Bus Route Costing Procedures:

Final Report

April 1984

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Washington, D.C. 20590

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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 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 final report from the study. It summarizes the findings and conclusions presented in the preceding four interim reports. Specifically, the report reviews incremental costing techniques for bus service planning; presents application procedures for the Proposed Method; evaluates the Proposed Method against other prevalent costing techniques; and develops conclusions based on study results. We believe that this report should be valuable to transit planners who are interested in the costing of bus service at the route level.

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

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ACKNOWLEDGMENTS

This study was conducted under the close direction of Mr. Michael G. Ferreri, a Senior Vice President in Booz·Allen & Hamilton's Transportation Consulting Division, and Director of the firm's transit practice. Mr. Ferreri was an early leader in the bus route costing field, and has contributed extensively to cost model development ranging from development of the cost allocation model in the mid-1960's, to preparation of complex financial forecasting models in the 1980's. He provided challenging insights throughout this study.

We wish to express our appreciation to all who have provided us with information regarding bus cost estimation procedures.

We would also like to thank the members of the study review panel for their assistance and contributions. The panel included members of a variety of organizations, as follows:

- Small Transit Operator
  - Richard L. Oram
    Greater Bridgeport Transit District
    . . . Bridgeport, Connecticut

- Medium Transit Operator
  - Gary D. Hufstedler
    Dallas Transit System . . . Dallas, Texas

- Multi-Modal Transit Operator
  - Harris M. Schechtman
    New York City Transit Authority
    . . . New York, New York

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    Los Angeles County Transportation Commission
    . . . Los Angeles, California
  - Ron T. Fisher
    Urban Mass Transportation Administration
    . . . Washington, D.C.
  - Ronald J. Hartman
    Mass Transit Administration of Maryland
    . . . Baltimore, Maryland
  - Lewis Polin - Transportation Consultant
    (formerly with Orange County Transit District)
    . . . Garden Grove, California
  - Robert G. Stanley
    American Public Transit Association
    . . . Washington, D.C.

We would like to acknowledge Benjamin Porter for his assistance in the conceptual design and development of the proposed method while with Booz, Allen & Hamilton Inc. Finally, we would like to thank Brian McCollom of UMTA for his comments and assistance in preparing this report.

CHAPTER 1
INTRODUCTION

Viewed from an economic standpoint, public transportation services can be examined in terms of both their supply and demand characteristics. While these two elements are generally understood at aggregate levels, the incremental cost and revnue impacts of small bus route service changes have received little attention. This is at least partially attributable to the economic environment and primary objectives of the transit industry during the past two decades. With the infusion of federal funds in the early sixties, the primary focus was on the rehabilitation and expansion of transit systems. The financial situation was such that detailed cost and revenue estimation techniques typically were not required. Aggregate financial techniques generally met transit planning needs.

Recently, transit operators have been confronted with a more constrained financial situation. In this era of limited resources, the emphasis has been placed on service rationalizations and changes to assure that operating deficits are within budgeted subsidy amounts. Overall, the objectives at many transit systems have been to concurrently maintain ridership and fare revenue levels and to limit operating costs to control system deficits. The net result of these revised priorities and objectives has been a new cost consciousness in the transit industry. In turn, this has led to a strong interest in developing a technique or procedure that accurately estimates the cost of proposed service changes.

At the present time, nearly all transit systems have established a mechanism to estimate the cost of implementing service changes. The techniques vary widely among agencies in terms of the level of detail, sensitivity, accuracy and sophistication. Agencies have 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 has proven entirely satisfactory. Moreover, the transit industry has not adopted a single preferred approach to estimate cost impacts of bus service changes.

Recognizing this need, the Urban Mass Transportation Administration contracted for the present study to be performed. The study's objective was 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 usable by all sizes of transit agencies. A corollary benefit of the current study is to increase awareness in the transit industry of the importance of cost estimating procedures and the various methodologies that have emerged during the past several years.

Recognizing the broad research goals of the current analysis, the study proceeded in several distinct sequential steps. The initial study effort was directed at cataloging and describing currently available costing procedures and evaluating these techniques against a broad set of criteria. Based on this review and an investigation of factors that influence costs, a proposed technique was devised. Next, a test design was formulated and carried out to compare incremental cost results for the proposed method and other prominent procedures. Finally, conclusions were drawn regarding the strengths and weaknesses of the proposed method relative to other techniques evaluated. In addition, other findings of the research effort were also reported along with a step-by-step manual of how to calibrate and apply the proposed method.

A review panel of persons active in the transit industry was formed to provide guidance at various stages of the study. These individuals critiqued study analyses and findings as well as offered comments on the research effort. The review panel members represented a diverse group in terms of responsibilities, size of operations and number of modes (Exhibit 1-1).

Reflecting the study approach, this Final Report has been organized into four subsequent chapters. A brief description of their contents is presented below.

Chapter 2: Review of Costing Procedures - This initial chapter provides an overview of costing procedures that have been developed and applied in the past. This inventory relied on a literature search and a survey of prevailing practices in the transit industry. A variety of testing procedures are cataloged and described in terms of necessary data collection, algorithms and computational procedures, outputs and application locations.

EXHIBIT 1-1
REVIEW PANEL MEMBERS

TRANSIT OPERATORS
(Small)

Richard L. Oram . . . . Pricing Demonstration Manager
Greater Bridgeport Transit District

TRANSIT OPERATORS
(Medium to Large)

Gary D. Hufstedler . . . . Service Planning Supervisor
Dallas Transit System

TRANSIT OPERATORS
(Multimodal)

H. M. Schechtman . . . . Superintendent/Executive Assistant
New York City Transit Authority

NON-OPERATORS

Wendell Cox . . . . Commissioner
Los Angeles County Transportation Commission

Ron T. Fisher . . . . Office of Methods and Support
Urban Mass Transportation Administration

Ronald J. Hartman . . . . Deputy Administrator
Mass Transit Administration of Maryland

Lewis Polin . . . . Transportation Consultant
Lewis Polin & Associates

Robert G. Stanley . . . . Director-Planning and Policy Analysis
American Public Transit Association

Chapter 3: The Proposed Method - This chapter presents an overview of the proposed method which evolved from the evaluation of the present methods and the research conducted in the current study on the nature of transit cost relationships. The method concentrates on driver wages and benefits and those provisions of the collective bargaining agreement that specify work rules and the computation of total compensation. Other transit cost items that vary with service changes are described along with the method of estimating expenditures for these resources. The proposed procedure consists of two phases - - calibration and application. The initial phase permits the quantification of various factors, ratios and other measures of the cost relationship. During application, these measures along with the resource requirements of the service change are utilized to estimate anticipated incremental operating costs. Both the calibration and application phases are described in a step-by-step manner to assure complete understanding of the study method and encourage its use.

Chapter 4: The Techniques Test - This chapter provides a description of the testing program and subsequent results for the proposed method. For comparison purposes, "baseline" costs were established utilizing a detailed scheduling-based, cost build-up approach. In addition, other promising or widely used procedures appearing in the literature were also evaluated for comparison purposes. Utilizing the transit operator in Minneapolis-St. Paul as a test site, approximately a dozen service changes were costed out utilizing the different techniques. Various comparisons were made between the methods with respect to accuracy, sensitivity and ease of use.

Chapter 5: Conclusion - The final chapter summarizes the overall capability and performance of the proposed method along with the other tested procedures. The strengths and weaknesses of each procedure are assessed. Accompanying this discussion is a description of the tradeoffs associated with somewhat conflicting evaluation criteria. Proposals are also presented on the need for further research and those areas that offer the most promising areas of investigation. The concluding topic in this chapter is the potential for automation which would simplify and reduce resource requirements for applying the costing procedure.

CHAPTER 2
REVIEW OF COSTING PROCEDURES

The initial phase in the development of an incremental cost procedure was the documentation of cost methods that have been formulated and applied in the past. A variety of approaches and methods were found for estimating specific transit expenditures. For clarity, the costing procedures have been grouped into four generic types which all have one distinctive characteristic. Within a generic type, several approaches may exist in which similar techniques are utilized which vary at the detailed level. These individual approaches are termed "models." Models are distinct costing techniques developed by a single researcher or research team.

A large number of cost procedures were identified and documented. These procedures were then evaluated on the basis of several criteria to assess their relative strengths and weaknesses. In this way, the proposed model could evolve from earlier research efforts and incorporate attractive features of previously formulated models. A corollary benefit of the inventory phase of the study was the development of a useful description and summary of available costing procedures. The initial report, Bus Costing Procedures: A Review[1] is a handy reference on costing for planners and operators in the transit industry.

Cost Concepts

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

- Capital and operating cost;
- Fixed and variable cost;
- Average and marginal cost; and
- Incremental and fully allocated cost.

Capital costs refer to the expense associated with the acquisition of long term capital assets such as buses, shelters 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 and include items such as driver wages, fuel and tires, to cite only a few. Because the focus of the study was on developing a procedure to estimate cost increases or decreases associated with service changes, only operating costs were considered.

Four terms are often used to describe operating costs. These four terms are "fixed", "variable", "average" and "incremental" cost. These cost terms are drawn from economics and accounting and are not unique to the transit industry. Some authors may differ in their use of these terms; however, to facilitate a uniform nomenclature the following definitions were 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 2-1A.

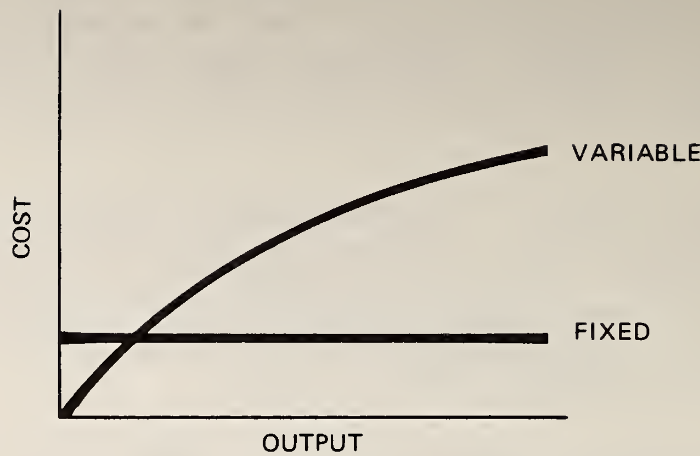
- Average Cost - As the name implies, this is merely the cost divided by the level of output. In Exhibit 2-1B, the average cost at output level O_1 is merely the slope of the line from the origin (C_1/O_1). Similarly, at output level O_2, the average cost is C_2/O_2.

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

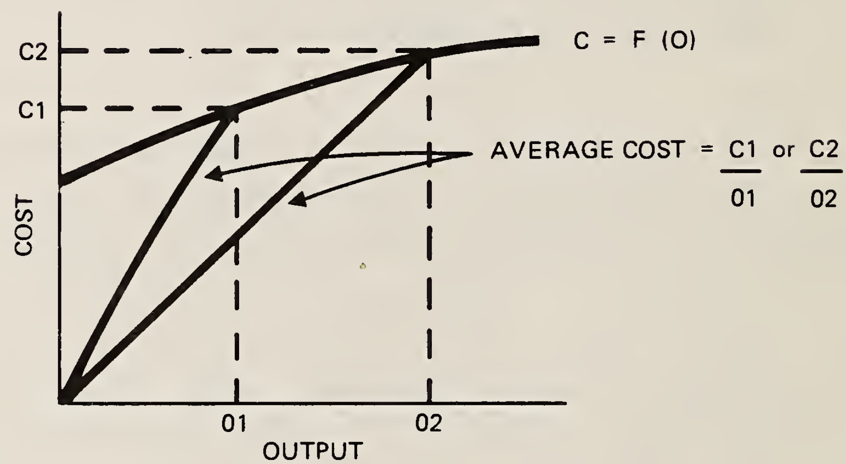
The focus of the study was on the incremental (marginal) cost of a service change. The incremental cost concept stands in contrast to the concept underlying the techniques typically used to evaluate the cost/revenue performance of existing bus routes. Most route performance evaluations begin with the 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

EXHIBIT 2-1
COST DESCRIPTION

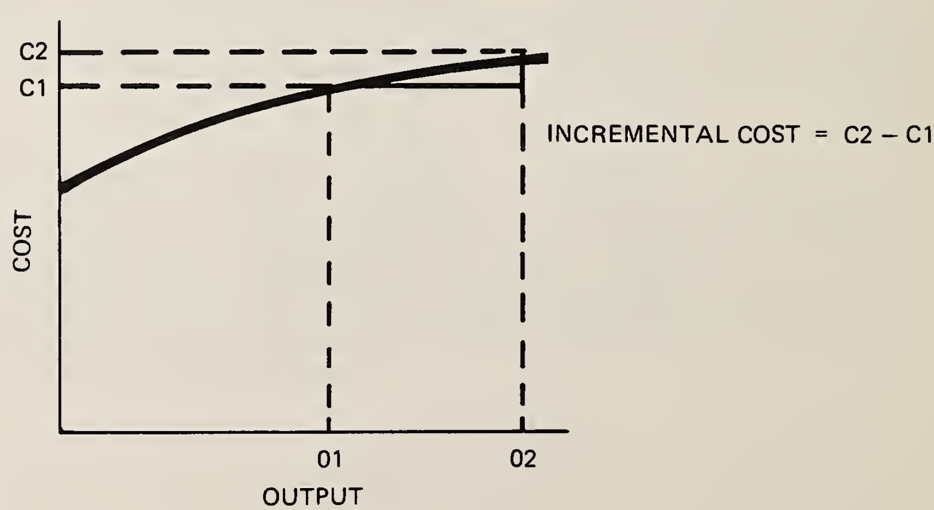
A. FIXED AND VARIABLE COST



B. AVERAGE COST



C. INCREMENTAL COST



are not suited to the estimation of incremental costs. Nonetheless, certain elements of these fully allocated techniques are adaptable to cost estimating associated with service changes.

Generic Types

To provide an analytical framework for review and evaluation, the various estimation techniques were cataloged into four generic types. Each procedure has been designated as representative of a particular generic type, recognizing that some procedures are not generically pure, and are combinations or hybrids of more than a single generic type. The four generic types used are discussed 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 unit costs for each statistic. These unit costs are then used as the coefficients of a cost estimation formula.

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.

Key Cost Models

Within each of the generic cost model categories, several approaches have been suggested by reseachers. Further, each approach includes several distinct models that have been developed and applied at transit agencies. The report Bus Route Costing Procedures: A Review[2] described several dozen specific models in terms of input data, algorithms used, output information and application sites. Only those models tested along with the proposed methodology are presented in the following section. The models chosen for testing were selected after an extensive qualitative evaluation. The evaluation process included factors such as simplicity, ease of use, accuracy and sensitivity. The results of the evaluation for the four selected models clearly indicate that they represent a broad spectrum of approaches and model attributes.

Cost Build-Up - This causal factor technique was used in the current analysis to establish the "true" cost of service changes performed as part of the testing process. Because of the level of detail involved in this method, the build-up approach is the most accurate estimate of cost impacts that would result from service changes.

The cost estimating process consists of estimating driver and non-driver related costs separately. Because of the complex provisions of the collective bargaining agreement, the estimates of driver costs rely extensively on the scheduling process. Schedules are prepared that would indicate how the service change would be operated if it was to be implemented. The output of the scheduling process is the number and type of assignments, their length and applicable penalty and bonus situations. These results are then used in the computation of payroll costs along with fringe benefits and other payment provisions to establish the driver related costs associated with a service change.

Non-driver expenditures are calculated on a more simple basis. For example, cost for fuel, servicing and maintenance, tires and tubes and other variable expenses are determined by merely multiplying the necessary quantities times the appropriate unit cost rates. The quantities (e.g., vehicle miles) are computed based on the resource levels associated with the particular service change. Unit cost rates are calculated from recent cost experience.

