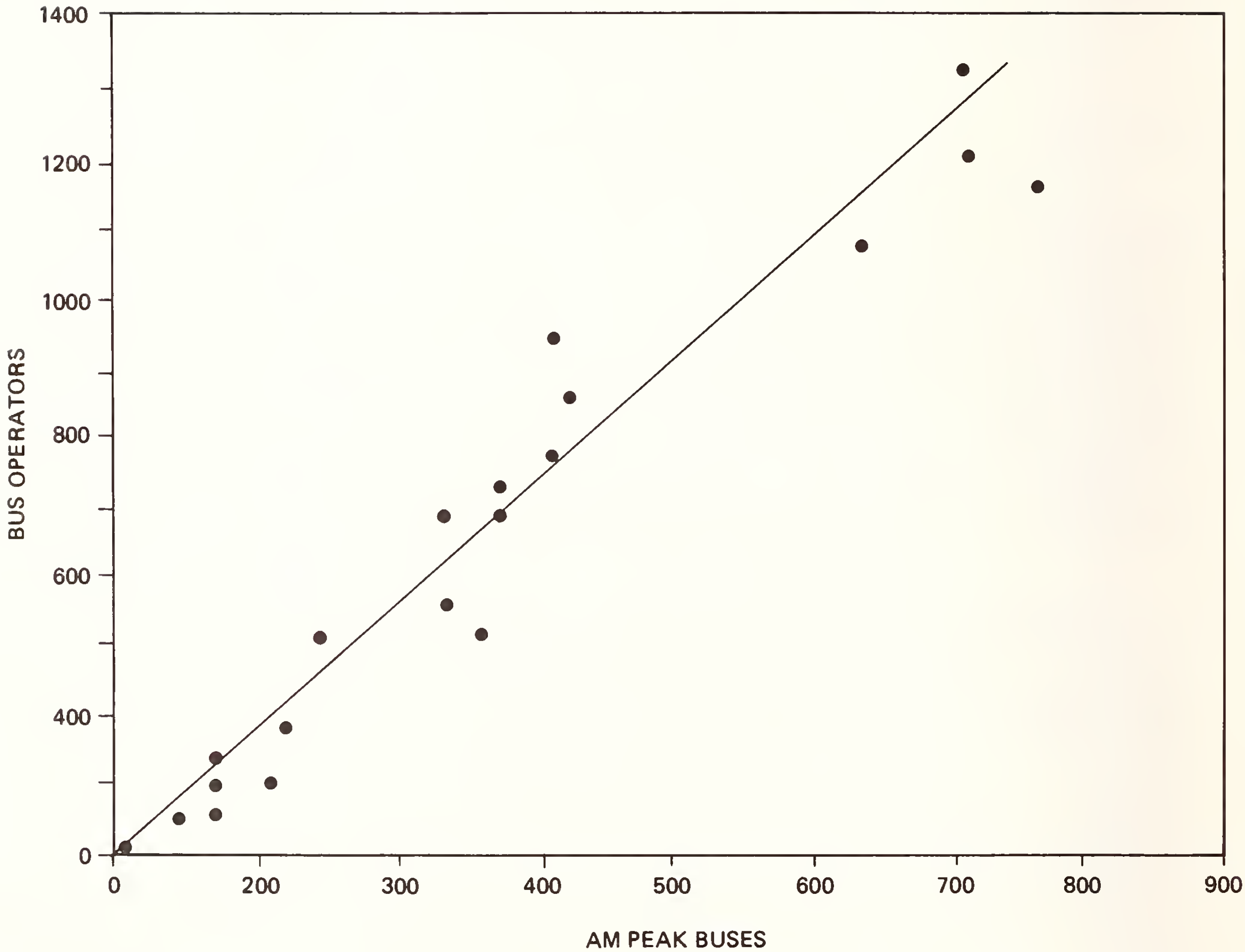
An example scatter diagram is shown in Exhibit 4-1.

To apply the model one takes the inputs of peak buses and bus miles as given, enters the graphs to find the resource requirements, and multiplies them by unit costs (which are not derived in the model) to find the total cost. For example, suppose 400 buses are required by the system in the A.M. peak period. The graph in Exhibit 4-1 is entered with 400 A.M. peak buses on the horizontal axis. This value corresponds to approximately 750 bus operators, as read from the vertical axis. Thus, the system requires 750 bus operators. The scale of this graph is rather large, which means it is probably not sensitive to applications involving less than 25 buses. It should be noted that the model also contains a procedure to incorporate the impact of inflation on the cost estimate.

Several studies with distinctive characteristics classifying them within other generic types also include regression techniques, although they may not be directly applicable to costing service changes. Two studies within the cost allocation method are in this category. In the first, Ferreri(4) justified the assignment procedure used in his model for Miami by identifying relationships between major expenese and resource levels for several bus systems. In the second, Cherwony and McCollom(5) used regression analysis to study the relationship between unit costs and various system statistics for several Chicago area bus systems. The unit cost values were produced through an application of a four-variable cost allocation model.

Several of the temporal variation models (Chapter 5) also include regression techniques. Two of these models, Arthur Andersen and London Transport,(6) use cross sectional

EXHIBIT 4-1
EXAMPLE OF QUILLIAN, HILLEGASS,
AND ZIMMERMAN MODEL



Source: Quillian, et al, "A Bus Operating Cost Method for Planning Analysis," Figure 1.

samples based on one system's disaggregate data to estimate labor cost variations. The Adelaide and Bradford[7] studies examined time series data at the systemwide level in an attempt to develop a rationale for allocating overhead costs.

In general, time series studies encounter problems of multicollinearity among the resources. When two resources such as vehicle hours and vehicle miles are highly correlated, it is impossible to determine their individual relationship with cost. Therefore, few time series approaches have been attempted, and of those completed, few produced conclusive results regarding the individual contributions of items such as vehicle hours and vehicle miles.[8].

FOOTNOTES - CHAPTER 4

(1) John D. Wells, et al, Economic Characteristics of the Urban Public Transportation Industry, Washington (D.C.): U.S. Government Printing Office, 1972.

(2) Robert McGillivray, Michael Kemp and Michael Beesley, "Urban Bus Transit Costing," Working Paper 1200-72-1, Washington (D.C.): The Urban Institute, September, 1980, pp. 38-43; Randall J. Pozdena and Leonard Merewitz, "Estimating Cost Functions for Rail Transit Properties," Transportation Research, Volume 23, Number 2, April 1978, pp. 73-78; and Philip A. Viton, "On the Economics of Rapid Transit Operations," Transportation Research A, August 1980, pp. 247-254.

(3) L. Quillian, T. Hillegass and S. Zimmerman, "A Bus Operating Cost Method for Planning Analysis," October 1977.

(4) Michael G. Ferreri, "Development of Transit Cost Allocation Formula," Highway Research Record 285, 1969.

(5) Walter Cherwony and Brian E. McCollom, "Development of Multi-Modal Cost Allocation Models," Proceedings of Fourth Annual Intersociety Conference on Transportation, ASME 1976.

(6) J.W. McClenahan, D. Nicholls, M. Elms and P.H. Bly, "Two Methods of Estimating the Crew Costs of Bus Service," Transport and Road Research Laboratory Supplementary Report, 364, 1978.

FOOTNOTES - CHAPTER 4
(Continued)

(7) R. Travers Morgan & Partners, Bradford Bus Study: Final Report. Prepared for West Yorkshire Metropolitan County Council and West Yorkshire Passenger Transport Executive, 1976; and R. Travers Morgan Pty. Ltd. Adelaide Bus Costing Study: Final Report. Prepared for the Director General of Transport, South Australia, 1978.

(8) McGillivray, op. cit., p. 29.

CHAPTER 5

TEMPORAL VARIATION METHOD

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 which specifically address this variation of peak and base cost have been termed "temporal variation models." Temporal cost variation arises from two sources, the labor cost differential associated with labor agreement provisions that specify wages and work rules, and 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. Several models also treat the vehicle cost differential, though 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 pay hour/platform hour ratio is higher for peak periods due to inefficiencies introduced by split shifts, spread penalties, guarantee time and other labor restrictions. Wage cost variations result from bonuses, overtime rates, penalty pay rates and other bonus or penalty provisions. Temporal variation models utilize 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, non-driver costs are handled within the traditional cost allocation framework, while special methods are reserved for the 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:

- Cost Adjustment Approach - These models examine productivity and peak service levels to adjust the vehicle hour unit cost coefficient of the traditional three variable cost allocation model.

- Statistical Approach - These models use sample data of productivity levels to relate cost to the proportion of peak service.

- Resource Approach - These models use rules based on labor assignment practices to estimate labor requirements reflecting time of day variations.

The remainder of this chapter covers each of these approaches. Models of the temporal variation type are certainly the most complex and perhaps the most important to the research effort. Hence a significant amount of space will be devoted to them.

Cost Adjustment Approach

Models representing the cost adjustment approach modify the conventional cost allocation models' unit cost coefficients to include differences between peak and off-peak operation. This adjustment is based on measurements of productivity differences in the peak and base periods. Cost adjustment models utilize the same equation structure as the three-variable cost allocation model discussed in Chapter 3. The models also retain the conceptual structure of cost allocation models, in that unit costs are derived by assigning expenses to resources.

Three models were identified as cost adjustment models:

- Peak-Base Model - This model calculates two systemwide vehicle hour unit costs, one for peak periods and one for off-peak periods. In one application, the model was extended by calculating unique peak and base vehicle hour unit costs for each individual route under consideration.

- Levinson Adjustment Factor - This adjustment factor determines the proportion of total cost that should be allocated to peak periods.

- Reilly Model - This model uses measures of peak and off-peak period straight time and overtime to adjust the vehicle hour cost coefficients.

The three techniques are discussed in the following sections.

PEAK-BASE MODEL

The peak-base model was developed by Cherwony and Mundle as part of the I-35W Urban Corridor Demonstration Project in Minneapolis-St. Paul (Twin Cities MTC).[1] The 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. The peak vehicle unit cost generally is higher than the base 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.

Input

The peak-base model requires the same basic input as the cost allocation model, namely, expense account data and operating statistics. In addition, the peak-base model requires an assignment of vehicle hours and pay hours to the peak and base periods. Since collection and processing of this data is time consuming and expensive, the analysis is performed for a single "audit month." The results obtained from the selected month are then used for up to a year unless invalidated through a major change in either the labor agreement or transit service levels. Revision is recommended to correct for the cummulative effect of many small service changes and work rules modifications that typically occur.

Algorithm

The peak-base model algorithm is basically the same as the cost allocation algorithm, with the addition of steps to obtain the adjustment factors. The following discussion uses the Twin Cities application as an example.

The first step in using the model, as for all temporal variation models, is defining the peak and base periods. Next, the "audit" month's vehicle hours and pay hours are assigned to either the peak or base periods. Results of this step for the Twin Cities are shown in Exhibit 5-1. The vehicle hours and pay hours are then inserted in the following equations to determine productivity rates for the peak and base periods:

$$E_p = \frac{PH_p}{VH_p} = \frac{98,130}{74,967} = 1.31 = \text{Peak period labor productivity}$$

$$E_b = \frac{PH_b}{VH_b} = \frac{83,086}{72,947} = 1.14 = \text{Base period labor productivity}$$

where:
PH_p = peak period pay hours
PH_b = base period pay hours
VH_p = peak period vehicle hours
VH_b = base period vehicle hours

The two productivity values are used to calculate the first index value:

$$n = \frac{E_p}{E_b} = \frac{1.31}{1.14} = 1.15 = \text{relative labor productivity}$$

The second index which describes system peaking is given by:

$$s = \frac{VH_p}{VH_b} = \frac{74,967}{72,947} = 1.03 \quad \text{service index}$$

The two indices summarize the information obtained from the "audit" month data. Once they are calculated, they are not changed until the "audit" exercise is repeated.