The baseline (build-up) cost estimating process is time consuming and requires substantial resources to apply. For this reason, its use in planning situations is typically limited. However, for purposes of this study, its use for establishing "true" cost of service change was needed.

Two-Variable Cost Allocation Model - Another model applied in the Twin Cities test case is a simple two-variable (vehicle hours and vehicle miles) cost allocation procedure. This model is a variation of the three-variable cost allocation model. In this model, operating costs are assigned to three variables: vehicle hours; vehicle miles; and peak vehicles. These variables appear to have a causal relationship with the corresponding expense item. For example, costs assigned to the vehicle miles variable include fuels and lubricants, tires and tubes, servicing revenue vehicles, inspection and maintenance, and accident repairs. Similarly, costs assigned to the vehicle hours variable include operators wages and benefits, and ticketing and fare collection. The mathematical form of the model is:

$$\text{Incremental Cost} = (U_h * H) + (U_m * M)$$

Where:

U_h = Unit Cost per Hour
H = Net Change in Vehicle HOurs
U_m = Unit Cost per Mile
M = Net Change in Vehicle Miles

In the three-variable model, the variable peak vehicles is assigned expenses that relate to the scale of the transit operation (e.g., maintenance of buildings and service equipment). As such, the coefficient of peak vehicles in the cost allocation model includes fixed expenses which would not vary with small service changes. For this reason, the three-variable formula is often referred to as a fully allocated cost model since it includes all operating expenditures.[(3)] The two-variable model is formed from the three-variable model by deleting peak vehicles from the cost formula. By deleting fixed costs, it is better suited to estimating incremental cost associated with service changes.

The development of the two-variable model in this manner is consistent with research work performed in England.[(4)] Several British cost allocation models segregate expenditures in terms of fixed and variable costs. By not including the fixed costs component, these fixed/variable cost models resemble the two-variable cost model utilized in the current analysis testing.

The model calibration process for the two-variable technique is relatively simple and easy to perform. Each expense item (excluding fixed costs) is assigned to either vehicle hours or vehicle miles. These allocated costs are then summed and divided by the appropriate operating statistic to determine the two coefficients of the model. In applying the model to service changes, the vehicle hours and vehicle miles associated with a service change are computed. In turn, these resource levels are substituted into the two-variable formula to compute incremental cost.

<u>Peak/Base Model</u> - This model is an extension of the straightforward cost allocation model procedure. It is an

attempt to combine the simplicity of the cost allocation model with a technique that is somewhat sensitive to transit costs that vary by time of day. The model was originally developed as an enhancement of the standard three-variable cost allocation model.[5] Two different vehicle hour unit cost coefficients were determined. One unit cost was established for weekday peak period vehicle hours and another for the base period. The other resource coefficients (vehicle miles and peak vehicles) were calculated and used as they are in the traditional three-variable cost allocation model formula.

Like the two-variable cost allocation model, the peak/base model was modified for use in incremental costing for this study. The elimination of fixed costs from the model resulted in the deletion of the peak vehicle unit cost coefficient from the model. Variable operating expenses were assigned to either vehicle hours or vehicle miles.

The peak/base model calibration is similar to that employed with the traditional cost model; each expense item is assigned to either vehicle hours or vehicle miles. The primary difference is the computation of the peak and base vehicle hour unit costs. Two separate unit costs are computed because it is recognized that often union contract provisions make it more costly to provide an hour of peak period service than to provide an hour of base period service. Essentially, more payhours per vehicle hour of service are required in peak periods than in base periods. The method used to compute the unit costs is to allocate to either peak or base periods the sum of expense items assigned to vehicle hours. This allocation is made in proportion to the amounts of total payhours in each period. Unit vehicle hour costs are computed by dividing the allocated vehicle hour cost for the time period by the total vehicle hours for the time period. By computing separate unit costs for peak and base periods in this manner, the model is expected to be more sensitive and accurate in estimating the incremental cost of service changes by time of day.

The computation of the unit vehicle hour cost for peak and base periods is relatively straightforward. All vehicle hours and pay hours are assigned to either peak or base periods. By defining the peak periods (morning and afternoon rush hours), vehicle hours are easily assigned to the appropriate period. Unfortunately, the assignment of pay hours is more complex and requires some effort. Because of the types of driver assignments and pay provisions, various rules must be established for the assignment process. Each driver work assignment and corresponding pay hours must be reviewed and pay hours allocated to either the peak or base period in accordance with the established rules. The results of this process leads to four quantities - - vehicle and pay hours for both peak and base periods. The formulae presented below are then used to compute the vehicle hour unit costs.

$$VC_p = TVHC * \frac{PH_p}{PH_p + PH_b} * \frac{1}{VH_p}$$

$$VC_b = TVHC * \frac{PH_b}{PH_p + PH_b} * \frac{1}{VH_b}$$

Where:

$TVHC$	=	Total Costs Assigned to Vehicle Hours
PH_p	=	Peak Period Pay Hours
PH_b	=	Base Period Pay Hours
VH_p	=	Peak Period Vehicle Hours
VH_b	=	Base Period Vehicle Hours
VC_p	=	Peak Period Vehicle Hour Unit Cost
VC_b	=	Base Period Vehicle Hour Unit Cost

Since the calibration of the peak/base model requires more effort than the two-variable model, the peak/base model formulae were modified to use the unit vehicle hour cost of the two-variable model and the concept of the "audit" period. The simpler two-variable vehicle hour cost was included in the formulae by using the following relationship:

$$TVHC = (VH_p + VH_b) * VC_s$$

Where:

VC_s	=	Two-Variable Vehicle Hour Unit Cost
TVHC	=	Total Costs Assigned to Vehicle Hours
VH_p	=	Peak Period Vehicle Hours
VH_b	=	Base Period Vehicle Hours

The concept of the audit month was used to minimize the need for a continuous update of the assignment of vehicle and pay hours. The values for these variables are based on an "audit" period which reflects recent experience with labor distribution and costs associated with bus operators. The "audit" period values are updated annually to reflect changes in work rules and other labor provisions of the collection bargaining agreement.

With these two changes, the modified formulae become

$$VC_p = VC_s \left[(VH_p + VH_b) * \frac{PH_p}{PH_p + PH_b} * \frac{1}{VH_p} \right]_A$$

Where:

$[\ ]_A$	=	Values Based on "Audit" Period
VC_p	=	Peak Period Vehicle Hour Unit Cost
VC_s	=	Two-Variable Vehicle Hour Unit Cost
VH_p	=	Peak Period Vehicle Hours
VH_b	=	Base Period Vehicle Hours
PH_p	=	Peak Period Pay Hours
PH_b	=	Base Period Pay Hours

Using the formulae presented above, the calculation of the vehicle hour unit costs is relatively straightforward. The time consuming process is the analysis of the "audit" period vehicle hours and pay hours disaggregated by time of day. Once the indices are computed, the traditional cost model can readily be adjusted.

Adelaide - This cost model represents an enhancement of previous research work by R. Travers Morgan, performed for the Bradford (United Kingdom) bus system.(6) Its treatment of non-driver-related expenditures is similar to the two-variable and peak/base cost allocation models. Like these models, the fixed costs associated with peak vehicles were eliminated to better estimate incremental costs. Similar to the peak/base model, the Adelaide procedure falls in the temporal variation category of cost models. However, unlike the peak/base approach which relies on an adjustment process, Adelaide utilizes a resource allocation approach in which pay hours and labor provisions are examined extensively to quantify the utilization and payroll computation for drivers. The novel and attractive feature of this model is a simplified driver scheduling algorithm that transcribes buses in service by time period into driver work assignments. This eliminates the need for detailed run cutting to quantify the costs of drivers. For this study, the Adelaide procedure was modified to reflect work assignments and rules common in the United States but not found in Commonwealth transit systems (i.e., tripper combinations, part-time trippers and overtime trippers).

With the elimination of fixed costs, the Adelaide model has the following form:

$$C = U_w(W) + U_p(P) + U_m(M) + U_h(H)$$

Where:

C	=	Cost
W	=	Worked Hours
P	=	Penalty Hours
M	=	Vehicle Miles
H	=	Vehicle Hours
U_w	=	Unit Cost per Worked Hour
U_p	=	Unit Cost per Penalty Hour
U_m	=	Unit Cost per Vehicle Mile
U_h	=	Unit Cost per Vehicle Hour

The first step in applying the Adelaide model is to compute vehicle requirements for each of five time periods -- early morning, morning peak, day base, evening peak and night base. Vehicle requirements are estimated by dividing the average round-trip time by the mean headway for the route in question for each of the time periods.

The next step is to convert the vehicle requirements into the number and type of assignments. To staff the bus requirements, four shift types are defined in the scheduling algorithm: morning straights; splits; trippers; and evening straights. The scheduling algorithm calculates the shift requirements by proceeding through the following steps:

- Assign one P.M. straight run for each night base bus.
- Assign all P.M. straight runs for night base to the evening peak as well.
- Determine the difference between P.M. straights and buses required in the evening peak. These open runs are to be assigned to split runs and trippers.
- Allocate evening peak open runs to split runs, tripper combinations, part-time trippers and overtime trippers utilizing the weighted average of pay hours to platform hours from before the service change.
- Assign one A.M. straight run for each early morning vehicle required.
- Assign all A.M. straight runs for early morning service to the morning peak. The day base requirements are also allocated to A.M. straight runs in the morning peak.
- Assign all evening peak split runs to the morning peak.
- Assign all evening peak tripper combinations to the morning peak.
- Determine the difference between the runs assigned (i.e., sum of straight runs, split runs and tripper combinations) and the vehicle requirements for the morning peak. Allocate these open runs to overtime and part-time trippers using the weighted average of pay hours to platform hours for each assignment type before the change.

- Assign A.M. straights covering the morning peak to the day base.

- Determine additional A.M. straights required by calculating the difference between day base vehicle requirements and A.M. straights covering the day base.

As part of the calculation process, an "audit" of driver work assignments is compiled to convert the shift requirements to work 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 produced the amount of worked hours and penalty hour values used in the cost equation presented above.

The incremental cost is calculated by multiplying the change in five resource units by their respective unit costs. The change in full-time worked hours, part-time worked hours and penalty hours (determined above) are multiplied by average wages determined from a month's audit and review of the contract award. The non-driver costs are determined by multiplying the change in vehicle hours and vehicle miles by their respective unit costs. These unit costs are determined in the same manner as the two-variable and peak/base cost allocation models.

The Adelaide model was adjusted to reflect U.S. transit industry work assignments and pay provisions. In particular, modifications were needed to accommodate trippers (overtime and combination) and part-time drivers. For this reason, the scheduling algorithm was revised and expanded to reflect the more complex labor situations. A total of twelve steps, described above, must be followed to convert vehicle requirements to the number and type of work assignments. The tripper assignments were allocated based on the weighted average of pay hours to platform hours for each assignment type at the division before the service change.

The Adelaide is a "difference" model which requires two iterations of the scheduling process at the route level. Costs are estimated before and after the proposed service change. The difference between the before and after cost estimates is the estimated incremental cost.

CHAPTER 2
FOOTNOTES

(1) Walter Cherwony, Greg Gleichman and Ben Porter, Bus Route Costing Procedures: A Review, Washington, D.C., U.S. Government Printing Office, May 1981.

(2) ibid.

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

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

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

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

CHAPTER 3
THE PROPOSED METHOD

A proposed method for estimating incremental bus route costs was developed with the intent of eliminating the apparent weaknesses of existing cost models while maintaining key strengths. The purpose of the proposed method is to provide a reliable tool for accurate incremental cost estimation by transit planners in bus service analysis.

The proposed method focuses on driver-related costs, since driver wages and benefits comprise by far the largest portion of costs resulting from a service change. Other, non-driver, incremental costs are estimated using a traditional two-variable (i.e., hours and miles) cost allocation approach. The proposed method, like all techniques involved in the test, focuses only on those costs which were believed to typically vary in response to changes in the scale or characteristics of fixed-route service (i.e., variable costs). Fixed costs are neither considered nor estimated by the technique.

The proposed method is deterministic in nature, as opposed to statistical, and is an effort to establish a causal relationship between service change characteristics and incremental cost behavior. The independent variables describe resources (e.g., number of assignments and drivers) that are frequently not known in the early stages of service planning. Therefore, a process is provided in the methodology for estimating the value of these variables. It involves the use of current operating and financial statistics to estimate the value of these variables. The application of the model requires the sequential application of several costing algorithms to estimate resource requirements, driver wages and benefits, and total incremental cost resulting from a particular service change. Specific calibration and application procedures are discussed below.

Model Calibration

This component consists of five steps. Each provides information for estimating the way new service is likely to be scheduled and dispatched. The inputs to this component include:

- A buses-in-service profile
- Assignment (i.e., run) data
  - type of run
  - on and off times per piece
  - spread premium hours
  - overtime
- Dispatching data
  - number of trippers assigned to part-timers by a.m., p.m.
  - number of trippers assigned at overtime by a.m., p.m.
  - number of trippers assigned to the extra board, and average number of pieces per combination assignment
  - spread premium paid for extra board trippers
  - number of regular, extra board and part-time drivers and absences per day

Step 1: Define Time Parameters for Weekday Services - This step is necessary when the service distribution is uneven due to peaks in demand. Its primary purpose is to define the duration of the peaks, since it is in these periods where split runs and trippers most frequently occur. In this study, the internal policy at the test site (Metropolitan Transit Commission, St. Paul) defined the periods when the closest headways are being operated as:

- A.M. peak - 6:30 to 9:00
- P.M. peak - 3:30 to 6:00

This distinction established five time periods for weekday service: early A.M., A.M. peak, midday, P.M. peak, and evening.

Step 2: Determine Allocation of Existing Platform Hours to Assignment Types - This step describes the way the current service is scheduled. If service is peaked, the platform hours operated in each time period are calculted for each assignment trip. If service is flat, total platform hours are calculated for each assignment type for the entire day. An example of calibration results for a peaked service is given in Exhibit 3-1 and for a flat service in Exhibit 3-2. The percent of platform hours allocated to each assignment type in each period is then used in application Steps 1 and 2 to assign the new platform hours after a service change.

Step 3: Determine Allocation of Existing Trippers to Part-Time, Overtime and Tripper Combinations - This step uses information compiled daily by a dispatcher in assigning trippers. The purpose of this step is to calculate the likelihood that an A.M. or P.M. tripper will be assigned to a part-timer, at overtime, or paired with another tripper to form an extra

EXHIBIT 3-1
CALIBRATION OF THE PROPOSED METHOD

STEP 2: DETERMINE ALLOCATION OF EXISTING PLATFORM HOURS
Time Periods for Weekday Service

Type of Assignment	No.	Platform Hours: Early A. M.	A. M. Peak	Midday	P. M. Peak	Evening	Total	Spread Premium Hours	Overtime Hours
Straight Runs	97	48.05	100.0	280.83	123.45	190.10	742.43	0.00	6.79
Split Runs	96	15.62	170.68	236.65	195.00	82.15	700.10	48.96	3.94
A.M. Tripper	87	10.60	143.67	20.42	0.00	0.00	174.68	0.00	0.00
P.M. Tripper	80	0.00	0.00	36.15	110.88	27.30	174.33	11.57	35.72
All Assignments		74.27	414.35	574.05	429.33	299.55	1,791.55	60.52	46.45

Type of Assignment	Percent of Platform Hours: Early A. M.	A. M. Peak	Midday	P. M. Peak	Evening
Straight Runs	64.70%	24.13%	48.92%	28.75%	63.46%
Split Runs	21.03%	41.19%	41.22%	45.42%	27.42%
A.M. Tripper	14.27%	33.68%	3.56%	0.00%	0.00%
P.M. Tripper	0.00%	0.00%	6.30%	25.83%	9.12%
All Assignments	100.00%	100.00%	100.00%	100.00%	100.00%

EXHIBIT 3-2
CALIBRATION OF THE PROPOSED METHOD

STEP 2: DETERMINE EXISTING ALLOCATION OF PLATFORM HOURS
Saturday and Sunday Service

Type of Assignment	No.	Platform Hours	Percent of Total Hours	Spread Premium Hours	Overtime Hours
			SATURDAY		
Straight Runs	94	695.51	77.49%	0.00	3.67
Trippers	52	201.95	22.51%	3.28	6.71
All Assignments		897.46	100.00%	3.28	10.38
			SUNDAY		
Straight Runs	43	347.27	77.88%	0.00	7.48
Trippers	26	98.66	22.12%	2.25	4.75
All Assignments		445.93	100.00%	2.25	12.23

board assignment,and thus determine the amount of overtime and spread premium hours associated with trippers. Dispatch data is also used to determine the average number of independent tripper pieces (e.g., runs assigned to a single driver. An example of this step's results is given in Exhibit 3-3. The information derived here is then used to assign tripper pieces to assignment types in application Steps 2.3 and 2.4.