EXHIBIT 5-1
PEAK-BASE MODEL
EXAMPLE CALCULATION OF INDICES

	Peak		Base	
Vehicle Hours	74,967	(VH_p)	72,947	(VH_B)
Pay Hours	98,130	(PH_p)	83,086	(PH_B)
Labor Productivity	1.31	(E_p)	1.14	(E_B)
Relative Labor Productivity		1.15 (n)		
Service Index		1.03 (s)		

Source: *Walter Cherwony and Subhash R. Mundle, "Peak-Base Cost Allocation Models,"* *Transportation Research Record 663, 1978.*

At this point the traditional cost allocation model is developed. In the Twin Cities case, the traditional model produced the following formula:

$$C = 9.90\ H + 0.31\ M + 7353\ V$$

where:

C = cost
H = vehicle hours
M = miles
V = peak vehicles

The next step involves adjusting the traditional model's vehicle hour unit cost with the previously calculated indices. By defining the following variables:

UC_s = vehicle hour unit cost (traditional allocation model, e.g. $9.90 in the Twin Cities formula)

UC_p = peak period vehicle hour unit cost

UC_b = base period vehicle hour unit cost

the two new vehicle hour unit costs (peak and base) are calculated as:

$$UC_p = \frac{n(1 + s)}{1 + ns} * UC_s = \frac{1.15\ (1 + 1.03)}{1 + (1.15)(1.03)} * (9.90) = 10.57$$

$$UC_b = \frac{1 + s}{1 + ns} * UC_s = \frac{1 + 1.03}{1 + (1.15)(1.03)} * (9.90) = 9.20$$

Through albegraic manipulation, it can be shown that these two equations are equivalent to:

$$UC_p = \frac{PHp}{VH_p} * \frac{VHb + VH_p}{PH_b + PH_p} * UC_s$$

$$UC_b = \frac{PH_b}{VH_b} * \frac{VHb + VH_p}{PH_b + PH_p} * UC_s$$

In effect, two cost allocation equations have now been defined, one for peak period service and another for base period service. For the Twin Cities, these equations were:

$$\text{Peak:} \quad C = 10.57\ H + 0.31\ M + 7353\ V$$

$$\text{Base:} \quad C = 9.20\ H + 0.31\ M$$

Note that the base period equation has no term relating to peak vehicle usage, which is consistent with the traditional cost allocation approach, where all vehicle related costs are allocated to peak vehicles.

Output

In addition to producing the same outputs as a traditional cost allocation model, the peak-base model also produces vehicle hour unit costs defined by peak or base period. The peak-base model also produces the service index and relative labor productivity values.

Applications

The peak-base model was developed as part of express bus and ramp metering demonstration project in the Twin Cities area. This application is representative of the most common cost allocation application, which is evaluating the performance of individual routes within a transit system.

A subsequent fare equity study of three properties in California expanded the calculation of the service and relative labor productivity indices.(2) In this study, performed by a team of researchers at UCLA, the two indices (n and s) and resulting adjustment factors were calculated for each individual route in the transit system. This is in contrast to the Twin Cities application where two systemwide indices were calculated and used to create two systemwide cost equations, peak and base. In the UCLA study, each route has its own unique pair of peak and base cost equations derived from an "audit" of that route's peak and base period pay hours and vehicle hours. For example, the equations calculated for two San Diego Transit Corporation routes were:

Route 2:	Peak:	$C = 24.76\ H + 0.43\ M$
	Base:	$C = 17.45\ H + 0.43\ M$
Route 27:	Peak:	$C = 22.34\ H + 0.43\ M$
	Base:	$C = 19.77\ H + 0.43\ M$

The traditional cost allocation model normally used in San Diego produced the following systemwide equation:

$$C = 20.76\ H + 0.43\ M$$

Note that the San Diego model includes only two variables, vehicle miles and vehicle hours.

LEVINSON ADJUSTMENT FACTOR

A technique similar to the peak-base model was developed by Levinson to calculate the proportion of total operating cost that should be allocated to peak periods.(3) The technique was not developed as part of a costing model, but as part of an investigation of the cost/revenue implications of different combinations of peaking, labor efficiency and load factor. Since the technique itself does not estimate operating cost, some other technique would have to be used to obtain the operating cost.

Input

The model requires information regarding bus utilization and pay hours stratified by time of day. It also requires the number of hours of the day devoted to peak and base service, respectively.

Algorithm

The Levinson adjustment factor is calculated from the following formula:

$$s = \frac{1 + xy}{1 + xy + z}$$

where:

s	=	the proportion of operating costs to be allocated to peak periods
x	=	ratio of excess peak buses to base buses
y	=	ratio of peak pay hours per bus hour to base pays hour per bus hour (same as "n" in peak-base model)
z	=	ratio of non-peak hours of operation to peak hours of operation

Base service is assumed to operate throughout the day, including peak periods. Thus, excess peak buses are defined as those extra buses needed to provide peak service over and above the base service requirement.

Output

The technique's output is simply the percentage of operating cost that is attributable to peak period operation.

Applications

Levinson used this technique in a theoretical discussion of the impact of peaking on cost. It was not applied to data from an actual transit system. To use the formula for cost estimation, it would need to be calibrated using data from the transit system in question. This data would be used to calculated the ratios x, y and z, and value of s, which would be the percentage of total operating cost to be assigned to peak period operation. This percentage would then be applied to an operating cost estimate previously obtained using some exogenous cost estimation method.

REILLY MODEL

The concept underlying the Reilly model is that labor costs variations are a function of the relative use of straight time and overtime to staff peak and base period service.[4] In general, peak service has a higher proportion of overtime than base service, resulting in a higher labor unit cost during peak periods. The model incorporates these concepts in a four variable cost allocation model. The variables are the same as those used in the peak-base models: vehicle miles, peak vehicles, peak period vehicle hours, and base period vehicle hours. However, the Reilly model does not calculate the traditional hourly unit cost. Instead, the peak and base vehicle hour unit costs are calculated separately, based on the proportions of straight time and overtime. Thus, though it is similar in structure to the peak-base model, the Reilly model does not include the peak-base model's indices for adjusting the vehicle hour unit cost produced by the traditional allocation model.

Input

The inputs required by the Reilly model include the expense and resource data common to all cost allocation models. In addition, driver work assignments classified by straight time and overtime are required.

Algorithm

The Reilly model begins with a cost allocation model. Two resources, vehicle miles and peak vehicles, are analyzed in the traditional manner. Vehicle hours are separated into two distinct resources: peak period vehicle hours and base period vehicle hours. Each of these two resources are then further subdivided into driver and non-driver costs. Non-driver unit costs (e.g., supervision) are found using traditional cost allocation techniques. There is no distinction between peak and base for non-driver costs. The method for calculating peak and base driver costs is more complex.

Total driver costs for the peak and base periods are found from the equation below:

$$D_i = W_s S_i + W_t T_i$$

where: i = period (peak or base)
D_i = total driver cost for period i
W_s = straight time wage rate
W_t = overtime wage rate
S_i = straight time paid hours for period i
T_i = overtime paid hours for period i

This equation is applied twice, once for the peak period and once for the base period, as shown in Exhibit 5-2.

The data shown in Exhibit 5-2 was found in the following manner. All driver hours were classified as either straight time or overtime and as either peak or base. Total cost for straight time and overtime was found by applying the actual wage rate to the hours in each time period. Total driver cost for a time period is simply the sum of the overtime and straight time cost. Driver unit cost per vehicle hour is obtained by dividing total driver cost by total vehicle hours. Non-driver hourly costs are added to produce peak and base period vehicle hour unit costs.

Output

The model produces the resource related unit costs and total cost typical of an allocation model. In addition, the intermediate calculations provide aggregated driver cost by period of operation and driver cost disaggregated to straight time and overtime.

Applications

The Reilly model was developed and applied at the Capital District Transportation Authority in Albany, New York. The purpose was to compare the average cost per passenger in the peak and base period. Aggregate system data covering a three month period were used.

Statistical Approach

Statistical Approach models assume driver cost variations are a function of peak and off-peak labor utilization. The relationship between peaking and driver cost is calibrated from sample data obtained from the driver assignment schedules

EXHIBIT 5-2

REILLY MODEL

EXAMPLE VEHICLE HOURS UNIT COST CALCULATION

Item [a]	Peak	Base
Straight Time Hours	42,428	57,866
Straight Time Wage Rate	$ 6.47	$ 6.47
Straight Time Cost	$274,509	$374,393
Overtime Hours	9,881	2,333
Overtime Wage Rate	$ 8.60	$ 8.60
Overtime Cost	$ 84,977	$ 20,064
Total Driver Labor Cost	$359,486	$394,457
Total Vehicle Hours	42,173	51,788
Driver Cost per Vehicle Hour	$ 8.53	$ 7.63
Non-Driver Costs per Vehicle Hour	$ 1.68	$ 1.68
Vehicle Hour Unit Cost	$ 10.21	$ 9.31

(a) Systemwide data over a three-month period.

Source: *J. Reilly, "Transit Costs During Peak and Off-Peak Hours,"* *Transportation Research Record* *490, 1974.*

of the transit property under study. Only driver cost receives this special treatment. Other expenses are treated within the framework of a traditional cost allocation model.

The two models representing the statistical approach were developed in Great Britian. One was developed by the firm of Arthur Andersen and Company, the other by London Transport.(5) The Arthur Andersen model assumes driver cost is a function of peak and off-peak vehicle hours. Once calculated, driver cost becomes just one component within the fixed/variable cost allocation model discussed in Chapter 3. Using a slightly different approach, the London Transport model assumes driver cost depends on the number of straight and split shifts.

Since the models are basically cost allocation techniques, the discussion focuses on the models' treatment of labor costs and weekday peaking.

ARTHUR ANDERSEN MODEL

Input

In addition to the expense account and operating data required for a typical cost allocation model, the Arthur Andersen model requires a sample of from 30 to 50 driver shifts to calibrate the labor cost relationship. The sample data includes pay hours and vehicle hours for each shift stratified by peak and base period. The sample also includes all types of shifts (straight, split, overtime, evening, extra) representing the full range of staffing arrangements used at the property.

Algorithm

The Arthur Andersen model is basically an enhanced fixed/variable cost allocation model. Thus, the first step towards using the model is development of the cost allocation portion. Expense accounts are assigned to one of three cost types: direct costs, variable overheads (semi-fixed), or fixed overheads. The expenses are also assigned to one of three resources: 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 direct driver costs, the initial step is to define the peak and base periods. Next, the sample shift data is used to estimate the coefficients of the following equation:

$$D_a = a_1(P) + a_2(B)$$

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

B = base period vehicle hours

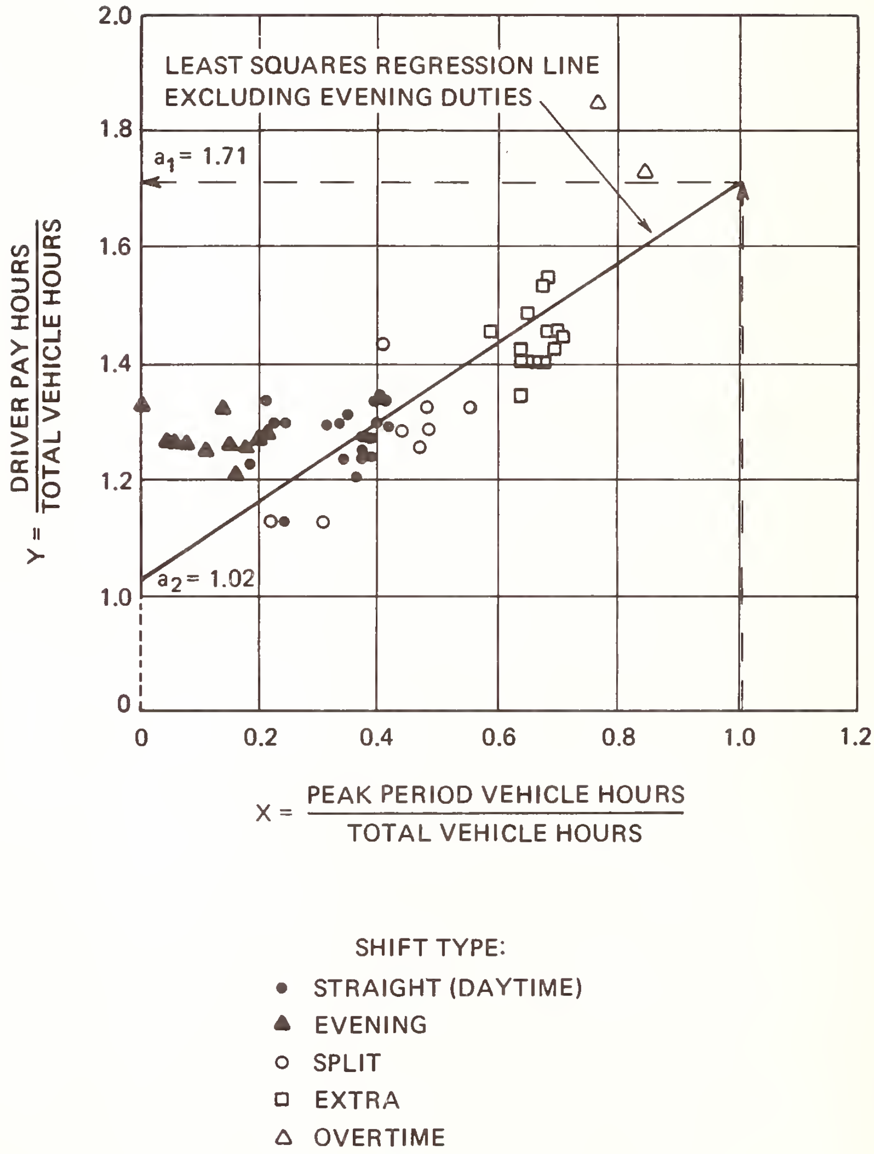
The coefficients a_1 and a_2 are found by plotting the sample data and fitting a curve. Each sample point is a shift, with its combination of peak and base period vehicle hours (P and B). The proportion of peak and base hours depends on the shift's type, as shown in Exhibit 5-3. Generally, split shifts will have a higher proportion of peak period vehicle hours than straight shifts. Extra shifts have a higher pay hour/vehicle hour ratio than split shifts. Overtime shifts have the highest ratio. Regression analysis is performed to find the curve relating the ratio of peak period vehicle hours and total vehicle hours to the ratio of driver pay hours and total vehicle hours.

Estimates of the coefficients a_1 and a_2 can be found from the graph of the regression analysis results (see Exhibit 5-3). 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 in Exhibit 5-4, this calculation produces estimates of driver unit cost for peak and off-peak periods. The unit costs are then applied to resource quantities to obtain total driver cost. Driver cost is combined with the results obtained from the fixed/variable cost allocation model to produce total cost.

Output

The Arthur Andersen model produces output typical of fixed/variable allocation models: unit costs, stratified by cost category. In addition, the model user obtains the

EXHIBIT 5-3
ARTHUR ANDERSEN MODEL
REGRESSION ANALYSIS EXAMPLE



SOURCE

Adapted from U.K. Transport and Road Research Laboratory, Symposium on the Costing of Bus Operations, Supplementary Report 180UC,1975, p. 51; and McClenahan, Nichols, Elms and Bly, "Two Methods of Estimating the Crew Costs of Bus Service," TRRL Supplementary Report 364, 1978, Figure 5.

EXHIBIT 5-4
ARTHUR ANDERSEN MODEL
EXAMPLE DRIVER COST CALCULATION

	Peak	Off-Peak
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
Vehicle Hours Operated	180	300
Driver Cost	$616.00	$ 612.00

Source: *Derived from data in Exhibit 5-3.*

and

McClenahan, et al, "Two Methods for Estimating the Crew Costs of Bus Service," p. 42.

calibrated relationship between pay hours and vehicle hours by operating period, the calibrated direct labor cost formula, and the estimated direct labor cost. Indirect driver costs and all other costs are products of the fixed/variable model.

Applications

The Arthur Andersen model was intended to be used as a potentially more accurate substitute for the traditional cost allocation model. Consequently, typical applications are similar to those of the traditional model, such as route performance evaluation and comparing costs of various transit systems.

LONDON TRANSPORT MODEL

The model developed by London Transport[6] is quite similar in concept and structure to the Arthur Andersen model. It also focuses on direct driver cost and assumes indirect driver costs are equal across all time periods. In addition, the model retains the assumption that the impact of peaking on direct driver cost can be generalized from a sample of driver work assignments. However, the London Transport model assumes the direct driver cost of a service segment is a function of the number of split shifts and straight shifts required to staff the service. In addition, the London Transport model focuses on driver cost alone. The driver cost procedure is not part of a broad technique for estimating costs, as is the case for the Arthur Andersen model.

Input

The London Transport model requires pay hour data stratified by shift type. These data are obtained from a sample of driver assignments. The model also requires a definition of the daily vehicle hours and number of vehicles by time period required to operate the service under consideration.

Algorithm

The model's algorithm relates driver cost to the number of straight and split shifts through the following equation:

$$D_L = L_1 s_1 + L_2 s_2$$

where:

D_L = total driver pay hours under the London Transport model

L_1 = average hours paid per split shift

L_2 = average hours paid per straight shift

s_1 = number of split shifts

s_2 = number of straight shifts

The coefficients L_1 and L_2 are found from a sample of existing driver schedules stratified by shift type and hours paid. The coefficient values are the sample averages obtained by dividing the total hours worked for a particular shift type by the number of shifts of that type.

Though this example utilizes split and straight shifts, alternate categories of work (e.g., overtime) can be used as needed to conform with the particular driver assignment practices existing at the application property.

An estimate of the number of split and straight shifts is needed as input to the model to estimate the cost of a proposed service change. The London Transport model contains a procedure for estimating straight and split shifts, unlike most other costing techniques which do not address the resource requirement estimation task. The shift estimating procedure is illustrated in Exhibit 5-5.

At the beginning of the process, the proportion of straight and split shifts is not known. However, the total number of shifts required can be easily found by dividing the vehicle hours required (known from the service change definition) by the average hours per shift obtained from the sample of driver assignments. This step is shown in Lines 1 and 2 of Exhibit 5-5. Twenty-seven shifts are required.

Next, the number of "peak-ends" required is obtained from the definition of the service change. A "peak-end" is essentially a bus operating in either the morning or evening peak period. Thus, the number of peak-ends required equals the number of buses required in the A.M. peak plus the number needed in the P.M. peak. There are 37 peak ends in the

EXHIBIT 5-5
LONDON TRANSPORT MODEL
EXAMPLE DRIVER COST CALCULATION

SHIFT CALCULATION

1)	Vehicle Hours					=	182
2)	Total Shifts	=	182	÷	6.67 (veh. hrs. per shift)	=	27
3)	Peak Ends	=	18 morning	+	19 evening	=	37
4)	Straight Shifts	=	2 (27)	–	37	=	17
5)	Split Shifts	=	27	–	17	=	10

COST CALCULATION

		Straight Shifts	Split Shifts	Total
6)	Shifts Required	17	10	27
7)	Average Pay Hours per Shift Type	8.0	11.5	—
8)	Driver Pay Hours Required	136	115	251
9)	Wage Rate per Pay Hour	$ 2.00	$ 2.00	$ 2.00
10)	Driver Cost	$272.00	$230.00	$502.00

Source: *Adapted from McClenahan, et al, "Two Methods for Estimating the Crew Costs of Bus Service," p. 48.*

example (Line 3). Each peak-end is staffed with either a straight shift or half of a split shift. Thus, the total number of peak-ends equals the number of straight shifts plus twice the number of split shifts.

The remainder of the process involves allocating the 27 required shifts as either splits or straights in conformance with the number of peak ends. The relationships between peak-ends, shift types and total shifts are:

$$PE = ST + 2(SP), \text{ and}$$
$$T = ST + SP$$

where:

PE	=	number of peak-ends
ST	=	number of straight shifts
SP	=	number of split shifts
T	=	total shift requirement

Solving this pair of simultaneous equations gives:

$$ST = 2(T) - PE$$

Thus, the number of straight shifts can be found from the known number of peak ends and total shifts. As shown in Line 4, the example requires 17 straight shifts. A balance of 10 straight shifts are required to achieve the total shift requirement of 27 (Line 5).

Once calculated, the shift requirements are multiplied by the coefficient values previously obtained from the sample to produce driver pay hours required. Driver cost is the product of this pay hour quantity and the wage rate.

Output

The final product of the model algorithm is driver cost stratified by shift type. The intermediate steps of the model also produce outputs, such as shift and pay hour requirements delineated by shift type.

Applications

Since the London Transport model only deals with driver cost, it is not as comprehensive as other cost allocation and temporal variation models which include all categories of cost. Hence, model applications are limited to estimating the driver cost component of route service changes and performance evaluations.

Resource Approach

Resource approach models simulate the influence of peaking on cost by modifying the resource quantity estimates of the traditional models to reflect differences by time of day and day of week. Peaking influences cost through variations in the quantity of pay hours and vehicles needed during the day. Therefore, the resource quantity modifications are based on models of driver and vehicle assignment practices.

Aside from their direct approach to peaking cost variations and common cost allocation framework, the resource models exhibit a wide range of differences. Some, particularly those developed by R. Travers Morgan and Partners, are relatively complex in design and application. The three models representing the resource approach are:

- Northwestern Model - Assumes operator requirements area function of time of day.
- Bradford Model - Examines impact of peaking through application of a cost allocation model to various resource measurements.
- Adelaide Model - Combines a five factor fixed/variable model with a scheduling algorithm to obtain the incremental cost of a service modification.

NORTHWESTERN MODEL

The Northwestern Model is a three variable cost allocation model designed specifically for estimating the cost of service changes.[7] The model includes a resource estimating technique that:

- converts vehicle requirements to driver requirements stratified by time of day, and

- makes adjustments for the impact of spread penalties.