Step 4: Calculate Average Times - The average platform time, spread premium and overtime is determined in this step for each assignment type within a schedule. It involves dividing total values for each of the above categories by the corresponding number of assignments. As shown in Exhibit 3-1, a total of 742.43 platform hours was calculated for straight runs. Dividing this by the number of assignments (97) yields the average platform time (7.65) for straight runs on weekdays.

This information is used for two purposes. First, the average platform time is used in applying Step 2.2 to estimate the number of assignments by type. Second, average overtime and spread premium hours are used to estimate daily totals in Step 2.5 of model application for their respective categories.

The averages calculated from the calibration phase of the techniques test are presented in Exhibit 3-4.

Step 5: Compute Driver Utilization Ratios - This step calculates the ratio of full-time drivers to full-time assignments (i.e., straight and split runs, tripper combinations) which is later used in Step 3 of model application to determine driver requirements.

EXHIBIT 3-3
CALIBRATION OF PROPOSED METHOD

STEP 3: DETERMINE ALLOCATION OF EXISTING TRIPPERS

	A.M. Tripper	P.M. Tripper
Number	87	80
Number Assigned to Part-Time Drivers	28	25
Percent Assigned to Part-Time Drivers	32.18%	31.25%
Number Assigned at Overtime	23	39
Percent Assigned at Overtime	26.44%	48.75%
Number Assigned to Tripper Combinations	36	16
Percent Assigned to Tripper Combinations	41.38%	20.00%

Total Tripper Overtime	35.72 Hours
Total Tripper Combination Spread Premium	11.57 Hours
Average Tripper Pieces Per Combination:	
Weekday	2.21
Saturday	2.45
Sundays	2.00

EXHIBIT 3-4
CALIBRATION OF PROPOSED METHOD

STEP 4: CALCULATE AVERAGE PLATFORM LENGTH, SPREAD PREMIUM, AND OVERTIME FOR EXISTING ASSIGNMENTS

Day/Type of Assignment	Average Hours		
	Platform Length	Spread Premium	Overtime
Weekday			
. Straight Run	7.65	0.00	0.07
. Split Run	7.29	0.51	0.04
. A.M. Tripper	2.01	0.00	- -
. P.M. Tripper	2.18	0.00	0.69
. Tripper Combination	*	0.41	0.00
Saturday			
. Straight Run	7.40	0.00	0.04
. Split Run	- -	- -	- -
. A.M. Tripper	- -	- -	- -
. P.M. Tripper	- -	- -	- -
. Tripper Combination	3.61	0.13	0.26
Sunday			
. Straight Run	8.08	0.00	0.17
. Split Run	- -	- -	- -
. A.M. Tripper	- -	- -	- -
. P.M. Tripper	- -	- -	- -
. Tripper Combination	3.80	0.17	0.37

* Average platform length for tripper combinations is not used in any calculations.

Driver utilization ratios are derived by dividing the total full-time drivers scheduled to work on any given day by the number of full-time drivers actually working. An example of these ratios is given in Exhibit 3-5. This ratio should always be greater than unity. Since absences inflate the number of drivers required to operate the schedule, the number of drivers scheduled to work should exceed the number of assignments to be filled.

Although no explicit treatment is given to the effect of part-time absences to full-time driver requirements, a relief factor is included. Extra board drivers cover all driver absences, including part-time. As long as part-time drivers remain at a constant percentage of the workforce (e.g., ten percent), their absence reliefs should be implicit in the above ratio.

Step 6: Identify Driver Wage Parameters - Driver wage parameters can be compiled from the labor contract and basic payroll data. The labor agreement may specify part-time driver allowance, overtime and spread premium rates, paid holidays, and variable and fixed-benefit awards. Payroll records can be used to determine average wage rates, show-up hours paid, and percent of absences paid. The parameters specified for the test site (i.e., MTC) are shown in Exhibit 3-6. These parameters are used in all costing formulae (i.e., application Step 4).

Step 7: Determine Unit Costs for Allocated Expenses - The proposed method estimates non-driver costs utilizing a cost allocation approach. Section 15 expense accounts are assigned to resource variables, as shown in Exhibit 3-7. The expense elements for the audit year are summed and divided by the

EXHIBIT 3-5
CALIBRATION OF PROPOSED METHOD

STEP 5: COMPUTE DRIVER UTILIZATION RATIOS FOR EXISTING SERVICE

	Drivers	Absences	Working
Weekday			
. Regular	232	39	193
. Extra Board	37	9	28
. Total	269	48	221
. Full-Time Driver Assignments	221		
. Ratio of Drivers to Work	1.216		
Saturday			
. Regular	114	20	94
. Extra Board	39	12	26
. Total	153	33	120
. Full-Time Driver Assignments	120		
. Ratio of Drivers to Work	1.274		
Sunday			
. Regular	55	12	43
. Extra Board	21	8	13
. Total	76	20	56
. Full-Time Driver Assignments	56		
. Ratio of Drivers to Work	1.351		
Weekly			
. Regular	266		
. Extra Board	49		
. Total	315		

EXHIBIT 3-6
CALIBRATION OF PROPOSED METHOD

STEP 6: IDENTIFY DRIVER WAGE PARAMETERS

Maximum Percent Part Time:	10%
Average Wage Rate:	
. Full Time	$10.996
. Part Time	$9.097
Overtime Premium Multiplier	1.5
Spread Premium Multiplier	1.5
Percent of Time Show-Up Paid	3.34%
Percent of Absences Paid	50%
Number of Paid Holidays	10
Variable Benefits Rate:	
. Full Time	0.165
. Part Time	0.067
Fixed Benefit Award:	
. Full Time	$1,167/Year
. Part Time	$300/Year

EXHIBIT 3-7
CALIBRATION OF PROPOSED METHOD

ASSIGNMENT OF EXPENSE ACCOUNTS
PROPOSED METHOD

Function/Section 15 Account		Assigned Resource
012	Revenue Vehicle Movement Control	Hours
031	Revenue Vehicle Operations Accounts:	
	Operators' Salaries and Wages (501.1)	Special Analysis
	Fringe Benefits Distribution (502.15)	Special Analysis
	Fuel and Lubricants (504.01)	Miles
	Tires and Tubes (504.02)	Miles
051	Servicing Revenue Vehicles	Miles
061	Inspection and Maintenance of Revenue Vehicles	Miles
062	Accident Repairs of Revenue Vehicles	Miles
151	Ticketing and Fare Collection	Hours
165	Injuries and Damages	Miles

appropriate resource value (i.e., vehicle miles or hours) to determine the unit cost to be used in model application (i.e., Step 5).

Step 8: Determine Base Driver Cost - The final step in model calibration entails applying the model to the existing service characteristics. This produces an existing driver cost estimate for the division. The existing cost is the estimate against which planned service change costs are compared to derive the incremental driver cost estimate. The base driver cost is found by applying application Steps 1 through 4 in the same manner as service changes are evaluated.

Model Application

Application of the proposed method requires completion of five basic steps. First, run-type coefficients are modified to reflect the unique characteristics of the route being changed (as opposed to using division-wide average characteristics). Second, driver assignments, spread premium hours and overtime hours are estimated by applying the calibrated ratios to the net change in platform hours at the division level. Third, driver requirements are estimated from assignment projections and the daily driver-to-work ratios developed in the calibration phase. Fourth, wage and benefits cost is determined in terms of regular, overtime, spread premium, show-up wages, paid absences, and variable and fixed benefits. The incremental wage and benefit cost is estimated by taking the difference between the base cost estimated developed in model calibration and the cost estimate for the service change. Finally, non-driver costs are calculated using a cost allocation approach for mile- and hour-related expenditures. A step-by-step discussion of the proposed method as applied to Scenario 9 of the techniques test follows. Scenario 9 called for reducing weekday service on MTC Express Route 52B by about sixteen hours per day. The reduction was achieved by reducing headways throughout the day, thereby affecting three of the five time periods discussed in calibration Step 1 (i.e., A.M. peak, midday, P.M. peak).

Step 1: Modify Run Type Coefficients - In this step, run type coefficients from calibration Step 2 are modified to reflect the unique characteristics of the specific route change. This step is an attempt to make the model more sensitive to service changes, particularly in cases where the route change does not reflect average system operating characteristics. The run type coefficients (i.e., the proportion of platform hours allocated to each assignment type by time of day) for weekday peak periods (i.e., A.M. peak and P.M. peak) are adjusted in this step; impacts on midday, early A.M. and evening periods are assumed to be minimal. For weekend only changes, the costing process begins with application Step 2. The peak coefficients are modified using six sequential calculations as follows.

Step 1.1: Determine New Platform Hours (Exhibit 3-8)

New platform hours for the service change are calculated by adding (subtracting) the net change in platform hours by time of day to (from) the existing hours, as shown in Exhibit 3-8. The existing hours were defined in calibration Step 2.

Step 1.2: Determine Expected Values for Peak Period Changes (Exhibit 3-9)

The expected values for the peak period changes were estimated based on the net change in midday hours and the ratio of current peak period to current midday hours for A.M. and P.M. peak periods separately. If there are no midday hours (e.g., peak service only), go on to Step 1.3.

EXHIBIT 3-8

APPLICATION OF PROPOSED METHOD
STEP 1.1 - DETERMINE NEW PLATFORM HOURS FOR SERVICE CHANGE

Day/Type of Assignment	Platform Hours Before Change	Net Change In Platform Hours	Platform Hours After Change
Weekday			
. Early A.M.	74.27	0	74.27
. A.M. Peak	414.35	(5.73)	408.62
. Midday	574.05	(10.90)	563.15
. P.M. Peak	429.33	(0.67)	428.66
. Evening	299.55	0	299.55
Total	1,791.55	(17.30)	1,774.25
Saturday	897.46	0	897.46
Sunday	445.93	0	445.93

EXHIBIT 3-9

APPLICATION OF PROPOSED METHOD
STEP 1.2 - DETERMINE EXPECTED VALUE FOR PEAK PERIOD CHANGES

$$\text{NETMDAY} * (\text{CURPK}_p / \text{CURMDAY}) = \text{EV}_p$$

WHERE:

p	=	Peak Period (i.e., A.M. or P.M.)
NETMDAY	=	Net Change in Midday Hours
CURPK	=	Current Peak Period Hours
CURMDAY	=	Current Midday Hours
EV	=	Expected Value for Peak Hours Change

A.M. Peak:

$$(10.90) * (414.35 \div 574.05) = (7.87)$$

P.M. Peak:

$$(10.90) * (429.33 \div 574.05) = (8.15)$$

Step 1.3: Determine Factor for Modifying Splits and Trippers (Exhibit 3-10)

This step begins by determining the difference between the actual and the expected net change in peak period hours separately for A.M. and P.M. peaks. The difference is then divided by the existing proportion of split runs and trippers in the peak (i.e., one less the coefficient for straight runs shown in calibration Step 2). The quotient is added to the current peak period hours in each peak, as shown in Exhibit 3-10, and yields the factor for adjusting peak period split runs and trippers.

Step 1.4: Modify Vehicle Hour Proportions for Peak Periods (Exhibit 3-11)

The new vehicle hours proportion (coefficient) for peak period straights is found by multiplying the existing peak period hours by the existing proportion for A.M. and P.M. Straights (both defined in model calibration in Step 2), adding the expected value for peak hours change (calculated in application Step 1.2) to that product, and dividing the sum by the new peak period hours (determined in Step 1.1 of the model application). The resulting proportions are then used to apply Step 2.

Step 1.5: Modify Vehicle Hour Proportions for Peak Period Splits (Exhibit 3-12)

The proportion of vehicle hours assigned to peak period split runs (defined in Step 2 of model calibration) are modified by multiplying the existing proportion for splits (determined in model calibration Step 2) by the adjustment factor calculated in application Step 1.3, and dividing the product by the new peak period hours (found in Step 1.1). The resulting proportions are used to apply Step 2. Calculations for both A.M. and P.M. peaks are shown in Exhibit 3-12.

EXHIBIT 3-10

APPLICATION OF PROPOSED METHOD
STEP 1.3 - DETERMINE FACTOR FOR MODIFYING SPLITS AND TRIPPERS

$$[(NETPK_p - EV_p) \div (1 - CURSTR_p)] + CURPK_p = FAC_p$$

WHERE:

p	=	Peak Period (i.e., A.M. or P.M.)
EV	=	Expected Value for Peak Hours Change
CURPK	=	Current Peak Period Hours
NETPK	=	Net Change in Peak Hours
CURSTR	=	Current Coefficient for Straights in Peak
FAC	=	Factor for Modifying Splits and Trippers

A.M. Peak:

$$[((5.73) - (7.87)) \div (1 - 0.2413)] + 414.35 = 417.17$$

P.M. Peak:

$$[((0.67) - (8.15)) \div (1 - 0.2875)] + 429.33 = 439.83$$

EXHIBIT 3-11

APPLICATION OF PROPOSED METHOD
STEP 1.4 - MODIFY COEFFICIENT FOR PEAK PERIOD STRAIGHTS

$$[(CURSTR_p * CURPK_p) + EV_p] \div NEWPK_p = NEWSTR_p$$

WHERE:

p	=	Peak Period (i.e., A.M. or P.M.)
CURSTR	=	Current Coefficient for Straights in Peak
CURPK	=	Current Peak Period Hours
EV	=	Expected Value for Peak Hours Change
NEWPK	=	New Peak Period Hours
NEWSTR	=	New Coefficient for Peak Period Straights

A.M. Peak:

$$[(0.2413 * 414.35) + (7.87)] \div 408.62 = 0.2254$$

P.M. Peak:

$$[(0.2875 * 429.33) + (8.15)] \div 428.66 = 0.2689$$

EXHIBIT 3-12

APPLICATION OF PROPOSED METHOD
STEP 1.5 - MODIFY COEFFICIENT FOR PEAK PERIOD SPLITS

$$(CURSPL_p * FAC_p) \div NEWPK_p = NEWSPL_p$$

WHERE:

p	=	Peak Period (i.e., A.M. or P.M.)
FAC	=	Factor for Modifying Splits and Trippers
NEWPK	=	New Peak Period Hours
CURSPL	=	Current Coefficient for Peak Period Splits
NEWSPL	=	New Coefficient for Peak Period Splits

A.M. Peak:

$$(0.4119 * 417.17) \div 408.62 = 0.4205$$

P.M. Peak:

$$(0.4542 * 439.83) \div 428.66 = 0.4660$$

Step 1.6: Modify Vehicle Hour Proportions for Peak Period Trippers (Exhibit 3-13)

The proportion of service hours assigned to peak period trippers are modified in a manner similar to split run proportions. The existing proportion for peak period trippers (found in model calibration Step 2) is multiplied by the adjustment factor defined in application Step 1.3, and the product is divided by the new peak period hours (determined in application Step 1.1). The resulting proportions are used in the following step.