Input

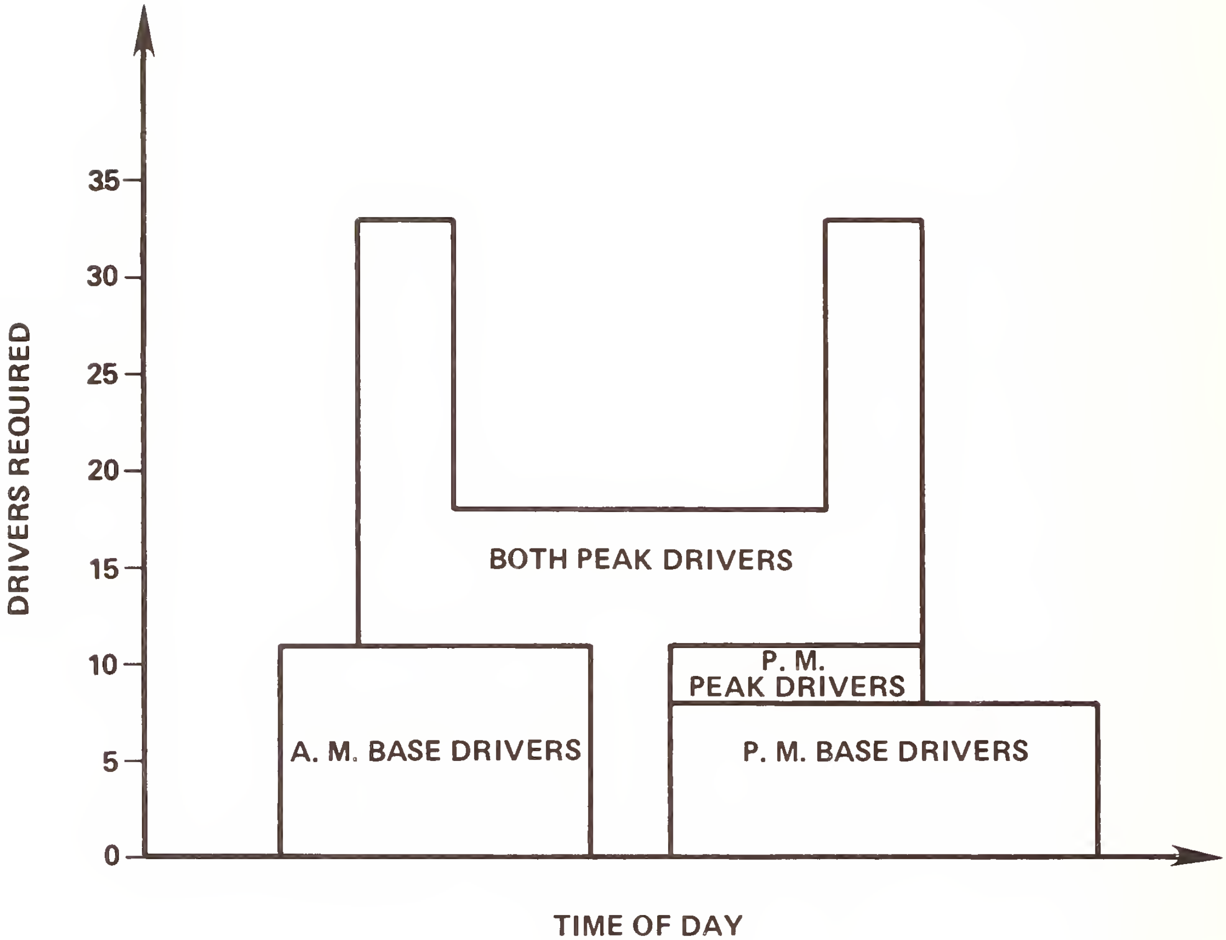
Inputs to the model include the expense and resource data needed to calculate the unit costs in all allocation models. Additional data regarding the proposed service change is required for use in the resource estimating routine. This data includes peak passenger flow at the maximum loading point, headway by time of day, passenger capacity of the vehicle, route length, and vehicle speed by time of day.

Algorithm

The Northwestern model is basically a cost allocation model using vehicles, vehicle miles and operator days as the three resources. However, only those expenses expected to change as a result of a service change; i.e., the variable costs, are included in the allocation process. First, the expense accounts are classified as either variable or fixed. Second, the standard allocation model procedure is applied to the variable accounts to find the unit costs and calibrate the cost equation. Third, resource requirement estimates are made by applying transit service planning formulae to the resource inputs. Most of these formulae are commonly understood, but the driver requirement procedure deserves some explanation.

Driver requirements are defined in units of "driver-days;" i.e., one day of work for one driver. The bus requirement profile is divided into four sectors: A.M. Base, P.M. Base, Single Peak and Both Peaks, as shown in Exhibit 5-6. One driver is assumed to be required for each bus required. Thus, the number of A.M. and P.M. base drivers equals the number of buses required in these periods. In the example shown in Exhibit 5-7 a total of 33 peak buses are required. Eleven and eight drivers are required in the A.M. and P.M. base periods, respectively. The number of single peak drivers is the difference between the driver requirements for the A.M. and P.M. base periods. Three are needed in the example. The drivers required for both peaks is the difference between the total peak requirement and the larger of the A.M. or P.M. base requirements. In the example, the AM base requirements are

EXHIBIT 5-6
NORTHWESTERN MODEL
TIME PERIOD DEFINITION



Source: *Morlok, Kulash and Vandersypen, The Effect of Reduced Fare Plans for the Elderly on Transit System Routes.*

EXHIBIT 5-7
NORTHWESTERN MODEL
EXAMPLE DRIVER REQUIREMENT CALCULATION

Buses Required

Total Peak	=	33
Base (a.m.)	=	11
Base (p.m.)	=	8

Driver-Days Required

Base (a.m.)	=	11				
Base (p.m.)	=	8				
Single Peak	=	11	—	8	=	3
Both Peaks	=	33	—	11	=	22

higher, so 22 both peak drivers are needed. Since the drivers required for both peaks will encounter a long spread time, their requirement is expanded to account for the spread penalty. The driver-day requirements for each time period are summed to obtain the total driver-day requirement estimate. This estimate, and the other resource estimates are then inserted into the calibrated cost equation to produce total cost.

Output

The Northwestern model produces unit costs, total cost and resource requirement estimates.

Applications

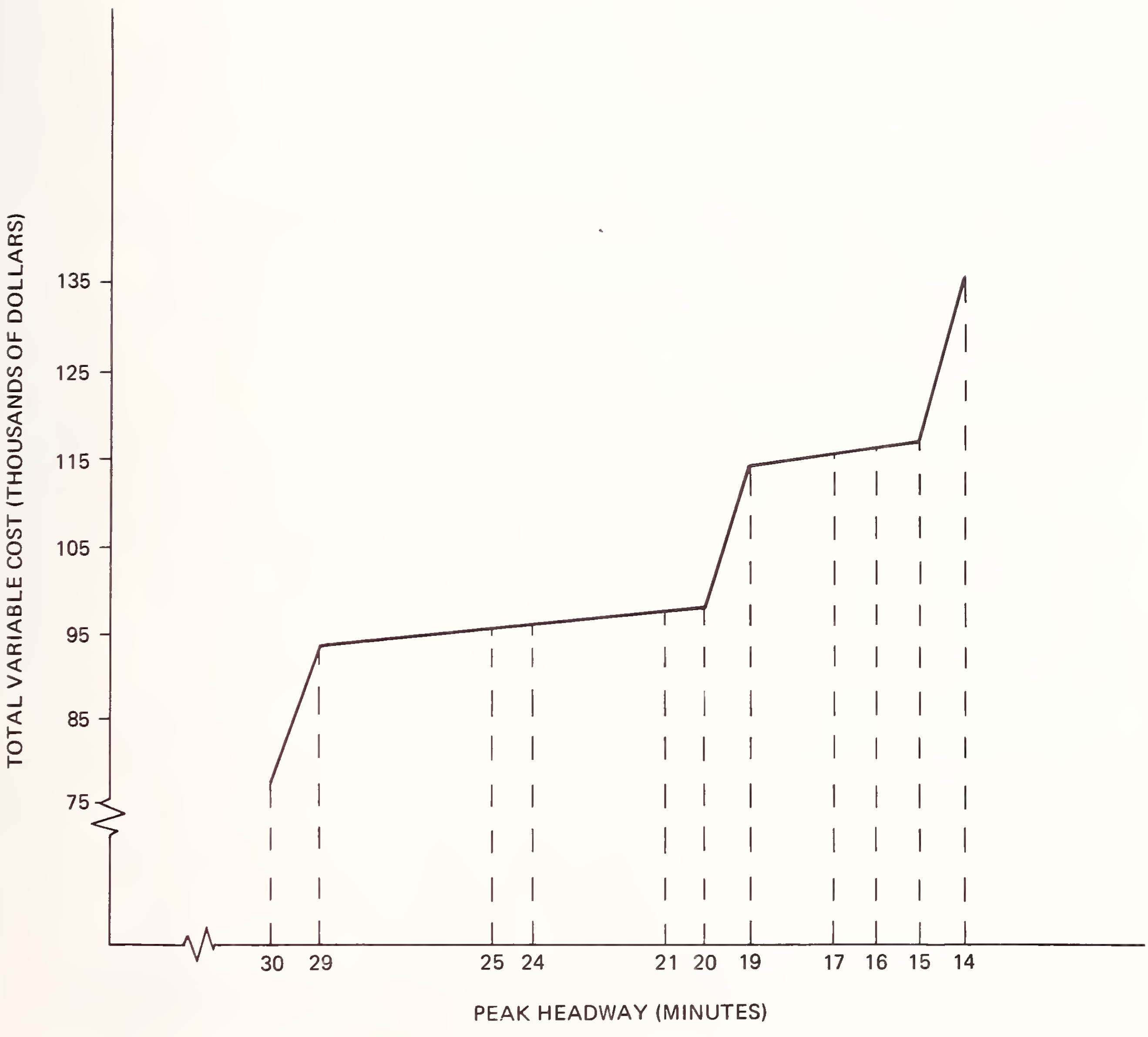
The model was originally developed at Northwestern University for use in a study of the impact of reduced fares for elderly persons. In another paper, the model was adopted to produce a sample application of estimating the cost of incremental changes in service frequency.(8) This application produced a curve of total variable cost as a function of headway, as shown in Exhibit 5-8. The curve was produced through an iterative application of the resource estimation technique and cost allocation model. For each iteration, the headway input value was decreased by one minute. The curve's discontinuity results from the addition of a bus and driver when critical headway intervals are reached.

BRADFORD MODEL

The Bradford model was developed by R. Travers Morgan and Partners for their cost analysis of the Bradford (England) bus system.(9) Two aspects of the analysis are of particular interest. One is the treatment of vehicle cost variations included within the study's examination of systemwide cost variations by time of day and day of week. The second is the treatment of labor cost variation within a hypothetical examination of the incremental cost of adding or subtracting service.

The model itself generally follows the fixed/variable cost allocation approach, but also uses the "audit" month concept to analyze regular and overtime wage costs as part of the

EXHIBIT 5-8
NORTHWESTERN MODEL
SERVICE CHANGE APPLICATION



Source: Antie Talvitie and Austin Neal, "A Route Cost Model for Bus".

labor unit cost calculation. The temporal variation treatments developed for the study include:

- system cost variations by day of week
- system cost variations by time of day
- system cost variations by "layer" of service ("layer" defined as all day, working day and peak only services)
- incremental cost of adding or subtracting service

Input

The model requires the usual expense account and operating statistics for use in the cost allocation technique. In addition, an "audit" of one month's driver work assignments is needed to expand platform hours to pay hours and find unit costs by shift type. A review of driver scheduling practices is also needed for determining shift requirements used in the incremental cost analysis.

Algorithm

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, direct operating and overhead expenses as the cost categories. Expense accounts are assigned to resources 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 hour week. Next, the driver schedule "audit" month data are used to find the ratio of pay hours to worked hours (Exhibit 5-9). Worked hours are the sum of platform and non-platform hours. Pay hours are worked hours plus penalty time and excess spread time. The pay hour/worked hour ratio is then used to calculate the pay hours associated with the basic 40 hour week. For the example described in Exhibit 5-9, where there is an average of 1.15 pay hours per worked hour, 46 hours are paid during a standard 40 hour work week.

EXHIBIT 5-9

BRADFORD MODEL

DRIVER PAY HOURS PER HOURS WORKED

	Monday-Friday	Saturday	Sunday	Total
Platform Hours	14,688	2,608	1,224	18,520
Non-Platform Hours	2,169	396	383	2,948
Total Hours Worked	16,857	3,004	1,607	21,468
Penalty Hours	–	1,615	1,204	1,819
Excess Spread-Over Hours	1,397	23	–	1,420
Total Payable Hours	18,254	4,642	2,811	24,707
Payable Hours per Hour Worked	1.08	1.55	1.75	1.15

Source: *R. Travers Morgan, "Bradford Bus Study," Table E.02.*

The unit cost per pay hour for basic (as opposed to overtime) work is found by dividing total wage cost per week by the hours paid per week. The unit cost per pay hour of overtime work is simply the hourly overtime wage rate plus a shift allowance. Overall unit cost includes both basic and overtime work. It is calculated as the weighted average of the basic cost per pay hour and the overtime cost per pay hour. The weighting is based on the proportion of basic and overtime hours worked during the "audit" month.

The vehicle hour unit cost has two components, direct operating cost and the overhead expenses allocated to vehicle hours. Each component is calculated differently. Direct operating cost consists of the per mile costs of fuel, oil and tires. The per-mile figure is then converted to a per-hour figure by applying an average speed factor. The overhead component is found with the traditional cost allocation technique. The vehicle hour unit cost rate used in the model is simply the sum of the two component rates.

One portion of the Bradford study focused on time period variations in those expenses assigned to vehicles. The per vehicle unit cost includes items such as maintenance, management and depreciation. Attributing vehicle cost to various time periods depends on the assumed purpose of the transit service. The Bradford study defines two views, a peak service approach and a basic service approach.

Under the peak service approach, the system purpose is assumed to be provision of weekday peak period service. Accordingly, all vehicle costs are assigned to weekdays and to peak periods. This is the view implicit in the traditional cost allocation models' assignment of all vehicle costs to peak vehicles.

Under the basic service approach, the system purpose is assumed to be the provision of a basic level of service throughout the week and throughout the day. Accordingly, vehicle costs are apportioned in relation to the utilization of vehicles by time period.

Vehicle cost variations by day of the week is the first issue treated under the basic service assumption. The rationale is that all buses have the same weekly unit cost, £212 per week, which was found when calibrating the model. Though the weekly cost is the same for each bus, the cost per day depends on how many days per week the bus is used. A bus used every day of the week has a lower daily cost than one used only on weekdays.

This approach is used to find the systemwide daily vehicle cost for weekdays, Saturdays and Sundays, as shown in Exhibit 5-10. First, the number of buses used five, six and seven days per week is determined. Next, the unit cost per day for each utilization level is found by dividing the weekly cost by the number of days of use. For example, buses used six days per week cost £35.3 per day, which is 212 divided by six. The daily unit cost times the number of buses used gives the system vehicle cost at each level of utilization. Since 79 buses are used six days per week, the total daily cost of these buses is £2,790. Finally, the system costs are summed to obtain total vehicle costs by day of the week. The mean cost per bus by day of the week is found by dividing the systemwide total cost by the number of buses operated that day. For instance, mean cost per bus on a weekday is £9,880 divided by 275 buses, or £35.9 per bus.

The second issue treated under the basic service assumption is 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. Bus utilization is defined in terms of the number of hours of use (18, 11 and 4 hours) as well as days of use, as shown in Exhibit 5-11. Five different combinations of days and hours were defined, as were three time periods: peak, between peak, and early A.M./late P.M.

The results of the time of day examination were subsequently used to determine the cost of three "layers" of service. The layers were defined as shown in Exhibit 5-12:

- Peak Only - Average duration is about 4 hours, typically from 7:00-9:00 A.M. and 4:00-6:00 P.M.
- Working Day - Average duration is about 11 hours, typically from 7:00 A.M. to 6:00 P.M.
- All Day - Average duration is about 18 hours, staggered starting times from 4:00-7:00 A.M. and finishing times from 11:00 P.M. to midnight.

Using these definitions, the values obtained from the intermediate steps of the time of day examination (the three right hand columns of Exhibit 5-11) were rearranged and summed to obtain the vehicle cost for each service layer. Total cost for each layer was found by adding the appropriate pay hour and vehicle hour cost components to the vehicle cost.

EXHIBIT 5-10

BRADFORD MODEL

VEHICLE COST APPORTIONMENT

BY DAY OF THE WEEK

Utilization of Buses		Cost per Bus per Day	Systemwide Vehicle Cost per Day		
Days per Week (U)	No. of Buses	(£212/U)[a]	Weekdays	Saturdays	Sundays
7	101	£30.3	£3,060	£3,060	£3,060
6	79	35.3	2,790	2,790	–
5	95	42.4	4,030	–	–
Total	275		£9,880	£5,850	£3,060
Number of Buses			275	180	101
Mean Cost per Bus			£ 35.9	£ 32.5	£ 30.3

(a) Weekly cost previously calculated as £212 per bus.

Source: *R. Travers Morgan, "Bradford Bus Study," Table 6.07.*

EXHIBIT 5-11

BRADFORD MODEL

VEHICLE COST APPORTIONMENT

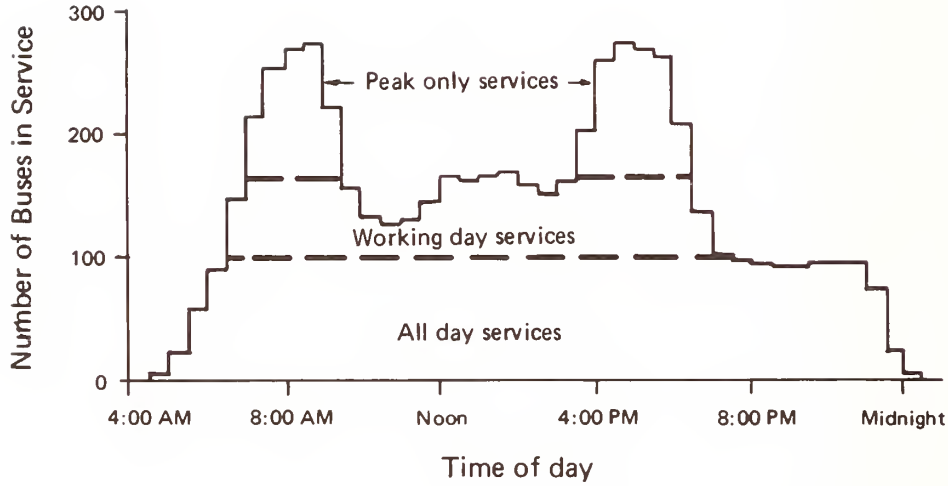
BY TIME OF DAY

Utilization: Days per Week	Utilization: Hours per Weekday	No. of Buses	Cost per Day (£): per Bus(a)	Cost per Day (£): Total	Weekday Cost per Period (£): Peak Periods (4 hours)	Weekday Cost per Period (£): Between Peaks (7 hours)	Weekday Cost per Period (£): Early A.M./ Late P.M. (7 hours)
7	18	99	30.3	3,000	670	1,165	1,165
7	11	2	30.3	60	20	40	–
6	11	63	35.3	2,220	810	1,410	–
6	4	16	35.3	570	570	–	–
5	4	95	42.4	4,030	4,030	–	–
Total		275		9,880	6,100	2,615	1,165
Number of Buses					275	164	99
Average Cost per Bus (£)					22.2	16.0	11.8

(a) As calculated in Exhibit 5-10.

Source: *R. Travers Morgan, "Bradford Bus Study," Table 6.12, September 1975.*

EXHIBIT 5-12
BRADFORD MODEL
LAYERS OF SERVICE



Source: adapted from R. Travers Morgan, Bradford Bus Study, Figure 6.06.

Another area of temporal cost variation examined by the model is the incremental cost of service modifications. This examination centered on labor cost variations by time of day. This exercise produces a general cost value, rather than the cost of a specific service change. The magnitude of a service modification is measured by the number of buses utilized. Thus, the smallest unit of change is one bus. Incremental cost is calculated separately for the three service layers defined above.

The calculations are based on the following equation:

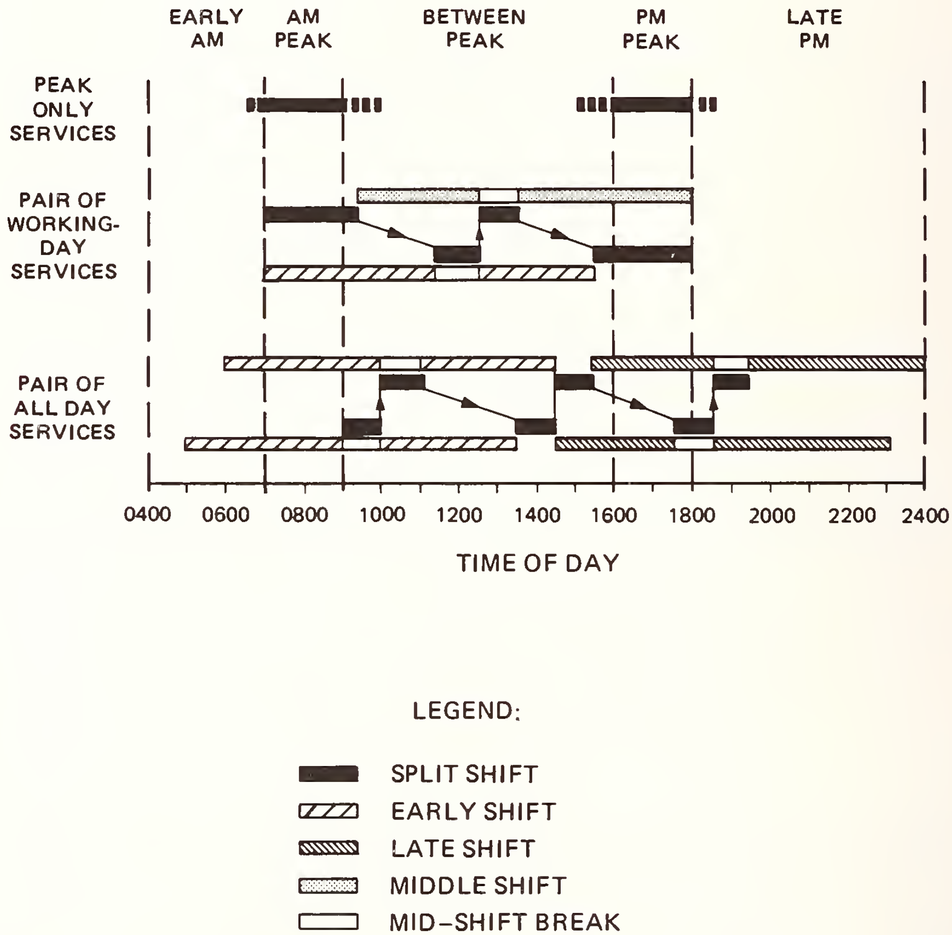
$$C_i = U_h (H_i) + U_v + U_s(S_i) + U_p(P_i)$$

where:

- C = incremental cost (or savings) of adding (subtracting) one bus for service layer i
- U_h = unit cost per vehicle hour
- H_i = vehicle hours associated with service layer i
- U_v = unit cost per vehicle
- U_s = unit cost per straight shift
- S_i = straight shifts required to provide service layer i
- U_p = unit cost per split shift
- P_i = split shifts required to provide service layer i

The number of straight and split shifts needed are found from a simple scheduling model, shown in Exhibit 5-13. The model is based on the labor scheduling practices prevailing at the transit property. The model assumes a single split shift staffs a peak-only service, 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. These assumptions translate into the following requirements for the incremental change of one bus:

EXHIBIT 5-13
BRADFORD MODEL
DRIVER SCHEDULING MODEL



Source: R. Travers Morgan, Bradford Bus Study, Figure 7.01.

- All day service:
  - 2 straight shifts
  - 1/2 split shift

- Working day service:
  - 1 straight shift
  - 1/2 split shift

- Peak-only service:
  - 1 split shift for increase
  - 1/2 split shift for decrease

A decrease in peak-only service only reduces the requirement by an average of one half a split shift because the other half is still needed to staff off-peak service.

The unit costs per shift are derived from the driver assignment "audit" and the direct labor cost calculation discussed earlier. The "audit" provides information regarding pay hours per shift. The cost calculation provides the associated unit cost per pay hour. The two values are multiplied to obtain the unit cost per shift. This unit cost calculation is done twice, once for split shifts and once for straight shifts. The unit costs per vehicle hour and per vehicle are produced by the basic Bradford model, as discussed earlier.

Repeated applications of the equation produces a curve of the relationship between incremental cost savings and incremental changes in service, shown in Exhibit 5-14. The curve is not smooth because of the pairing of services in the scheduling model. The joint use of some shifts means that the per bus cost of changing an odd number of buses in larger than per bus cost of changing an even number of buses.