Step 2: Estimate Driver Assignments - Driver assignment impacts are estimated based on the platform hours which will be added to or deleted from existing service. Where existing service is peaked, as is commonly the case on weekdays, the platform hours should be stratified by the time periods defined in model calibration. Where service levels are more constant, as on Saturdays and Sundays, platform hours need only be specified in aggregate, rather than by time period. The five sequential steps which comprise this component are explained below.

Step 2.1: Allocate Platform Hours to Assignment Types (Exhibit 3-14)

The new platform hours by time of day, resulting from the change in service, were determined in Step 1.1. Using the percentage distribution of platform hours (i.e., from Step 2 of model calibration) early A.M., midday, and P.M. peak hours are distributed to assignment types (i.e., straight runs, split runs, A.M. trippers and P.M. trippers). The new A.M. and P.M. peak period coefficients for straights, splits and trippers (developed in application Steps 1.4, 1.5 and 1.6, respectively) are used to allocate peak period hours to assignment types. Then, the total number of hours allocated to each assignment type is summed, as shown in Exhibit 3-14.

EXHIBIT 3-13

APPLICATION OF PROPOSED METHOD
STEP 1.6 - MODIFY COEFFICIENT FOR PEAK PERIOD TRIPPERS

$$(CURTRP_p * FAC_p) \div NEWPK_p = NEWTRP_p$$

WHERE:

p	=	Peak Period (i.e., A.M. or P.M.)
FAC	=	Factor for Modifying Splits and Trippers
NEWPK	=	New Peak Period Hours
CURTRP	=	Current Coefficient for Peak Period Trippers
NEWTRP	=	New Coefficient for Peak Period Trippers

A.M. Peak:

$$(0.3468 * 417.17) \div 408.62 = 0.3541$$

P.M. Peak:

$$(0.2583 * 439.83) \div 428.66 = 0.2651$$

EXHIBIT 3-14

APPLICATION OF PROPOSED METHOD
STEP 2.1 - ALLOCATE PLATFORM HOURS TO ASSIGNMENT TYPES

	Type of Assignment				
	All Assignments	Straight Runs	Split Runs	A.M. Trippers	P.M. Trippers
Weekday					
. Early A.M.	74.27	48.05	15.62	10.60	0.00
. A.M. Peak	408.62	92.10	171.83	144.69	0.00
. Midday	563.15	275.49	232.13	20.05	35.48
. P.M. Peak	428.66	115.27	199.75	0.00	113.64
. Evening	299.55	190.10	82.15	0.00	27.30
Total	1,774.25	721.01	701.48	175.34	176.42
Saturday	897.46	695.51	0.00	201.95	
Sunday	445.93	347.27	0.00	98.66	

For weekdays, the platform hours in each time period are distributed to each of four assignment types. Straight runs, for example, account for approximately 27 percent of P.M. peak platform hours. Applying this percentage to the total P.M. peak platform hours results in 115 hours allocated to straight runs. Summing the platform hours for straight runs for all five time periods yields an estimate of 721 platform hours. Similarily, estimates of 701, 175 and 176 hours are derived for weekday split runs, A.M. and P.M. trippers, respectively. For Saturday and Sunday schedules in this example, percentages are applied to the total daily hours as opposed to time of day. This is because weekend service at the test site is characterized by relatively constant service levels throughout the day.

Step 2.2: Estimate Driver Assignments (Exhibit 3-15)

The number of drivers assigned to a particular run type (i.e., straight, split or tripper) is estimated by dividing the platform hours allocated to that run type by the average assignment length determined in Step 4 of model calibration. The resulting number of assignments is expressed as a real number, as opposed to an integer, in an attempt to increase model sensitivity to minute service changes. The results are shown in Exhibit 3-15.

Step 2.3: Allocate Tripper Pieces to to Assignment Types (Exhibit 3-16)

Trippers are allocated in one of three ways: to part-time drivers, extra board (i.e., tripper combinations), or overtime. The percentages assigned to each reflect current dispatching behavior, as determined in the calibration phase in Step 3. The calculations for assigning trippers for Scenario 9 are shown in Exhibit 3-16.

Step 2.4: Determine the Number of Tripper Combinations (Exhibit 3-17)

The previous step determined the number of tripper pieces to be assigned to the extra board; this step

EXHIBIT 3-15

APPLICATION OF PROPOSED METHOD
STEP 2.2 - ESTIMATE DRIVER ASSIGNMENTS

Day/Type of Assignment	Platform Hours	Average Length	Total Assignments
Weekday			
. Straight Run	721.01	7.82	94.20
. Split Run	701.48	7.29	96.19
. A.M. Tripper Piece	175.34	2.01	87.32
. P.M. Tripper Piece	176.42	2.18	80.96
Saturday			
. Straight Run	695.51	7.56	94.00
. Split Run	0.00	0.00	0.00
. Tripper Piece	201.95	3.61	56.00
Sunday			
. Straight Run	347.27	8.08	43.00
. Split Run	0.00	0.00	0.00
. Tripper Piece	98.66	3.79	26.00

EXHIBIT 3-16

APPLICATION OF PROPOSED METHOD
STEP 2.3 - ALLOCATE TRIPPER ASSIGNMENTS

	A.M.	P.M.
Weekday		
• Number of Tripper Pieces	87.32	80.96
• Percent Available for Part-Time Drivers	32.18%	31.25%
• Number Assigned to Part-Time Drivers	28.10	25.30
• Percent Available for Tripper Combinations	26.44%	48.75%
• Number Assigned to Tripper Combinations	23.01	39.47
• Percent Available for Overtime	41.28%	20.00%
• Number Assigned to Overtime	36.13	16.19
Saturday		
• Number of Tripper Pieces	56.00	
• Percent Available for Tripper Combinations	100.00%	
• Number Assigned to Tripper Combinations	56.00	
Sunday		
• Number of Tripper Pieces	26.00	
• Percent Available for Tripper Combinations	100.00%	
• Numbewr Assigned to Tripper Combinations	26.00	

EXHIBIT 3-17

APPLICATION OF PROPOSED METHOD
STEP 2.4 - DETERMINE NUMBER OF TRIPPER COMBINATIONS

Weekdays	
• A.M. Tripper Pieces Assigned to Combinations	23.09
• P.M. Tripper Pieces Assigned to Combinations	39.47
• Total Tripper Pieces	62.56
• Average Number of Pieces per Combination	2.21
• Number of Tripper Combinations	28.26
Saturdays	
• Tripper Pieces Assigned to Combinations	56.00
• Average Number of Pieces per Combination	2.15
• Number of Tripper Combinations	26.00
Sundays	
• Tripper Pieces Assigned to Combinations	26.00
• Average Number of Pieces per Combination	2.00
• Number of Tripper Combinations	13.00

estimates the number of drivers needed to fill these runs. Tripper pieces assigned to the extra board are generally worked in combination - - i.e., two or three separate pieces of work are filled by one driver. The number of tripper combinations required are determined by summing A.M. and P.M. tripper pieces assigned to combinations, and dividing the sum by the division's average number of pieces assigned per combination for each schedule type. The average number of pieces per assignment was determined in Step 3 of model calibration. The quotient is expressed as a real number, as shown in Exhibit 3-17.

Step 2.5: Estimate Spread Premium and Overtime Hours (Exhibit 3-18)

These premiums are estimated for each schedule type based on the number of assignments which typically incur these costs and the average number of premium hours worked (determined in model calibration in Step 4). The number of straight runs and split runs, overtime trippers, and tripper combinations were calculated in Steps 2.2, 2.3 and 2.4 of the application phase, respectively. The spread premium and overtime hours worked are totalled for each schedule type, as shown in Exhibit 3-18.

Step 3: Estimate Driver Requirements - Driver requirements are estimated by applying daily driver-to-work ratios, developed in the calibration phase in Step 5, to the work assignments developed in Steps 2.2 and 2.4 of model calibration. A salient feature of the proposed method is that it estimates weekly driver assignments based on daily requirements and a five day work week.

The driver requirements calculation for Scenario 9 is presented in Exhibit 3-19. Full-time driver assignments are the sum of straight runs, split runs and tripper combinations estimated in Steps 2.2 and 2.4. Application of driver-to-work

EXHIBIT 3-18

APPLICATION OF PROPOSED METHOD
STEP 2.5 - ESTIMATE SPREAD PREMIUM AND OVERTIME HOURS

O V E R T I M E

Type of Assignment	Weekday			Saturday			Sunday		
	No.	Average Overtime	Total	No.	Average Overtime	Total	No.	Average Overtime	Total
Straight Runs	94.20	0.07	6.59	94.00	0.04	3.67	43.00	0.17	7.48
Split Runs	96.19	0.04	3.94	—	0.00	—	—	0.00	—
Overtime Trippers	52.33	0.69	35.95	—	0.00	—	—	0.00	—
Tripper Combinations	28.26	0.00	--	26.00	0.26	6.71	13.00	0.37	4.75
Total			46.49			10.37			12.23

S P R E A D   P R E M I U M

Type of Assignment	Weekday			Saturday			Sunday		
	No.	Average Spread	Total	No.	Average Spread	Total	No.	Average Spread	Total
Split Runs	96.19	0.51	49.05	—	0.00	—	—	0.00	—
Tripper Combinations	28.26	0.41	11.67	26.00	0.13	3.28	13.00	0.17	2.25
Total			60.72			3.28			2.25

EXHIBIT 3-19

APPLICATION OF PROPOSED METHOD
STEP 3 - ESTIMATE DRIVER REQUIREMENTS

	Weekday	Saturday	Sunday
Full-Time Driver Assignments	218.64	120.00	56.00
Driver-to-Work Ratio	1.22	1.27	1.35
Daily Driver Requirements	265.87	152.88	75.66
Driver Absences	47.23	32.88	19.66

Total Drivers Needed = [(5 * 265.87) + 152.88 + 75.66] ÷ 5 = 311.57

Part-Time Driver Allowance = 311.57 * 0.10 = 31.16

Part-Time Drivers Scheduled = 28.10

ratios result in driver requirements of 266.867, 152.881 and 75.655 for weekdays, Saturdays and Sundays, respectively. Driver absences are calculated as the difference between daily driver assignments and requirements. Total full-time drivers are estimated by totalling weekly driver requirements and dividing by the five day work week.

This step is also used to review the part-time driver assignments estimated in Step 2.3 in light of contractual constraints. At the test site, the labor agreement places a ceiling of 10 percent of total full-time drivers for part-time drivers. The maximum number of part-time drivers allowed in Scenario 9 is 31.157. This compares favorably with the number scheduled - - 28.100 drivers. If scheduled drivers exceed the maximum allowance, an adjustment must be made in application Step 2.3, and all subsequent steps reapplied.

Step 4: Calculate Wages and Benefits Cost - Driver costs are now calculated by applying cost rates to the resource variables estimated in the previous two components (e.g., number of drivers and pay hours) and the driver wage parameters identified in Step 6 of the model calibration. Costs are calculated directly for four wage categories and three benefit categories. Wages are calculated for each schedule type, then summed, in order to represent each schedule's unique contribution to cost. The nine sequential steps which comprise this component are discussed below:

Step 4.1: Calculate Regular Wages for Full-Time Drivers (Exhibit 3-20)

These wages include all time by working drivers which is always paid at a straight rate. Regular wages are

EXHIBIT 3-20

APPLICATION OF PROPOSED METHOD
STEP 4.1 - CALCULATE REGULAR WAGES FOR FULL-TIME DRIVERS

$$\text{Regular Wages} = \left(\sum_{i=1}^{3} DW_i * DAYS_i \right) * DG * AW$$

WHERE:

i	=	Schedule Type (1 = Weekday, 2 = Saturday, 3 = Sunday)
DW	=	Total Drivers Working
DAYS	=	Days Schedule Operates
DG	=	Daily Guarantee
AW	=	Average Wage

Regular Wage Cost for Full-Time Drivers:

[(218.64 * 255) + (120.00 * 52) + (56.00 * 58)] * 8 * $11.00 = $5,739,159.80

the product of four variables: number of drivers working; days schedule operates; daily guarantee; and average wage rate from Step 6 of the calibration. The regular full-time wages calculated for Scenario 9 are presented in Exhibit 3-20.

Step 4.2: Calculate Regular Wages for Part-Time Drivers (Exhibit 3-21)

Regular wages for part-time drivers are calculated based on their time at work (i.e., platform plus report) rather than a guarantee. Since part-time absences are not explicitly addressed elsewhere in this model, their wages are adjusted here to account for this reduction. The formula and results for Scenario 9, are shown in Exhibit 3-21.

Step 4.3: Calculate Overtime Wages (Exhibit 3-22)

These wages reflect time worked in excess of the daily guarantee, and are normally paid at a premium rate. Typically, only full-time drivers receive overtime wages. Their value is the product of four variables: overtime hours (from Step 2.5); days schedule operates; overtime multiplier; and the average wage (from Step 6 of the calibration). The overtime wage calculated for Scenario 9 is presented in Exhibit 3-22.

Step 4.4: Calculate Spread Premium Wages (Exhibit 3-23)

These wages reflect time worked in excess of a given spread (e.g., 10.5 hours) which are not paid at overtime and which are paid exclusive of the guarantee. Typically, spread premium is paid only to full-time drivers. Spread premium wages are a product of four variables: spread premium hours (from Step 2.5); days schedule operates; spread premium multiplier; and the average wage (from calibration in Step 6), as shown in Exhibit 3-23.

EXHIBIT 3-21

APPLICATION OF PROPOSED METHOD
STEP 4.2 - CALCULATE REGULAR WAGES FOR PART-TIME DRIVERS

Part-Time Wages =

[(A.M. Trippers * (Average Platform Time + Report Time))

\+ (P.M. Trippers * Average Platform Time)]

* (1 - Part-Time Absence Rate) * Average Wage * Weekdays

Regular Wage Cost for Part-Time Drivers:

[(28.10 * (2.01 + 0.17)) + (25.30 * 2.18)] * (1 - 0.22) * 255 * $9.10 = $211,366.60

EXHIBIT 3-22

APPLICATION OF PROPOSED METHOD
STEP 4.3 - CALCULATE OVERTIME WAGES

$$\text{Overtime Wages} = \left(\sum_{i=1}^{3} OH_i * DAYS_i \right) * OM * AW$$

WHERE:

i	=	Schedule Type
OH	=	Daily Overtime Hours
DAYS	=	Days Schedule Operates
OM	=	Overtime Multiplier
AW	=	Average Wage

Overtime Wages Cost:

[(46.49 * 255) + (10.37 * 52) + (12.23 * 58)] * 1.5 * $11.00 = $216,113.36

EXHIBIT 3-23

APPLICATION OF PROPOSED METHOD
STEP 4.4 - CALCULATE SPREAD PREMIUM WAGES

$$\text{Spread Premium Wages} = \left(\sum_{i=1}^{3} SPH_i * DAYS_i \right) * SPM * AW$$

WHERE:

i	=	Schedule Type
SPH	=	Daily Spread Premium Hours
DAYS	=	Days Schedule Operates
SPM	=	Spread Premium Multiplier
AW	=	Average Wage

Spread Premium Wages Cost:

[(60.72 * 255) + (3.28 * 52) + (2.25 * 58)] * 0.5 * $11.00 = $86,788.21

Step 4.5: Calculate Show-Up Wages (Exhibit 3-24)

These wages are paid to drivers who stand by to fill vacant assignments created by unanticipated absences. Since some portion of show-up wages is included in regular wages, only that portion paid in excess of the guarantee is included here. This portion of show-up wages may be paid at a straight rate or overtime, depending on the applicable union agreement. Show-up time is estimated by expressing it as a rate (i.e., show-up hours per platform hour from calibration in Step 6) and applying it to the number of platform hours by schedule type calculated in Step 1.1. The show-up wages calculation for Scenario 9 appears in Exhibit 3-24.

Step 4.6: Calculate Paid Absence Cost (Exhibit 3-25)

Two types of paid absences are calculated in this step. First, there are those absences which vary with the number of drivers required to operate scheduled assignments. Second, there are paid holidays which are awarded to all full-time drivers. Although some drivers do not receive holiday pay due to violating some labor provision (e.g., being absent one day prior to a holiday), it is assumed that this number is insignificant.

Paid absences are estimated by adjusting daily full-time absences determined in Step 3 down to reflect only that proportion of absences which are paid (i.e., 50 percent in the example). Holiday pay is then calculated as the product of full-time drivers and the number of holidays awarded. Both categories are multiplied by the daily guarantee and average wage to yield paid leave cost, as depicted in Exhibit 3-25.

Step 4.7: Calculate Variable Benefits (Exhibit 3-26)

These benefits vary directly with wages, being calculated on a proportion basis. The sums of all wages for full-time and part-time drivers, calculated in Steps 4.1 through 4.6, are applied against their respective variable benefit rates (from Step 6 of the calibration) as shown in Exhibit 3-26.

EXHIBIT 3-24

APPLICATION OF PROPOSED METHOD
STEP 4.5 - CALCULATE SHOW-UP WAGES

$$\text{Show-Up Wages} = \left(\sum_{i=1}^{3} PH_i * DAYS_i \right) * SR * AW$$

WHERE:

i	=	Schedule Type
PH	=	Daily Platform Hours
DAYS	=	Days Schedule Operates
SR	=	Show-Up Hours Multiplier
AW	=	Average Wage

Show-Up Wages Cost:

[(1,774.25 * 255) + (897.46 * 52) + (445.93 * 58)] * 0.033 * $11.00 = $192,802.23

EXHIBIT 3-25

APPLICATION OF PROPOSED METHOD
STEP 4.6 - CALCULATE PAID ABSENCE COST

$$\text{Paid Absence Cost} = \left[\left(\left(\sum_{i=1}^{3} DA_i * DAYS_i \right) * PA \right) + \left(TD * DH \right) \right] * DG * AW$$

WHERE:

i	=	Schedule Type
DA	=	Net Driver Absences
DAYS	=	Days Schedule Operates
PA	=	Proportion of Absences Paid
TD	=	Net Weekly Drivers
DH	=	Annual Driver Holidays
DG	=	Daily Guarantee
AW	=	Average Wage

Paid Absence Cost:

[(((47.23 * 255) + (32.88 * 52) + (19.66 * 58)) * 0.5) + (311.57 * 10)] * 8 * $11.00 = $929,114.41

EXHIBIT 3-26

APPLICATION OF PROPOSED METHOD
STEP 4.7 - CALCULATE VARIABLE BENEFITS

Variable Benefits = (RM + OTW + SPW + SUW + PAW) * VBR

WHERE·

RW	=	Regular Wages
OTW	=	Overtime Wages
SPW	=	Spread Premium Wages
SUW	=	Show-Up Wages
PAW	=	Paid Absences
VBR	=	Variable Benefit Rate

Variable Benefits Cost for Full-Time Drivers:

($5,739,159.80 + $216,113.36 + $86,788.21 + $192,802.23 + $929,114.41) * 0.17 = $1,182,056.40

Variable Benefits Cost for Part-Time Drivers:

$211,366.60 * 0.07 = $14,161.56

Total Variable Benefits Cost = **$1,196,217.96**

Step 4.8: Calculate Fixed Benefits (Exhibit 3-27)

These benefits are paid as a fixed amount for each driver on staff. They can be calculated on an annual or monthly basis and pro-rated for the length of time being costed. The weekly driver total, from Step 3, is multiplied by the fixed benefit rate (from Step 6 of the calibration) for each driver type (i.e., part-time and full-time). The fixed benefit calculation for Scenario 9 of the techniques test is presented in Exhibit 3-27.

Step 4.9: Calculate Total Driver Wages and Benefits Cost (Exhibit 3-28)

Total driver wages and benefits cost is determined by summing all wage and benefits amounts calculated in Steps 4.1 through 4.8, as shown in Exhibit 3-28.

Step 5: Calculate Incremental Cost - The incremental cost of a service change is comprised of three elements: net change in driver wages and benefits; net change in non-driver, hours-related expenses; and net change in miles-related costs. The net driver wage and benefit cost is calculated as the difference between the calibrated base cost estimate and that developed for the service change. Non-driver costs are determined with a traditional cost allocation approach using unit costs developed in Step 7 of the calibration, as shown in Exhibit 3-29.

EXHIBIT 3-27

APPLICATION OF PROPOSED METHOD
STEP 4.8 - CALCULATE FIXED BENEFITS

Fixed Benefits = Total Drivers * Fixed Benefit Rate

Fixed Benefits Cost of Full-Time Drivers:

311.57 * $1,617 = $363,606.86

Fixed Benefits Cost of Part-Time Drivers:

28.10 * $300 = $8,430.00

Total Fixed Benefits Cost = $372,036.86

EXHIBIT 3-28

APPLICATION OF PROPOSED METHOD
STEP 4.9 - CALCULATE DRIVER WAGES AND BENEFITS COST

Regular Wages	=	$5,950,526.40
Overtime Wages	=	216,113.36
Spread Premium Wages	=	86,788.21
Show-Up Wages	=	192,802.23
Paid Absences	=	929,114.41
Variable Benefits	=	1,196,217.90
Fixed Benefits	=	372,036.86
Total		$8,943,599.37

EXHIBIT 3-29

APPLICATION OF PROPOSED METHOD
STEP 5 - CALCULATE INCREMENTAL COST

Marginal Cost of Driver Wages and Benfits:		
Before Service Change		$9,017,836.97
After Service Change		8,943,599.37
Incremental Cost		$ (74,236.60)
Change in Non-Driver, Hours-Related Costs:		
(17.30) Hours * $1.7589 * 255	=	$ (7,759.38)
Change in Non-Driver, Miles-Related Costs:		
(384.60) Miles * $0.9580 * 255	=	$ (93,953.93)
Total Incremental Cost:		$ (175,949.91)

CHAPTER 4
THE TECHNIQUES TEST

The techniques test had two key objectives. The first objective was to ensure that the proposed method could be understood and applied by its intended users. The Metropolitan Transit Commission (MTC) staff applied the proposed method, along with other selected models, to the hypothetical and actual service changes. The second objective was to assess the accuracy of the proposed method and several prevalent incremental costing techniques. These techniques were evaluated by their relation to a baseline cost which was estimated by the MTC.

The original intent of the techniques test entailed application of candidate models to 60 actual service changes and to evaluate model performance against actual cost impacts. Constrained resources, however, limited the test to only twelve actual and hypothetical service changes. Further, all cost estimates were compared against MTC's "best estimate" of incremental costs as it was not possible to isolate the cost impacts resulting from actual route level service changes. Because the test was quite limited in magnitude and no real incremental costs exist, the results of the test can not be assumed to be statistically valid for all circumstances. Additional testing at other systems could produce different results. The test does, however, suggest some indication of model applicability and performance.

Test Organization

Four key groups participated in the techniques test, including the Consultant, MTC staff, the review panel and UMTA staff. Each group performed a different role in executing the test. The Consultant directed all test activities and was responsible for orientation of the MTC staff, quality control in model application and evaluation of test results. The MTC staff calibrated and applied each of the models to the twelve service scenarios comprising the test. Additionally, MTC staff provided their best estimate of cost impacts for each scenario. The review panel provided direction and critiqued findings and analysis at critical points in the test. UMTA staff members also provided project guidance, and assisted in the orientation of MTC staff members to each of the cost estimation techiques.

In all, five costing techniques were calibrated and applied during the test, including:

- Proposed Method
- Modified Adelaide Model
- Peak/Base Cost Allocation Model
- Two-Variable Cost Allocation Model
- MTC's Best Estimate

When normally applied, several of these models address total operating costs (i.e., the Adelaide, Peak/Base, and Cost Allocation Models). These cost techniques were modified, where appropriate, to include only variable costs to allow meaningful comparison with estimates from the proposed method and MTC's best estimate. The specifics of these modifictions are contained in the descriptions of the models in Chapter 2.

Route changes were the basic unit of analysis during the techniques test. A summary of the twelve service scenarios utilized in the test is presented in Exhibit 4-1. Route changes encompassed a variety of time periods, including:

- Weekday - Peak Only
- Weekday - Midday Only
- Weekday - All Day
- Weekend.

The service scenarios are comprised of three basic change types - - change in running time, addition or deletion of an entire route, and addition or deletion of single trips. Changes in running time may result from any number of factors - - extending or shortening a route, changes in load factors, and changes in traffic conditions or controls. All of these can contribute to a change in driver and vehicle utilization. Additions or deletions of entire routes, or of single trips, are situations faced by transit planners in tailoring service to match new fiscal or ridership conditions. All of these conditions can contribute to changes in driver and vehicle utilization, with corresponding cost implications.

It should be noted that the magnitude of the service changes was generally quite small. Daily changes in vehicle hours range from 2.12 to 116.22 hours. This translates to a range of about 0.04 to 3.0 percent of division hours. Specifically, eight of the scenarios represent a change of less than one percent of total division hours, and four scenarios represent changes of more than one percent of service hours.

EXHIBIT 4-1

SERVICE SCENARIOS USED IN MODEL TESTING

Scenario Number	Type of Change	Description	Net Change in Daily Hours	Percent of Division Hours
1	Weekday-Peak Only	Extend an express route/MTC Express Rte. 35C	2.50	0.121
2	Weekday-Peak Only	Reduce service by half/MTC Express Rte. 35C	(10.05)	0.484
3	Weekday-Peak Only	Discontinue one A.M. and one P.M. Trip MTC Express Rte. 35LU	(2.88)	0.139
4	Weekday-Peak Only	Discontinue one A.M. and one P.M. trip MTC Local Rte. 47	(2.12)	0.102
5	Weekday-Midday Only	Discontinue midday service/MTC Local Rte. 9	(32.70)	1.576
6	Weekday-Midday Only	Reduce midday service by half/MTC Local Rte. 2	(6.67)	0.322
7	Weekday-All Day	Double midday service/MTC Local Rte. 2	22.27	1.074
8	Weekday-All Day	Discontinue weekday service/MTC Local Rte. 47	(63.35)	3.054
9	Weekday-All Day	Reduce service on express route MTC Express Rte. 52B	(15.68)	0.756
10	Weekend	Discontinue Saturday service/MTC Local Rte. 21	(116.22)	1.142
11	Weekend	Discontinue Sunday service/MTC Local Rte. 21	(79.42)	0.871
12	Weekend	Discontinue six Sunday trips/MTC Local Rte. 9	(4.03)	0.044

Evaluation of Results

The evaluation of the test results was an interpretive process based on simple statistical measures. A key consideration throughout the evaluation process was that no method provides values of "true costs" for all the service change scenarios. While the MTC's baseline cost estimate is driven by complete run cut information, the translation of driver assignments into wage and benefits costs is subject to some degree of error. This methodology projects non-driver costs using a cost allocation approach, which is also subject to some degree of inaccuracy. Nonetheless, the MTC estimates were used as representing true costs in the evaluation because it was believed to be the best estimate by virtue of its extensive information requirements and deterministic algorithms. Where other models rely on scheduling simulators (i.e., proposed method, modified adelaide model) or average costing (i.e., peak/base model, cost allocation model), the MTC baseline estimate required actual scheduling processes to be completed and actual assignments and scheduled pay hours were used to ascertain incremental costs. This model corresponds to the generic cost build-up approach discussed in Chapter 2 of this report.

The test entailed application of five cost models to a total of twelve route-level service changes. All of the service changes occurred at one transit system and within a single operating division. The sample size suggests that the test results may not reflect actual model capabilities, or be a sound representation of model performance under all circumstances.

The incremental cost estimates produced in the techniques test are shown in Exhibit 4-2. Using the baseline cost estimate as the point of reference, the annualized incremental

EXHIBIT 4-2

ANNUALIZED INCREMENTAL COST ESTIMATES

	Incremental Cost Model				
Scenario	MTC's Baseline	Proposed	Modified Adelaide	Peak/Base	Cost Allocation
1	$25,584	$15,692	$47,496	$16,870	$16,532
2	(145,652)	(93,116)	(104,096)	(96,541)	(95,193)
3	(29,902)	(30,239)	(17,019)	(29,537)	(29,092)
4	(22,019)	(22,265)	(36,809)	(20,571)	(20,271)
5	(229,310)	(267,770)	(239,678)	(271,132)	(275,828)
6	(61,597)	(71,799)	(58,023)	(51,321)	(52,285)
7	178,627	155,202	154,671	166,393	183,696
8	(780,897)	(701,155)	(785,099)	(622,610)	(661,758)
9	(209,973)	(175,949)	(154,298)	(173,694)	(173,738)
10	(233,830)	(225,595)	(234,569)	(199,980)	(203,405)
11	(178,704)	(175,187)	(200,180)	(151,820)	(154,430)
12	(4,893)	(8,983)	(4,305)	(7,438)	(7,570)

cost impacts of the twelve service changes ranged from $4,895 (Scenario 12) to $780,895 (Scenario 8). These cost estimates formed the basis for the evaluation of model performance.

The evaluation of test results focused on three primary areas of concern, including:

- Model accuracy;
- Model sensitivity; and
- Level of effort.

Model Accuracy

For the purposes of this test, the MTC baseline estimate served as the yardstick against which the other models are measured. This comparison provides some indication of relative model accuracy, based on the assumption that MTC's detailed approach to cost estimation is accurate.

Relative model accuracy was examined using three primary screens:

- Percent deviation from the MTC's baseline cost estimate;
- Ranking of model performance; and
- Magnitude of model deviation.

Percent Deviation from Baseline Cost Estimate - One method for evaluating relative model accuracy is to examine the percent difference between each model's results and the MTC's baseline estimate. This measure can be examined from several different perspectives, including: by individual test situation; size of service change; and aggregate percent deviation.

- Percent Deviation by Individual Scenario - This measure examines the percent deviation from the MTC's baseline cost estimate by individual scenario for each model. For the purposes of this test, scenarios are grouped by type of service change. The results of this analysis are shown in Exhibits 4-3 through 4-6 for weekday peak only, midday only, all day, and weekend changes, respectively. All of the models show substantial variability in their performance for peak period changes, with the modified Adelaide model experiencing the greatest overall deviation. Each of the models appears to maintain more stable performance for midday only and all day changes, as shown in Exhibits 4-5 and 4-6. The weekend changes offer a mixed bag of performance - - all models perform reasonably well on two of three changes. The models perform poorly on one scenario which entails a change of less than 1/20th of one percent of total division hours.

- Percent Deviation by Magnitude of Change - Another way to view relative model accuracy is how well each model performs in relationship to the magnitude of the service change. This relationship is illustrated in Exhibits 4-7 through 4-10 for the proposed method, modified Adelaide model, peak/base model and cost allocation model, respectively. One pre-eminent trend is evident for each model - - overall accuracy improves with increases in the magnitude of the service change. This trend is most pronounced in the proposed method and the modified Adelaide model. The trend also exists in the peak/base and cost allocation models, although to a smaller degree. While these two models show lower variability, they also exhibit greater deviation from the MTC's best estimates overall.