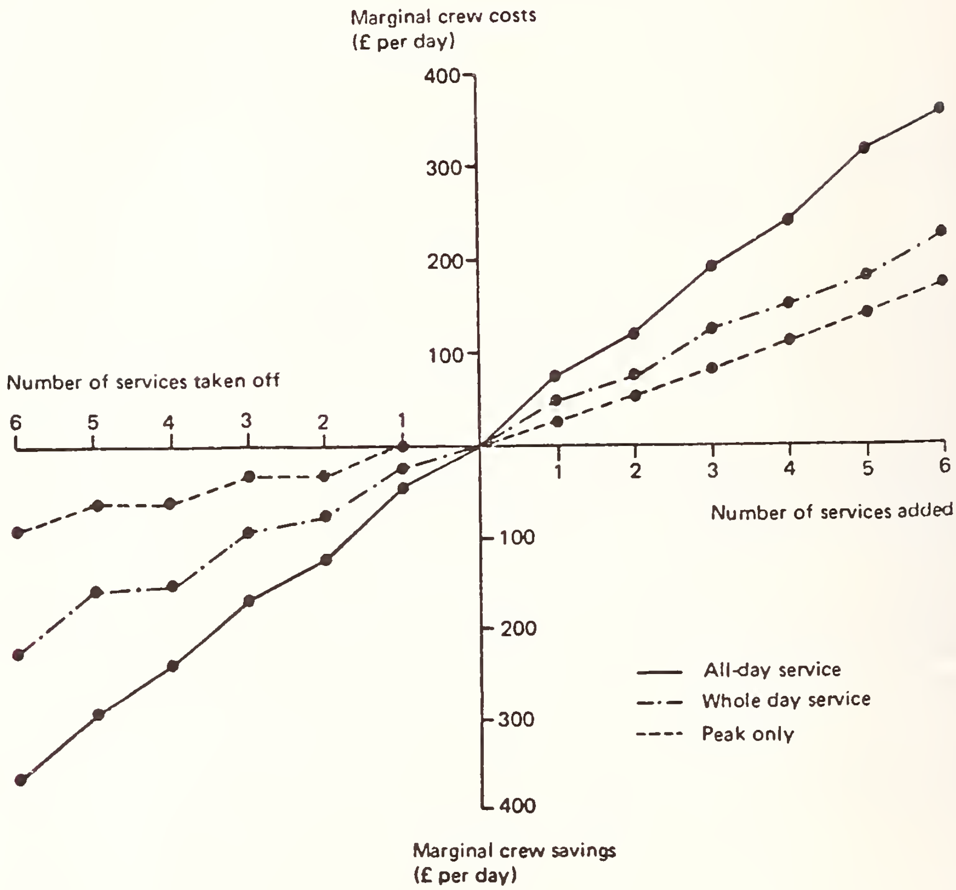
Output

The model's outputs include final products, such as the unit costs and total cost, plus the results of all of the intermediate calculations made in obtaining the final products.

Applications

The Bradford model was used to make a very detailed examination of the Bradford bus system. These applications include studying vehicle cost variation and determining the

EXHIBIT 5-14
BRADFORD MODEL
INCREMENTAL COST OF SERVICE CHANGE



Source: R. Travers Morgan, Bradford Bus Study, Figure 7.02.

incremental cost of changing the number of buses in service. The model was also used to evaluate the performance of individual routes in the system.

ADELAIDE MODEL

The Adelaide Model was developed by R. Travers Morgan several years after the Bradford Bus Study.[10] The Adelaide model incorporates many features of the Bradford model, plus several new aspects which enhance the previous work. Similar features include separate calculation procedures for different unit costs, use of a cost allocation framework, an "audit" of one month's driver assignments, and all of the temporal variation treatments presented in the Bradford Bus Study. The main difference is that the Adelaide study is based on a fixed/variable cost allocation model using the following resources: worked hours, penalty hours, vehicle kilometers, vehicle hours and peak vehicles. Other changes include a cost allocation process based on one month's expense account data, a more complex scheduling model, a step function definition of overhead costs, and applications to determine the cost of a new route and the incremental cost of modifying an existing route. Aspects of the Adelaide model which overlap the Bradford model are only briefly discussed.

Input

The Adelaide model inputs include data on resource levels, labor scheduling practices and one month's driver work assignments. Expense account data is also needed, but in contrast to most allocation models which use annual data, the Adelaide model uses one month's data.

Algorithm

The Adelaide model is based on the following equation:

$$C = U_w(W) + U_p(P) + U_k(K) + U_h(H) + U_v(V)$$

where: C = cost
W = worked hours
P = penalty hours
K = vehicle kilometers
H = vehicle hours
V = peak vehicles
U_w = unit cost per worked hour
U_p = unit cost per penalty hour
U_k = unit cost per vehicle kilometer
U_h = unit cost per vehicle hour
U_v = unit cost per peak vehicle

A fixed/variable approach is used to classify expense accounts as belonging to one of three categories: driver cost, direct operating cost, and overhead cost.

Driver cost includes wages and benefits, such as vacation, sick leave, and uniform allowance. Wage expenses are assigned to both worked hours and penalty hours. Other driver expenses are assigned to worked hours only. Worked hours include platform hours plus sign in/out time. Penalty hours are additional hours representing overtime, spread penalties, weekend bonuses, and early and late shift bonuses.

Direct operating expenses (fuel, oil, tires) are assigned to vehicle kilometers. The unit cost per vehicle kilometer is not converted to vehicle hour units as was done in the Bradford model.

Expenses categorized as overheads are assigned to either peak vehicles, vehicle hours or both. Vehicle-hour and peak vehicle unit costs are both defined as step functions dependent on the number of buses involved in the application, as shown in Exhibit 5-15. Five bus quantity intervals are defined. Each interval has associated vehicle hour and peak vehicle unit costs. The unit costs increase as the bus quantity increases. The size of the intervals and the magnitude of cost increase associated with each interval were determined from a comparison of fleet size and costs at two different points in the history of the transit property.

Vehicle kilometers and vehicle hours resource estimates are found from traditional scheduling techniques. The worked hours and pay hours requirements are obtained from a scheduling model conforming to the typical driver assignment practices of the property.

The scheduling model is applied to calculate the number of shifts required to staff the bus requirement profile. Three shift types are defined as morning, broken (split), and

EXHIBIT 5-15
ADELAIDE MODEL
OVERHEAD COST STEP FUNCTION

Level of Change	Rate per Peak Bus per Week	Rate per Bus Hour
Less than 6 Buses	$322	$3.41
6 to 14 Buses	373	3.41
15 to 34 Buses	385	3.63
35 to 69 Buses	403	3.63
70 or More Buses	433	3.75

Source: *R. Travers Morgan, "Adelaide Bus Costing Study," Table 5.02.*

evening. The morning and evening shifts are straight shifts. The model calculates the shift requirements by proceeding through the following steps, which are illustrated in Exhibit 5-16.

- Assign one afternoon shift per night base bus.

- For every three or fewer afternoon shifts assign one additional afternoon shift to provide meal relief.

- The afternoon shifts will cover part of the evening peak vehicle requirement. Assign additional split shifts to cover the remainder of the evening requirement.

- The split shifts needed for the evening peak will also cover part of the morning peak. Assign one morning shift for each morning peak bus not already covered by a split shift.

- The morning shifts needed to cover the morning peak will also cover part of the between-peak vehicle requirement. Assign additional morning shifts to cover the between peak requirement.

The example shown in the Exhibit 5-16 requires five morning shifts, four broken (split) shifts, and four afternoon shifts.

Data compiled from an "audit" of one month's driver work assignments is then used to convert the shift requirements to worked hours and penalty hours. The "audit" provides average worked hours and penalty hours per type of shift. When combined with the shift requirements these averages produce the worked hours and penalty hours values used in the cost model equation.

Though the preceeding discussion centers on an application of the scheduling model to weekday service, the model can also be applied to weekend service.

Output

The Adelaide model produces new output in addition to the unit costs obtained from all allocation models. Peak vehicle and vehicle hour unit costs are given as step functions. Additional output comes from the scheduling model, including shift requirements, average worked hours and average penalty hours by type of shift. This represents a new output not usually provided by models of the cost allocation type.

EXHIBIT 5-16
ADELAIDE MODEL
DRIVER SCHEDULING ALGORITHM EXAMPLE

	Morning Peak	Day Base	Evening Peak	Night Base
(1) Number of Buses	8	5	8	3
(2) Afternoon Shifts to Cover Night Base				3
(3) Afternoon Shifts to Provide Meal Relief				1
(4) Total Afternoon Shifts				4
(5) Afternoon Shifts Covering Evening Peak			4	
(6) Broken Shifts Needed			4	
(7) Broken Shifts Covering Morning Peak	4			
(8) Morning Shifts to Cover Morning Peak	4			
(9) Morning Shifts Covering Day Base		4		
(10) Extra Morning Shifts Needed		1		

Estimation of Number of Weekday Shifts Required

(1) From specification of level of service.
(2) Same as Row 1, night base buses.
(3) One shift needed for every three or fewer shifts of Row 2.
(4) Row 2 + Row 3.
(5) All afternoon shifts (Row 4) assumed to cover evening peak.
(6) Row 1 – Row 5: Remainder of evening peak buses manned by broken shift crews.
(7) All broken shifts (Row 6) assumed to cover morning peak.
(8) Row 1 – Row 7: Remainder of morning peak buses manned by morning shift crews.
(9) All morning shifts assumed to cover day base (meal relief provided by broken shifts).
(10) Row 1 – Row 9: Remainder of day base buses manned by morning shift crews.

Source: *R. Travers Morgan, "Adelaide Bus Costing Study," Figure 7.02.*

Applications

The Adelaide model, like the Bradford model, was used to examine incremental costs of a hypothetical service modification and systemwide costs by time of day, day of week, and "layer" of service. In addition, the Adelaide model was also used for two new applications:

- determining the cost of a proposed new route, and
- ascertaining the incremental cost of a proposed modification of an existing route.

The new route investigation involved a straightforward application of the cost and scheduling models outlined above. The existing route examination involved applying the models twice, once for the existing service structure, and once for the proposed service structure. The incremental cost was found by taking the difference of the two calculations.

(1) Walter Cherwony and Subhash R. Mundle, "Peak-Base Cost Allocation Models," Transportation Research Record 663, 1978.

(2) Robert B. Cervero, Martin Wachs, Renee Berlin and Rex J. Gephart, "Efficiency and Equity Implications of Alternative Fare Policies," UCLA, June 1980, pp. 63-67.

(3) Herbert S. Levinson, "Peak-Off Peak Revenue and Cost Allocation Model," Transportation Research Record 662, pp. 29-33, Washington, D.C.: Transportation Research Board, 1978.

(4) J. Reilly, "Transit Costs During Peak and Off-Peak Hours," Transportation Research Record 625, 1977.

(5) J.W. McClenahan, D. Nicholls, M. Elms and P.H. Bly, "Two Methods of Estimating the Crew Costs of Bus Service," Transport and Road Research Laboratory Supplementary Report 364, 1978.

(6) ibid.

(7) E.K. Morlok, W.M. Kulash and H.L. Vandersypen, The Effect of Reduced Fare Plans for the Elderly on Transit System Routes, Research Report, Northwestern University, Evanston, Illinois, March 1971.

(8) Antti Talvitie and Austin Neal, "A Route Cost Model for Bus," Norman, Oklahoma: Oklahoma University, 1974.

(9) R. Travers Morgan & Partners, Bradford Bus Study: Final Report. Prepared for West Yorkshire Metropolitan County Council and West Yorkshire Passenger Transport Executive, 1976.

(10) R. Travers Morgan Pty. Ltd. Adelaide Bus Costing Study: Final Report. Prepared for the Director General of Transport, South Australia, 1978.