EXHIBIT 4-3

SUMMARY OF MODEL PERFORMANCE
WEEKDAY -- PEAK ONLY SERVICE CHANGES

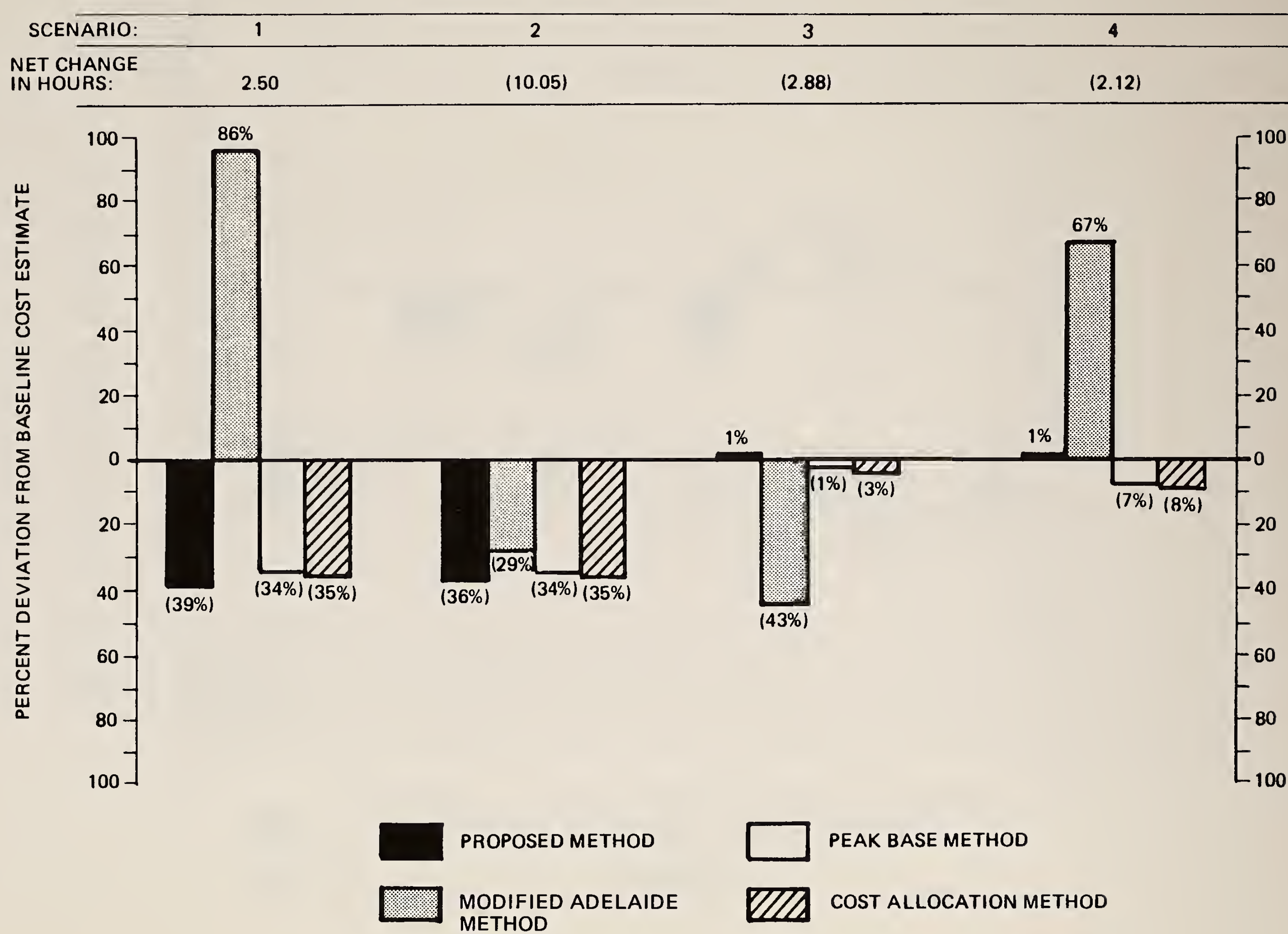


EXHIBIT 4-4

SUMMARY OF MODEL PERFORMANCE
WEEKDAY -- MIDDAY ONLY SERVICE CHANGES

SCENARIO:	5	6
NET CHANGE IN HOURS:	(32.70)	(6.67)

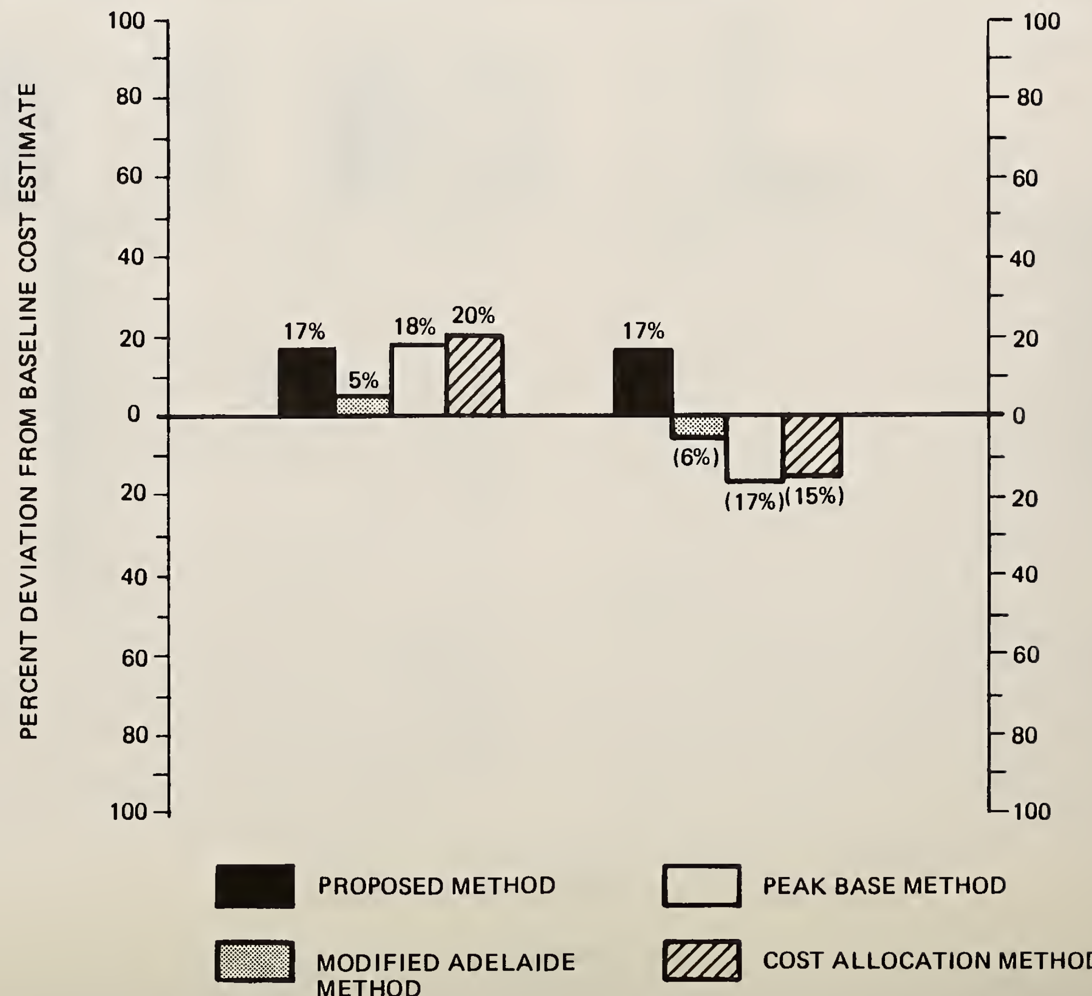


EXHIBIT 4-5

SUMMARY OF MODEL PERFORMANCE
WEEKDAY -- ALL DAY SERVICE CHANGES

SCENARIO:	7	8	9
NET CHANGE IN HOURS:	22.27	(63.35)	(15.68)

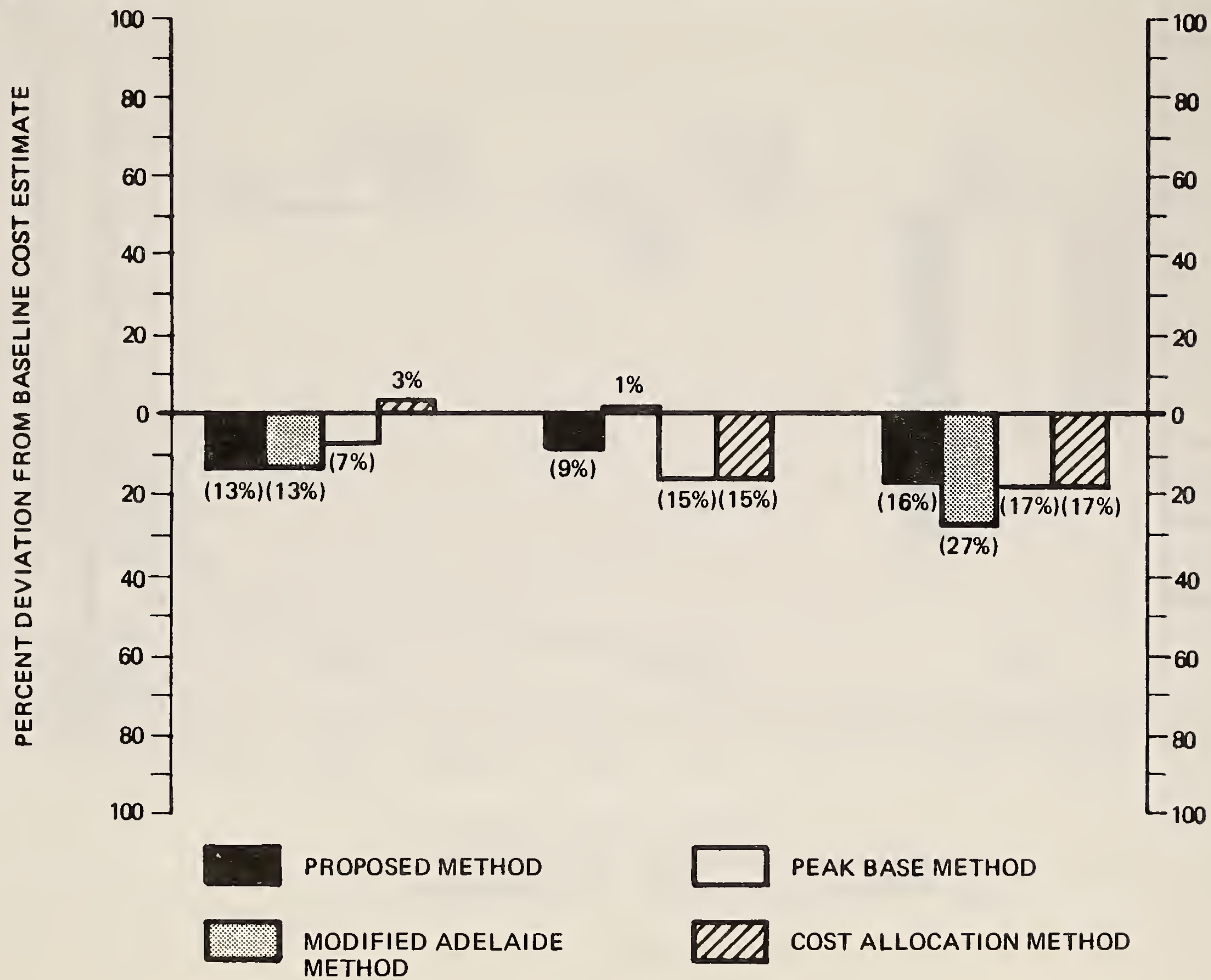


EXHIBIT 4-6

SUMMARY OF MODEL PERFORMANCE WEEKEND SERVICE CHANGES

SCENARIO:	10	11	12
NET CHANGE IN HOURS:	(116.22)	(79.42)	(4.03)

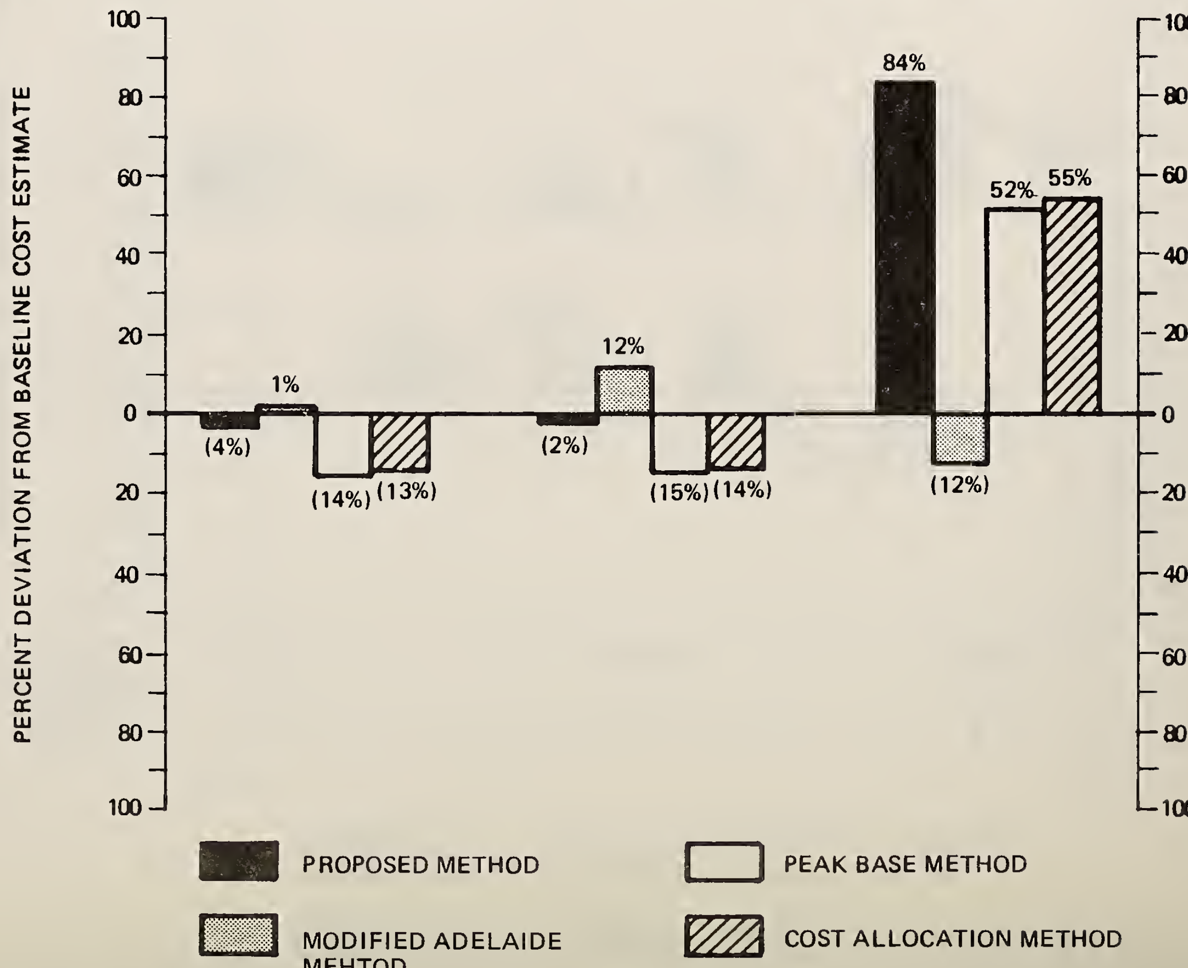


EXHIBIT 4-7

RELATIONSHIP OF MODEL ACCURACY TO MAGNITUDE OF SERVICE CHANGE
PROPOSED METHOD

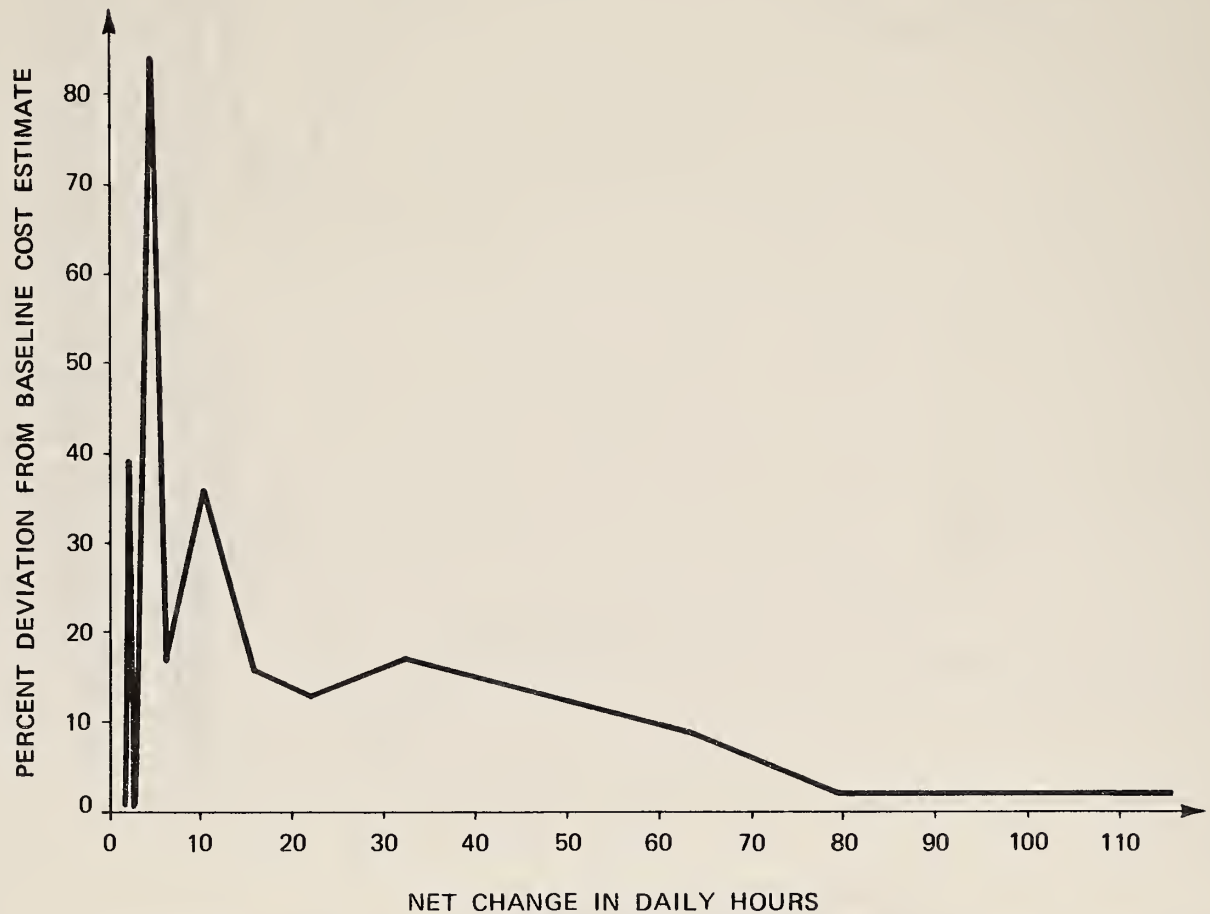


EXHIBIT 4-8

RELATIONSHIP OF MODEL ACCURACY TO MAGNITUDE OF SERVICE CHANGE
MODIFIED ADELAIDE MODEL

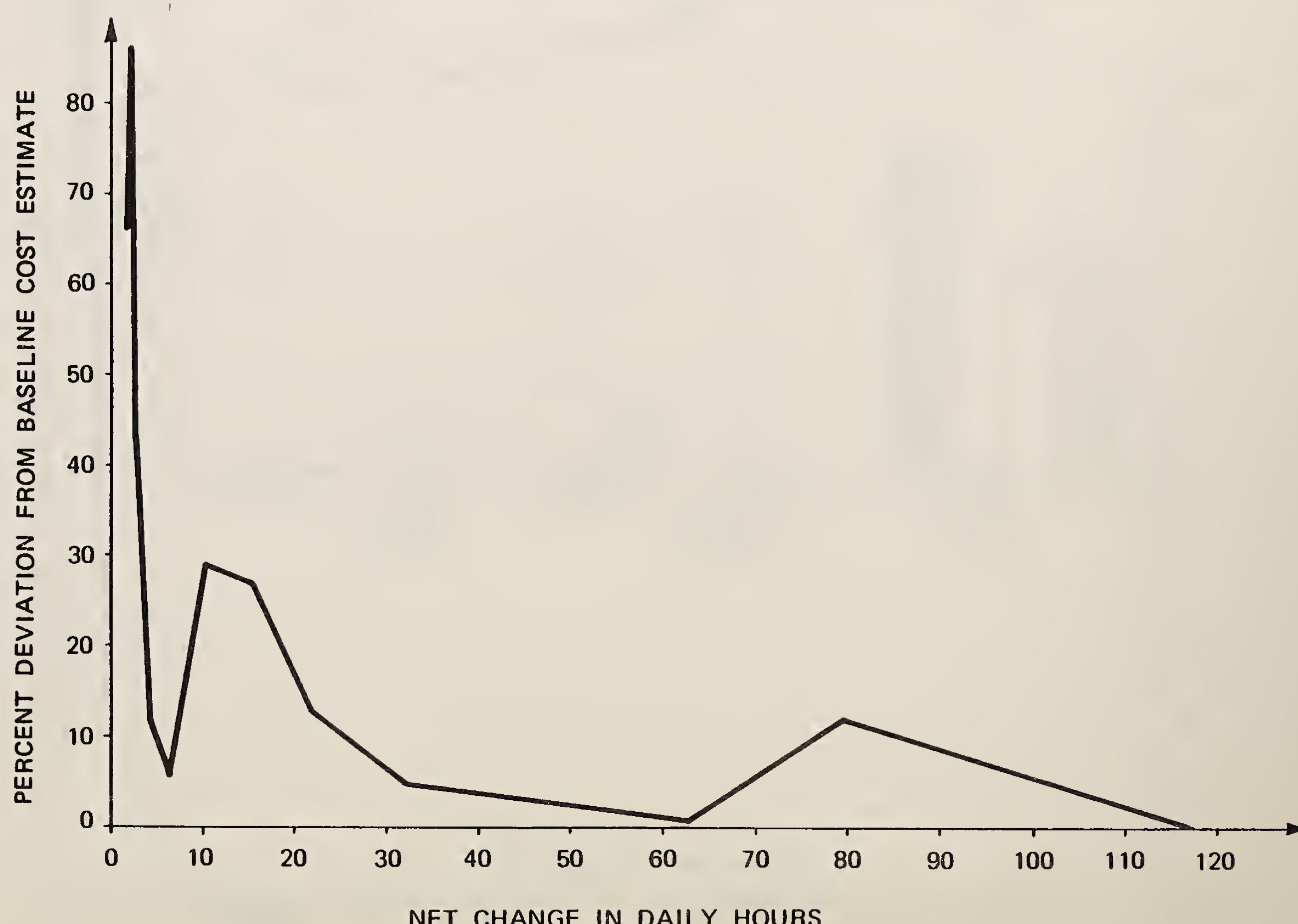


EXHIBIT 4-9

RELATIONSHIP OF MODEL ACCURACY TO MAGNITUDE OF SERVICE CHANGE
PEAK/BASE MODEL

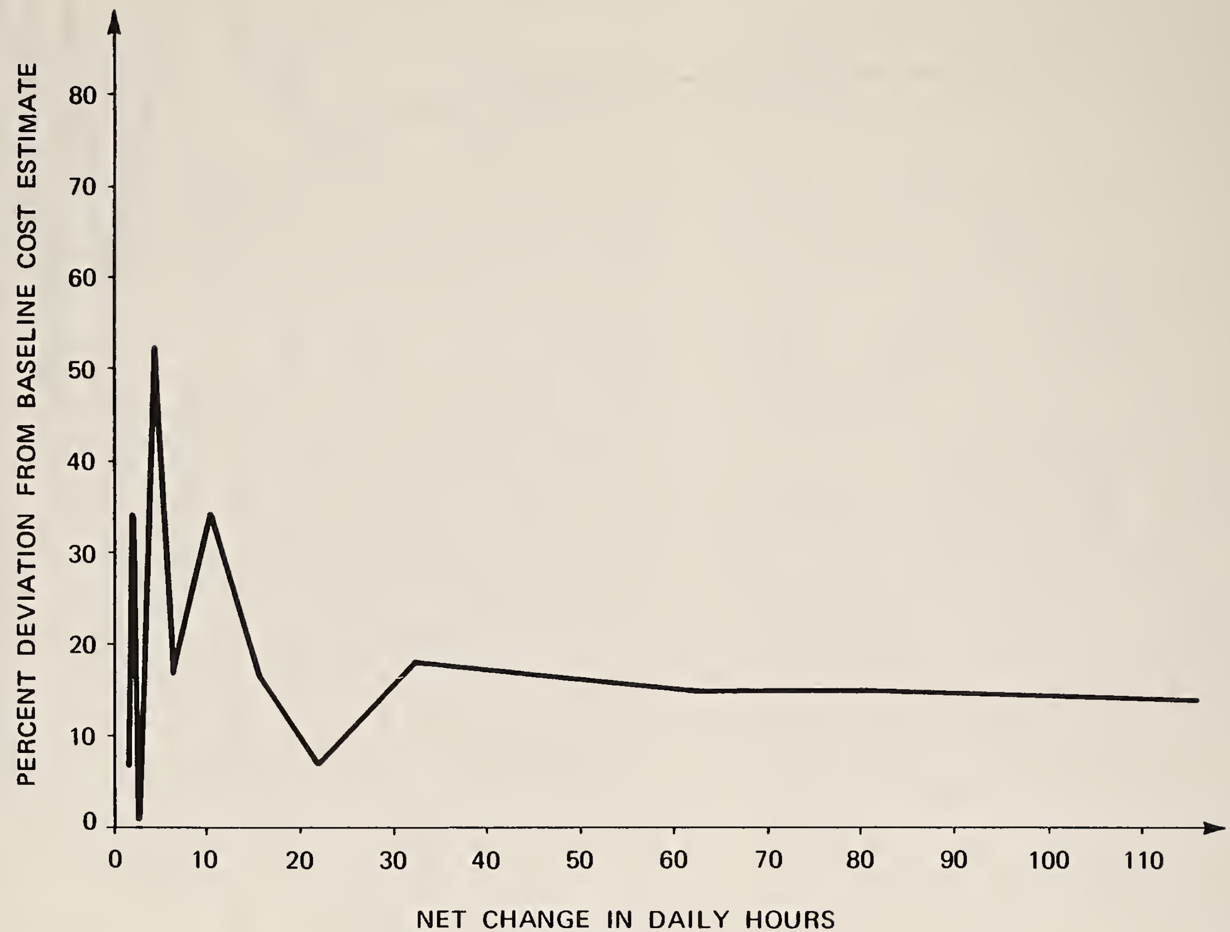
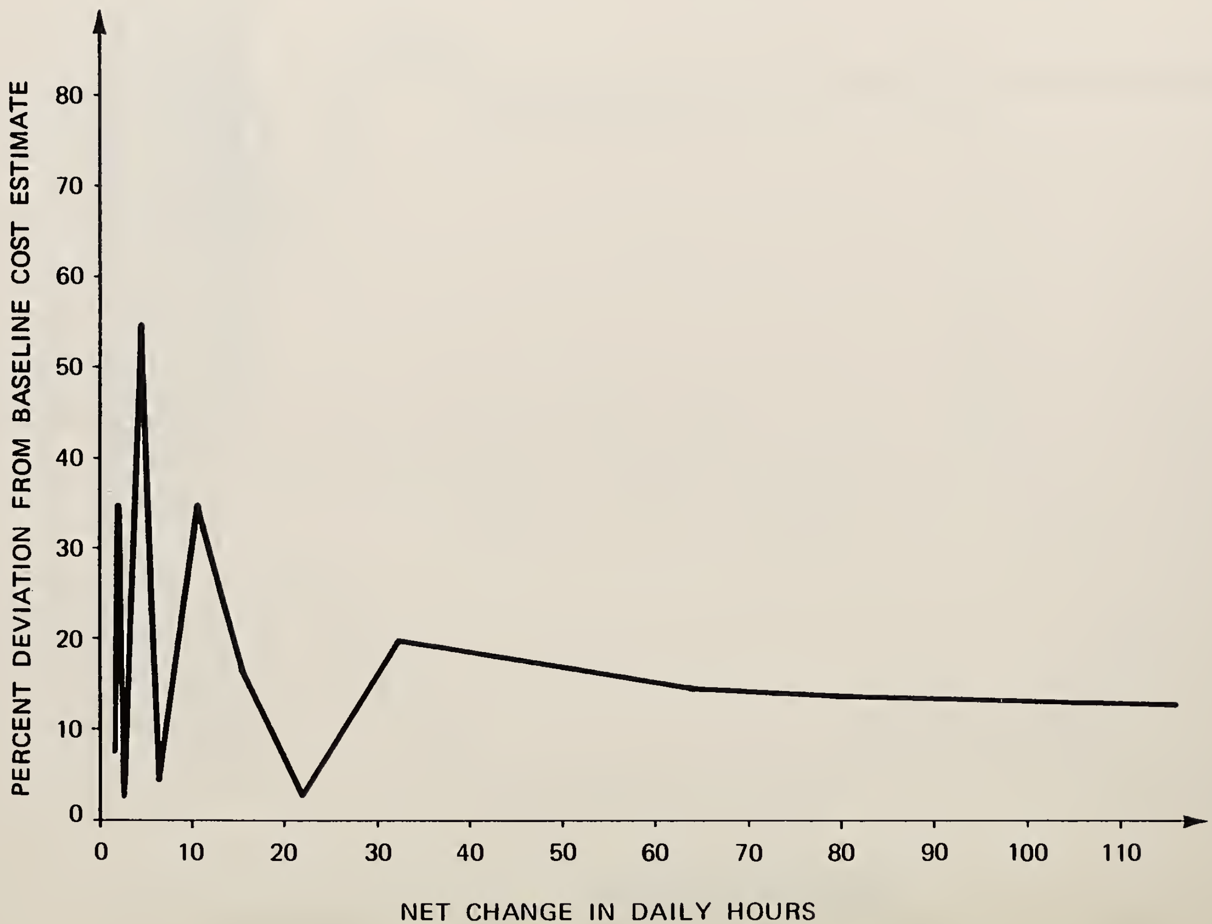