CHAPTER 6

EVALUATION OF EXISTING COST ESTIMATION TECHNIQUES

The costing techniques described in the preceding chapter represent a number of approaches for estimating transit service costs. The majority of these techniques, however, were not developed for the purpose of estimating the incremental cost of new service. Often, these models address the allocation of total systemwide costs to individual routes, with the end product being used for operating ratio (i.e., revenue/cost) analysis. When this method is applied to a service change, the cost may be over-estimated for two reasons. First, allocation procedures assume that all cost categories will increase proportional to the level of service. In reality, many items of overhead cost may not vary with increases in service unless the increase is substantial. Second, the use of high level systemwide average cost factors (e.g., cost per mile) may not reflect the real change of some cost items. For instance, actual driver cost per hour may vary significantly from the system average due to a route's unique operating characteristics.

The objective of this chapter is to evaluate the usefulness of existing models for estimating the marginal costs of service changes. Marginal costs may be affected by type of service, hours of operation, operating speed, vehicle requirements and temporal distribution of the service. The models which were reviewed in the preceding chapters address some or all of these variables in some fashion. Two groups of models, however, are judged to be inadequate for the needs of this study and will not be evaluated. Average costing models, using cost per hour or cost per mile alone, are simply too insensitive for this study's use. Regression models, developed chiefly for interagency comparisons, are not really adaptable to estimating marginal cost for a particular system.

A two step process was used to evaluate the remaining models and methods . This process is qualitative in nature. The evaluation steps address the following questions:

1. How well do the models reflect cost differentials implied by a series of service change variables; and

2. How well do the models perform against criteria which have been assigned weights by the review panel members?

The first step eliminates those models that are found to be insensitive to key service variables. The second step assesses the relative performance of the remaining models against criteria reflecting the desired characteristics of any proposed costing technique.

Model Sensitivity to Service Change Costs

Driver and other transportation and maintenance related expenses typically represent from 75 to 85 percent of total transit operating expenses. These cost elements are among those most directly affected by service changes. The accuracy of a model in estimating service change cost is largely dependent on their inclusion of variables which adequately explain variation in these expenses. Variation in cost is best explained when there is a direct, logical correlation between marginal cost and the independent variable(s) used to estimate it.

The major cost categories which would probably be affected by a service change include the following:

- drivers' wages and benefits;
- fuel and lubricants;
- tires and tubes;
- mechanics' wages and benefits;
- maintenance materials and supplies; and
- insurance.

Some of these categories may be reasonably estimated by using a single variable. For instance, the cost of tires and insurance are related to vehicle miles traveled. Other cost categories are more complex, such as driver costs (wages and benefits). Driver costs are comprised of a number of subelements, including scheduled wages, unscheduled wages, paid absences and other benefits. These subelements do not all vary with a common independent variable (e.g., vehicle hours). As shown in Exhibit 6-1 scheduled wages, for example, are dependent on the number of scheduled assignments, the minimum daily guarantee,

EXHIBIT 6-1
DRIVER RELATED EXPENSES
AND POSSIBLE SOURCES OF VARIATION

General Category	Sub-Elements	Factors Contributing to Variation
Wages	Scheduled Pay	
	• Regular	Number of drivers, daily guarantee
	• Overtime	Length of working day, all day service
	• Spread	Distance between beginning of AM peak, end of PM peak
	• Other Premiums (e.g. Articulated Premium)	Hours of that type of service per day
	Unscheduled Pay	
	• Extra Board Guarantee	Ratio of weekday to weekend work, average tripper length
	• Show-Up Time	Absence rate, day of week
	• Overtime	Difference in height of peaks, required versus actual manpower, ratio of weekday to weekend work
Paid Absences	Vacation	Number of operators, average vacation length
	Holiday	Number of operators, number of holidays
	Sick Leave	Number of operators, absence rate, sick leave policy
Benefits	Fixed Benefits	
	• Medical	Number of operators, premium rate
	• Dental	Number of operators, premium rate
	• Uniforms	Number of operators, uniform allowance
	Variable Benefits	
	• FICA	Wages
	• Life Insurance	Wages
	• Pension	Wages

and premiums paid above the guarantee. Unscheduled wages are extra costs incurred in daily operations, and are a function of the efficiency of manpower utilization. Paid absences and fixed benefits (e.g., medical and dental insurance) are largely a function of the number of drivers; variable benefits (e.g., FICA, pension) are based on gross wages. A model which addresses these categories of driver cost will be more accurate than one which addresses driver cost as a single entity.

A model will be sensitive to the marginal cost of service changes when its independent (i.e., explanatory) variables directly reflect the cause of the marginal costs. Most of the models that were investigated rely on using independent variables which reflect the aggregate affect of marginal cost rather than directly addressing the cause. For example, several models estimate driver cost from a pay hour/platform hour ratio. If this ratio is 1.5, then 15 driver pay hours would be incurred for each 10 additional service hours. Use of this type of ratio does not directly address the cause of change in marginal cost because it assumes that the ratio remains constant despite the characteristics of service added. However, driver cost is composed of a number of elements which do not all vary in the same fashion. A direct estimation of these costs will yield more sensitivity to their variation than will a more generalized estimation technique.

The use of resource variables (e.g., hours, vehicle) to allocate systemwide costs is a common characteristic among the models evaluated. This approach has both negative and positive effects. Most of the models allocate some or all costs based on systemwide averages (e.g., cost per vehicle). The use of these averages for estimating large, variable cost categories (e.g., labor, fuel) lessens the sensitivity of a model when the service characteristics are significantly different from the system average. A positive characteristic is the use of hours, miles and/or vehicles in combination as a resource base for allocation. Although systemwide expenses are allocated differently among the models, the use of these variables may aid in estimating costs that are affected by scale or operating speed.

The models were evaluated based on their ability to estimate the marginal costs of typical service changes including: additions/deletions of service; temporal distribution of service; types of service; operating speed; and operator/vehicle utilization. The results of this evaluation and illustrated in Exhibit 6-2. A summary of these results is presented below in order of overall performance. As noted previously, the average costing and regressions approach were eliminated after a cursory examination.

EXHIBIT 6-2
RELATIVE SENSITIVITY OF THE MODELS TO COST DIFFERENTIALS IMPLIED BY SERVICE VARIABLES

TRANSIT SERVICE VARIABLES	COST ALLOCATION MODELS		FIXED/VARIABLES MODELS		TEMPORAL VARIATION MODELS								
	ALLOCATION (HOURS, MILES)	ALLOCATION (HOURS, MILES, VEHICLES)	NATIONAL BUS CO.	LEVINSON & CONRAD	CHERWONY, MUNDLE (PEAK/BASE)	UCLA	LEVINSON	ARTHUR ANDERSON (PEAK/OFF-PEAK)	LONDON TRANSPORT	REILLY	NORTHWESTERN	R. TRAVERS MORGAN BRADFORD	ADELAIDE
SERVICE ADDITIONS/DELETIONS	◒	◒	◒	◒	◒	◒	◒	◕	◒	◒	◒	◒	◕
TEMPORAL EFFECTS													
PEAK	◔	◒	◒	◒	◕	◕	◕	◕	◕	◕	◕	◕	◕
WORKING DAY	◔	◔	◔	◒	◕	◕	◕	◕	◕	◕	◕	◕	◕
ALL DAY	◔	◔	◔	◒	◕	◕	◕	◕	◕	◕	◕	◕	◕
SATURDAY	◔	◔	◔	◒	◒	◒	◒	◕	◕	◒	◕	◕	◕
SUNDAY	◔	◔	◔	◒	◒	◒	◒	◕	◕	◒	◕	◕	◕
SERVICE TYPES	◔	◒	◒	◒	◒	◒	◒	◒	◒	◒	◒	◒	◕
OPERATING SPEED	◒	◒	◒	◒	◒	◒	◒	◒	◔	◒	◒	◒	◕
OPERATOR/VEHICLE UTILIZATION													
INTERLINING	○	◔	◔	◔	◔	◔	◔	◔	◔	○	◔	◔	◒
HOOKING THROUGH ROUTES	○	◔	◔	◔	◔	◔	◔	◔	◔	○	◔	◔	◒
VEHICLE CHANGE	○	○	○	○	○	○	○	○	○	○	○	○	○

● ADDRESSES ALL VARIABLES AFFECTING COST

◕ ADDRESSES THE PRIMARY VARIABLES AFFECTING COST

◒ ADDRESSES MOST VARIABLES INDIRECTLY AFFECTING COST

◔ ADDRESSES FEW OF THE VARIABLES DIRECTLY OR INDIRECTLY AFFECTING COST

○ ADDRESSES NONE OF THE VARIABLE AFFECTING COST

Temporal Variation Models - This group best reflected the cost differentials associated with different service changes. Their attention to variation in driver related expenses was the principal distinction between these and other models. These models performed best in estimating driver expenses because they either segmented this cost category, developed better independent variables than the other classes of models, or did both. The variation in performance within this group is largely based on their segmentation of driver costs.

The model developed by R. Travers Morgan for the Adelaide Bus Costing Study was rated the best of the group, for two reasons. First, a method is used for calculating driver requirements that appears to have little inherent error. Since driver costs are primarily influenced by manpower levels, this approach is assumed to increase accuracy and sensitivity. Second, step cost functions are developed for those elements of overhead cost that are not continuously incurred with additional service.

The Adelaide model has several significant features in calculating driver cost. The number and type of shifts, and penalty (i.e., premium) hours are determined for weekday, Saturday and Sunday schedules. This information serves as a base for calculating scheduled wages and accounts for the pay differentials often evident in these schedules. Unscheduled wages, paid absences and benefits are also calculated in a distinct fashion. It should be noted, however, that the Adelaide Model does not address open trippers. Because trippers are a common element in transit schedules of U.S. properties, this model should be modified prior to use.

The Adelaide model recognized that some items of overhead do not vary continuously, but rather increase in steps as threshold values are exceeded. These cost items were explained by several variables, rather than a single one. This enhances the model sensitivity to these variables and recognizes that no single variable can reflect cost impacts. The Adelaide model does not differ significantly from the other temporal variation models in the way it calculates continuous cost rates. For instance, fuel is calculated on a per mile unit cost, as are tires and lubricating oil.

The Arthur Andersen model was also highly rated. Driver costs were estimated on a per-hour basis, with different factors derived for weekday peak and off-peak, Saturday and Sunday service. Estimates were derived separately for direct driver costs (e.g., pay hours per assignment) and indirect driver costs, (e.g., extra board guarantees, absences, benefits and other unscheduled costs).

The key element in Arthur Andersen's estimate of weekday peak and off-peak driver costs is the derivation of coefficients for factoring vehicle hours as an estimate for pay hours. Use of this variable does not explain how pay hours differ between peak and off-peak. It is assumed that the derived coefficient is valid for all periods in the day. This appears to be a reasonable assumption, but is still open to question.

Another attractive aspect of the Arthur Andersen model is the distinction of fixed versus variable overhead cost. This distinction may help to prevent over estimation of costs for a service change. By allocating costs in this manner, only the costs which change as a result of the service change are addressed.

The London Transport model, like the Arthur Andersen model, stratified driver costs into direct and indirect categories for weekday, Saturday and Sunday service. However, a different approach was taken to estimate direct driver costs. The number and type of shifts were estimated and then multiplied by the average cost per type of shift to produce the cost estimate. This method appears to reduce the error inherent in using a peak/off-peak factor, since the type of shift (e.g., straight, split) is more the determinant of pay hours than whether the shift occurred in the peak. London Transport's method, like the Adelaide Model, did not include estimation of trippers, which occur in abundance in the United States.

The Northwestern model addressed only the direct costs of transit operations. Driver costs were derived from an estimate of driver requirements, while other direct costs were allocated on a vehicle mile basis. Driver costs were calculated by applying a cost per operator-day to the driver requirements for weekday, Saturday and Sunday service. The cost per operator-day was based on the daily guarantee (e.g., eight hours) plus spread bonuses. Since the other direct costs were estimated on a cost per mile basis, the model lacks sensitivity to changes in operating speed. Where speed affects a cost category, it will be either over or under-estimated if the speed is significantly different from the system average.

R. Travers Morgan's Bradford Bus Study treated driver, direct and overhead costs in a different manner than in their Adelaide study. Driver costs are derived from aggregating lower level data (e.g. hours per pay category, absences, and benefits) to an average cost per driver per week. While the derivation is sensitive to changes in sub-element costs, the final product (cost per driver per week) is not.

Direct costs (i.e. fuel, oil, tires) were each assigned a cost per mile factor. Overhead costs were allocated to peak vehicles and/or vehicle hours. These were continuous cost functions, as opposed to the step functions developed in the Adelaide study.

For those costs allocated to vehicles, a method was introduced for estimating weekday, Saturday and Sunday cost factors, based on the number of days the vehicle was in use. Schedule changes requiring a vehicle to be used seven days per week realized a lower unit cost than those utilizing a vehicle only five days per week.

The four remaining temporal variation models are alike in that they each develop peak and off-peak factors for estimating driver costs. Cherwony's Peak/Base model, and the UCLA route analysis model each calculate the relative labor efficiency of peak and off-peak periods. This factor is then applied to a systemwide cost per hour. A significant weakness is that no separate treatment is given to other elements of driver expense (e.g. benefits). Also, no unique cost factors are calculated for Saturday and Sunday service, further reducing accuracy.

Levinson's model produces essentially the same result through a slightly different procedure. Reilly's model finds peak and off-peak cost rates through analysis of regular and extra board drivers' straight and overtime wages, allocated to the two time periods.

Fixed/variable and three factor cost allocation models - These models represent the mid-range in sensitivity of the models evaluated. They are not as sensitive as the temporal variation models, primarily due to their use of a single variable (i.e. vehicle hours) for estimating driver costs. Little difference was found among the models in terms of their sensitivity.

The National Bus Company (NBC) model was rated the best of this group because expenses are allocated on a three variable basis (i.e. hours, miles and vehicles) and it addresses fixed and variable costs. The three factor allocation enables this model to reflect cost changes dependent upon the primary service variables. Costs are allocated to these variables based on a logical relationship. The temporal distribution of service is not accounted for, and where it is substantially different from the system average significant errors may be introduced. The breakdown of fixed, semi-variable and variable costs allows the level of detail and time horizons of the model to be varied, but does not significantly contribute to the model's overall sensitivity.

The three factor cost allocation model developed by Cherwony was also sensitive to changes in basic operating resources. However, there is no distinction between fixed and variable costs, in contrast to the NBC model above.

The Levinson and Conrad model is not directly applicable to marginal costing. This model requires actual driver wages to assess route-level costs, so it avoids estimation of more than half of operating costs. Further, several of the cost categories are allocated on the basis of driver pay hours. This is a weakness because the model assumes this data to be available, rather than estimating it as part of the process.

Two-variable cost allocation model - Using hours and miles as the allocation base, this model can reflect changes in operating speed and level of service. The omission of a factor describing scale (e.g. peak vehicles) causes inherent error in some cost categories, such as maintenance. Additionally, it suffers from the same fault of other cost allocation models in estimating labor costs - the use of a single surrogate variable (i.e., hours) to describe all cost variation.

Model Performance Against Weighted Criteria

The preceding evaluation addressed each model's sensitivity in estimating marginal costs for service changes. While sensitivity is as important criterion, it is only one aspect of a good model. A good cost model should also be reliable, logical, easy to apply and inexpensive. These and other desirable characteristics are included in the criteria used to evaluate the models. This section describes the approach and results of this evaluation.

Approach

This evaluation consisted of the following tasks:

- Defining the criteria;
- Assigning weights to the criteria,
- Rating each model according to the criteria
- Multiplying the ratings and weights for each overall score

A total of thirteen criteria were used in this evaluation (Exhibit 6-3). The relative importance of each criterion was determined by weights assigned to them by each of the review panel members. An interesting result of this weighting process was that the criteria expressing comprehension and sensitivity received greater weight than those expressing simplicity (Exhibit 6-4).

The thirteen weighted criteria were applied to each of the remaining models. A scale of one to ten was used to measure each model's performance, with ten representing the highest performance. This rating was then multiplied by the weight to derive a score. The overall performance for each model was obtained by summing the scores for all criteria. The performance of each model, overall and in respect to each criterion, is presented in Exhibit 6-5. These results are more fully described below.

Resource Approach Models - Taken together, the Northwestern, Bradford and Adelaide models achieve the highest average overall score. These models are the most sensitive to peak/off-peak cost variation, best able to handle differences in scale and time frames of service changes, and most applicable to differing levels of analysis. The models are also quite complex in that calibration and data requirements are substantial. This increased effort may lead to longer response times, more difficulty in use, and less expensive application.

The resource approach is sensitive because the representative models provide detailed, logical and direct analysis useful for a broad range of applications. A positive aspect of these models is that they directly treat the highest proportion of line items. The resulting information includes labor and vehicle cost, shift costs, penalty pay costs, fixed costs, and variable costs. This detailed output allows identification of the specific expenditure items that will probably change as a result of a service modification. Generally, these models allow a full range of service change sizes and horizon periods to be treated.

The Northwestern and Adelaide models specifically address applications to small service changes. The Bradford and Adelaide models were used to examine a wide range of issues. With their fixed/variable structure, various cost items can be included or excluded depending on the time frame of the service change. On the other hand, the Northwestern model is more narrowly focused on small service changes and only includes variable costs.

EXHIBIT 6-3
DEFINITION OF EVALUATION CRITERIA

Criterion:	Measure of:
• Proportion of Line Items	• The number of expenses estimated directly rather than allocated
• Simplicity	• The relative complexity of the model's theory and process
• Economy	• The level of effort and resources required to apply the model
• Logic	• The degree to which the model rests on a sound theoretical base and produces intuitively agreeable results
• Service Sensitivity	• The model's ability to produce acceptable results for service changes varying in scale
• Component Sensitivity	• The model's ability to reflect changes in component costs (e.g. driver benefits)
• Temporal Sensitivity	• The model's ability to incorporate the impact of inflation
• Flexibility	• The degree to which the model is suitable for use by different functional departments within the agency

EXHIBIT 6-3
DEFINITION OF EVALUATION CRITERIA
(Continued)

Criterion:	Measure of:
• Range of Results	• The range of analysis levels and planning horizons for which the model is useful
• Data Compatibility	• The similarity between data needed by the model and data normally collected by a transit agency
• Ease of Use	• The relative ease with which the model may be understood and applied
• EDP Adaptability	• The ease with which the model's process may be computerized (also a measure of objectivity)
• Response Time	• The length of time required to calibrate the costing technique and apply it to typical situations

EXHIBIT 6-4
CLASSIFICATION OF CRITERIA AND ASSOCIATED WEIGHTS

General Characteristic	Criteria	Weights(a)	
Comprehension/ Sensitivity	Logic	4.4	
	Component Sensitivity	4.2	
	Service Sensitivity	3.6	
	Proportion of Line Items	3.6	
	Temporal Sensitivity	3.4	
	Range of Results	3.2	
	Flexibility	3.2	
		25.6	Average = 3.66
Simplicity	Data Compatibility	3.8	
	Ease of Use	3.2	
	Response Time	3.0	
	Simplicity	2.6	
	EDP Adaptability	2.6	
	Economy	2.2	
		17.4	Average = 2.90

(a) 5 Indicates high importance
0 Indicates low importance

EXHIBIT 6-5
MODEL PERFORMANCE AGAINST WEIGHTED CRITERIA

		Fully Allocated Approach	Fixed/Variable Approach	Temporal Variation Method							
				Cost Adjustment Approach			Statistical Approach		Resource Approach		
	Weight	Hours, Miles, Peak Vehicle	Nat'l Bus Company	Peak-Base	UCLA Extension	Reilly	Arthur Anderson	London Transport	Northwestern	Bradford	Adelaide
Proportion of Line Items	3.6	2	2	4	4	6	4	5	4	8	8
Simplicity	2.6	9	8	6	6	5	4	5	4	3	2
Economy	2.2	9	8	7	6	5	5	5	6	2	2
Logic	4.4	2	3	5	6	5	4	6	7	8	9
Service Sensitivity	3.6	2	2	4	4	4	6	6	9	5	9
Component Sensitivity	4.2	2	5	3	3	3	7	4	3	8	8
Temporal Sensitivity	3.4	2	2	2	2	3	2	4	2	2	3
Flexibility	2.2	2	4	3	3	3	5	3	2	6	6
Range of Results	3.2	2	6	4	4	4	7	5	3	8	8
Data Compatibility	3.8	10	10	3	3	3	5	6	7	3	4
Ease of Use	3.2	9	8	7	6	6	5	6	6	3	3
EDP Adaptability	2.6	8	7	7	7	7	6	6	8	5	3
Response Time	3.0	9	8	5	4	4	5	6	7	4	3
Overall Performance Score		200	227	187	184	185	210	222	222	219	234
Ranking		7	2	8	10	9	6	3*	3*	5	1
Average Score for Approach		200	227		185		216			225	

* Denotes tie.

The increased sensitivity of these models demand additional time and effort in their implementation. The high level of detail requires extensive calculations and audit month data on driver assignments which may not be typically gathered by transit agencies. Initial efforts also are required to define a fixed/variable cost framework to classify expense accounts.

Statistical Approach Models - The Arthur Andersen and London Transport Models are slightly less complex and somewhat easier to use than the resource approach models. However, they are assumed to be slightly less accurate because they do not estimate costs as directly as in the resource approach. Only peak/off-peak driver cost variations are addressed by these two models. The issues of vehicle cost and day of week variations are not included. Expenditure identification is also a problem, particularly with the London Transport Model since it does not make a fixed/variable cost distinction. The driver cost estimate is based on a generalization from sample data, which may introduce some error into that estimate.

Despite these shortcomings, the statistical models are still fairly sensitive. For instance, both the Arthur Andersen and London Transport models address a range of service changes. In addition, the fixed/variable structure of the Arthur Andersen model makes it applicable to various planning horizons.

The statistical models are more simple to calibrate than resource models because they rely on sampling. This technique lessens the potentially time consuming and expensive "audit" of driver assignments by reducing the amount of data required. The Arthur Andersen model's utilization of regression analysis makes it slightly more complex than the London Transport model, which uses a simple averaging technique.

The Arthur Andersen model received a lower rating for the logic criteria due to a questionable portion of its analysis. The model's driver cost equation structure and estimation technique can produce a coefficient which suggests that less than one hour is paid per off-peak vehicle hour. Such a circumstance is not universal, even though it may be valid in certain periods (e.g., if the off-peak hour could be driven as part of a driver's daily guarantee). However, the coefficient may be less than one because a regression technique with sample data is employed; rather than reflecting a valid situation.

Fixed/Variable and Cost Allocation Models - The fixed/variable and cost allocation models achieve a high overall performance rating because they are so simple and easy to use. However, their use of system average cost units for major expense items (e.g., driver wages and benefits) resulted in a low score for sensitivity and logic. The only exception is the fixed/variable model's ability to identify changing expenditure items. Despite their high rating, the lack of sensitivity should negate the use of these models in estimating marginal costs.

Cost Adjustment Approach Models - These models obtain an overall performance level lower than resource and statistical models through the combined effect of lengthy set-up and lower sensitivity. The models are limited to considerations of peak/off-peak cost variations and do not include distinctions between fixed and variable cost.

Though based on a fairly simple algorithm, cost adjustment models are relatively difficult to use due to their reliance on an audit of driver work assignments. The audit requires tabulation of driver pay hour data which is not normally performed.

Evaluation Summary

The two-tier evalution has demonstrated some of the shortcomings of existing techniques for estimating the marginal cost of service changes. These shortcomings arise from the fact that these models were not, for the most part, developed for this type of application. Generally, they are particularly sensitive to changes in major cost categories (e.g., drivers, maintenance) and do not isolate the direct (i.e., unavoidable) costs of transit operations. Although there is not a specific model which serves as the best way to proceed, several valuable concepts are embodied in the models which were evaluated. It is these concepts that will be used as a starting point for the development of the proposed cost estimation technique.

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