EXHIBIT 4-10

RELATIONSHIP OF MODEL ACCURACY TO MAGNITUDE OF SERVICE CHANGE
COST ALLOCATION MODEL



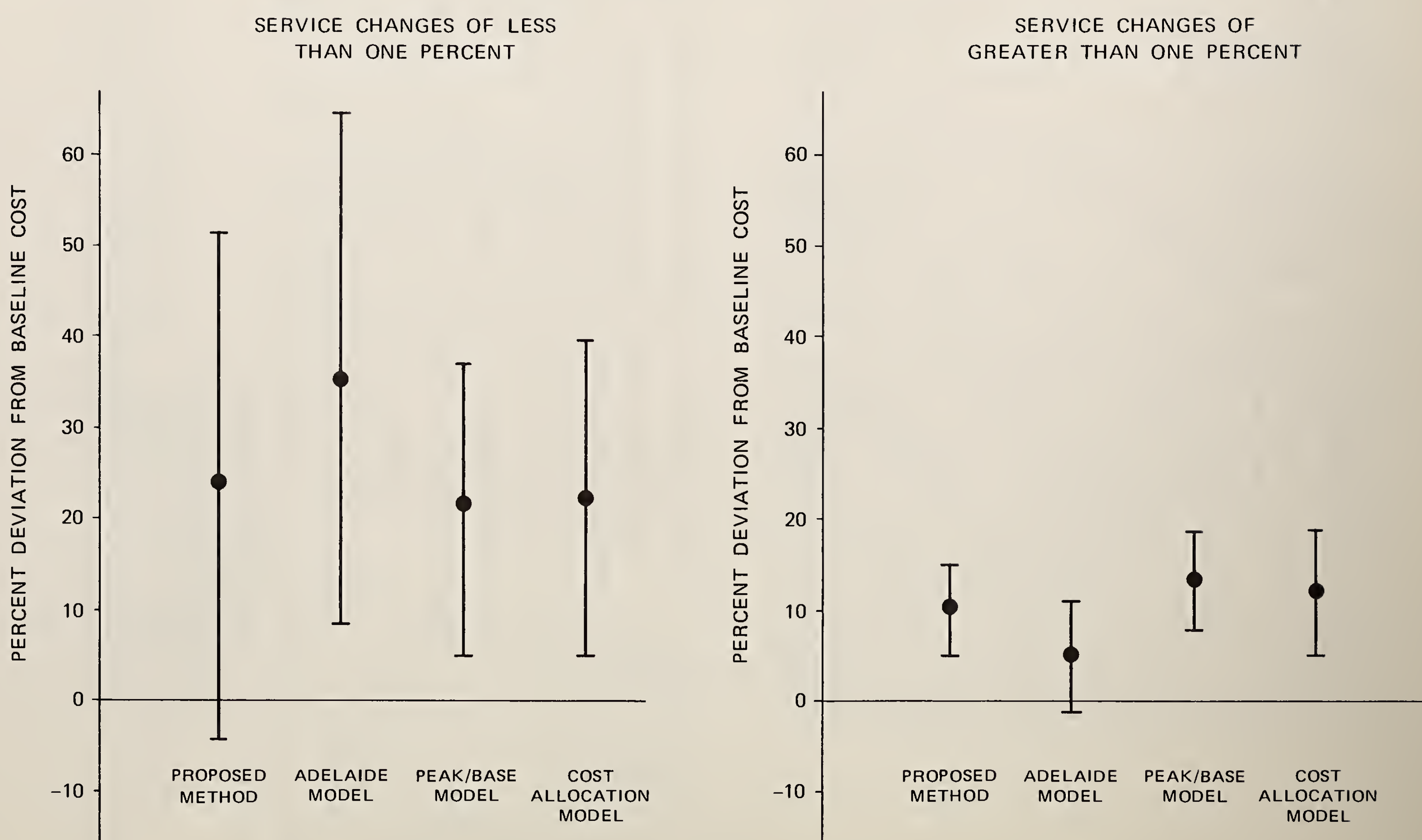
- Aggregate Percent Deviation - Still another way to examine performance is to evaluate aggregate accuracy over all twelve scenarios. This was accomplished by determining the mean and standard deviation of the percent difference from the MTC's best estimate separately for changes of less than one percent and those of greater than oen percent. The results, illustrated in Exhibit 4-11, indicate that all models have a mean deviation of more than twenty percent with a high degree of variance for the smallest changes (i.e., less than one percent of division hours). All of the models experience greatly improved performance on the larger service changes (i.e., 1 to 3 percent of division hours) both in terms of mean percent difference and standard deviation. Mean percent difference from the MTC's best estimate ranges from 5 percent (i.e., modified Adelaide model) to 14 percent (i.e., peak/base model). Model performance is also more consistent, as evidenced by standard deviations ranging from 5 percent (i.e., proposed method) to 7 percent (i.e., cost allocation model).

While each of these measures examines model accuracy from a different light, one common theme seems to prevail. All of the models tested exhibit high variability in their ability to replicate MTC's best cost estimates for minute service changes (i.e., less than 1 percent of division hours). Overall performance and consistency improve with increases in the magnitude of the service change. While the proposed method and modified Adelaide model appear highly accurate on many individual scenarios, they are also quite inaccurate on several scenarios. In comparison, the peak/base and cost allocation models tend to be less accurate overall, but also show less variability in their performance.

Ranking of Model Performance - Another method for evaluating model accuracy is to rank each model's performance for individual scenarios and to evaluate each model's overall rank

EXHIBIT 4-11

AGGREGATE PERCENT DEVIATION FROM BASELINE ESTIMATES



Note: Dot points represent mean values
Lines represent standard deviation

for the test. For the purposes of this test, the most accurate model was ranked first and the least accurate ranked fourth. The results, shown in Exhibit 4-12, indicate that on the average, the proposed method ranks highest. It is followed by the modified Adelaide, peak/base and cost allocation model, in that order.

The standard deviation of the mean rank was also calculated for comparative purposes. Again, the modified Adelaide and proposed models exhibited high variability, while the peak/base and cost allocation models remained relatively constant. The modified Adelaide's high variability is readily evidenced by its ranking for individual scenarios - - it is ranked first on 6 scenarios and is ranked last on 5 scenarios out of a field of 12 service changes.

Magnitude of Model Deviation - Yet another measure of model accuracy is the aggregate magnitude of deviation from the MTC's baseline cost estimate. This can be expressed in dollars, rather than percent, and is measured as the sum of the absolute values of the difference from MTC's best estimates. The model with the smallest total is the best performer.

The results of this measure, as shown in Exhibit 4-13, indicates that the modified Adelaide model is the best performer, with the proposed method a close second. The measure places the peak/base and cost allocation models significantly behind the front runners. Interestingly, the difference between the performance of the peak/base and cost allocation models is quite small.

EXHIBIT 4-12

RANKING OF COST MODEL PERFORMANCE

Scenario	Proposed Method	Adelaide Model	Peak/Base Model	Cost Allocation Model
1	3	4	1	2
2	4	1	2	3
3	1	4	2	3
4	1	4	2	3
5	2	1	3	4
6	3	1	4	2
7	3	4	2	1
8	2	1	3	4
9	1	4	3	2
10	2	1	4	3
11	1	2	4	3
12	4	1	2	3
Average Rank	2.22	2.33	2.67	2.75
Std. Deviation	1.14	1.50	0.98	0.87

Note: The most accurate cost model (i.e., model with smallest deviation from baseline) receives a rank of "1." The least accurate cost model receives a rank of "4."

EXHIBIT 4-13

AGGREGATE DEVIATION FROM MTC's BEST ESTIMATE

Costing Technique	Sum of Absolute Values (1)
Proposed Method	258,720
Modified Adelaide Model	211,730
Peak/Base Model	341,820
Cost Allocation Model	335,730

(1) Based on actual deviation from the MTC's best cost estimates

Model Sensitivity

The sensitivity of a model was measured by examining the amount of variation in its unit cost estimates of various service changes. It has been assumed that the unit cost (i.e., cost per hour) of a service change should be variable, reflecting the differential cost impacts of particular service characteristics (e.g., peak only service versus weekend service). When the unit costs produced by a model are relatively constant over a series of service changes, the model's sensitivity may be questioned.

Evaluation of model sensitivity is an interpretive process. The question of why one model shows greater variance than another in unit costs must be considered. This is essential because variation may be due to inaccurate cost estimates as well as sensitivity to particular conditions. In the test, this analysis was conducted by contrasting sensitivity findings with accuracy results by model.

The primary measure of model sensitivity in this test is the coefficient of variation (i.e., CV). The CV is calculated as the ratio of a model's standard deviation to its mean unit cost (i.e., cost per hour) for all the test situations. A low CV value indicates that all unit costs are grouped in a narrow band around the mean. A high CV value indicates a high degree of variance from the mean unit cost.

The results of this test, shown in Exhibit 4-14, indicate that the proposed method comes closest to replicating both the mean hourly cost and the CV produced by the MTC's baseline cost estimate. The modified Adelaide model produces the highest CV value, which exceeds the MTC's best estimate by more

EXHIBIT 4-14

MODEL SENSITIVITY
MEASURED BY THE COEFFICIENT OF VARIANCE

Model	Aggregate for 12 Scenarios		
	Mean Cost* Per Hour	Standard Deviation	Coefficient of Variance
MTC's Best Estimates	$39.4	$10.1	0.26
Proposed Method	37.2	6.2	0.17
Modified Adelaide Model	41.0	17.2	0.42
Peak/Base Model	34.7	5.2	0.15
Cost Allocation Model	34.6	5.2	0.15

* Incremental Cost

than 60 percent. A portion of this is attributable to sensitivity and the remainder is due to some inaccurate estimates -- however, it is difficult to separate the two. The peak/base and cost allocation models produced CV values only slightly lower than that of the proposed method. However, the mean unit cost estimate from these two models was significantly below that produced by MTC's baseline estimates.

Level of Effort

Another important consideration in model evaluation is the level of effort required to produce an incremental cost estimate. The level of effort needed to use a particular model falls into two categories - - calibration and application. Each model must be calibrated prior to actual use, with the level of effort proportional to the number of steps required. When applied, the level of effort is primarily a function of the data imputs required and time needed to apply the algorithms.

Model Calibration - The purpose of model calibration is to prepare the costing method for application to route change scenarios. Calibration requires three basic activities: data collection; data processing; and calculation of unit costs and coefficients. A primary source of data for each of the models included in this test is the Section 15 accounting report. Several of the test methods required additional information regarding driver assignments, which was obtained from assignment and dispatching data. This information was used to determine the relationships between shift types, platform hours, pay hours, premium hours, and other similar parameters.

Because each of the test models utilizes commonly available data for calibration, the relative level of effort required in this activity was examined using two measures:

- The number of unit costs and ratios to be calculated; and
- The relative time requirements for calibration.

Each of these measures is further discussed below.

- Calculation of Unit Costs and Ratios - Each model requires a different level of effort, measured by the number of unit costs and coefficients to be calculated during the calibration activity, as shown in Exhibit 4-15. The proposed method requires calculation of the greatest number of scheduling-related coefficients and unit costs in model calibration. The modified Adelaide model also requires a large number of calculations in model calibration, although less than the proposed method. The peak/base model only requires a few calculated ratios; and calibration of the cost allocation model consists of determining two unit costs.
- Relative Time Requirements in Model Calibration - Each of the models tested required a different level of effort as measured by the amount of time needed for calibration. The times discussed herein represent the relative level of effort experienced in the test situation, and may not be reflective of the actual time which may be required at other transit systems. Data availability, data processing capabilities, the format of existing information reports and the technical abilities of the individual(s) calibrating the models all significantly impact actual time requirements. In the techniques test, all models were calibrated in a uniform manner, so the relative time relationships should be valid.

EXHIBIT 4-15

MODEL CALIBRATION
UNIT COSTS AND COEFFICIENTS TO BE CALCULATED

PROPOSED METHOD

- % of Platform Hours Assigned to Straight Runs
  - Early A.M.
  - A.M. Peak
  - Midday
  - P.M. Peak
  - Evening

- % of Platform Hours Assigned to Split Runs
  - Early A.M.
  - A.M. Peak
  - Midday
  - P.M. Peak
  - Evening

- % of Platform Hours Assigned to A.M. Trippers
  - Early A.M.
  - A.M. Peak
  - Midday

- % of Platform Hours Assigned to P.M. Trippers
  - Midday
  - P.M. Peak
  - Evening

- Average Assignment Length
  - Straight Run
  - Split Run
  - A.M. Tripper Piece
  - P.M. Tripper Piece

- Average Spread Premium Hours by Schedule Type
  - Split Runs
  - Tripper Combinations

EXHIBIT 4-15

MODEL CALIBRATION
UNIT COSTS AND COEFFICIENTS TO BE CALCULATED
(Continued)

PROPOSED METHOD (Continued)

- % of Tripper Pieces Assigned to Run Types
  - Part-Time Drivers
  - Tripper Combinations
  - Overtime Trippers

- Average Number of Pieces per Tripper Combination
  - Weekday
  - Saturday
  - Sunday/ Holiday

- Average Overtime Hours by Schedule Type
  - Straight Runs
  - Split Runs
  - Overtime Trippers
  - Tripper Combinations

- Driver-to-Work Ratio

- Average Wage Rate
  - Full-Time Drivers
  - Part-Time Drivers

- Percent Show-Up Time Paid

- Proportion of Absences Paid

- Unit Cost per Vehicle Mile

- Unit Cost per Vehicle Hour

EXHIBIT 4-15

MODEL CALIBRATION
UNIT COSTS AND COEFFICIENTS TO BE CALCULATED
(Continued)

MODIFIED ADELAIDE MODEL

- Weighted Average of Pay to Platform Hours
  - Split Runs
  - Tripper Combinations
  - A.M. Part-Time Trippers
  - A.M. Overtime Trippers
  - P.M. Part-Time Trippers
  - P.M. Over-Time Trippers
- Average Worked Hours by Schedule Type
  - A.M. Streights
  - P.M. Straights
  - Split Runs
  - Tripper Combinations
  - A.M. Over-Time Trippers
  - P.M. Over-Time Trippers
  - A.M. Part-Time Trippers
  - P.M. Part-Time Trippers
- Average Penalty Hours by Schedule Type
  - A.M. Straights
  - P.M. Straights
  - Split Runs
  - Tripper Combinations
  - A.M. Over-Time Trippers
  - P.M. Over-Time Trippers
- Percent Stand-By Time Paid
- Unit Cost per Vehicle Mile
- Unit Cost per Vehicle Hour
- Unit Cost per Full-Time Worked Hour
- Unit Cost per Part-Time Worked Hour
- Unit Cost per Penalty Hour

PEAK / BASE MODEL

- Peak-to-Base Period Vehicle Hours
- Peak-to-Base Period Pay Hours
- Unit Cost per Vehicle Mile
- Unit Cost per Vehicle Hour

COST ALLOCATION MODEL

- Unit Cost per Vehicle Mile
- Unit Cost per Vehicle Hour

In the techniques test, the proposed method required the greatest amount of time for calibration - - about 24 working hours total. The modified Adelaide model also required a high level of effort in calibration -- about 18 hours total. The peak/base model, as calibrated at the test site, required expenditure of approximately 10 man-hours. Each of these three models required analysis of scheduling practices and stratification of pay and/or platform hours by time of day. This element accounted for the majority of the effort. Automation of these features could significantly reduce the time requirements listed above.

The remaining model, (i.e., cost allocation model) did not require analysis of scheduling practices. This greatly reduced the time requirements for model calibration. Experience in the techniques test indicated that the cost allocation model required approximately one hour to calibrate.

While the level of effort required in model calibration varies significantly, it should be noted that calibration occurs infrequently. Because calibration data is generally valid for a year, the level of effort required for model application may be of greater concern to potential users.

Model Application - The level of effort required in applying costing techniques is primarily a function of the data input needs and the time required to complete application algorithms. Each of these elements is discussed below.

- Data Requirements for Application - The two-variable cost allocation model can be applied knowing only the magnitude of the service change (i.e., net change in miles and hours). The peak/base model and proposed method require not only the scale of the change, but the span as well (i.e., time periods in which change occurs). The modified Adelaide model estimates incremental cost based on changes in headways by time of day, round-trip time, platform hours and vehicle miles. The specific data requirements for model application are listed in Exhibit 4-16.

- Relative Time Requirements in Model Application - Each of the models tested required a different level of effort as measured by time needed for application. The times discussed herein represent the relative level of effort experienced in the test situation, and may not be representative of actual requirements under all conditions. It should be noted that all models were applied manually; automation of some models may significantly improve performance. Each of the models was applied in a uniform manner to all service change scenarios, therefore, the relative relationship of time requirements should be valid.

The cost allocation and peak/base models required the lowest level of effort, with complete application averaging about 5 to 10 minutes per scenario. The proposed method required between 35 and 50 minutes for application; the major time driver being whether the change occurred on a weekday or weekend schedule. Application of the modified Adelaide model averaged 30 to 40 minutes, once the average headways and round-trip time had been determined for the five time periods.

As applied in this study, the establishment of average headways and round-trip time by time of day for before and after the service change increased expended time by 1 to 3 hours. Thus, total application time was generally 1 1/2 to 3 1/2 hours per scenario.

It should be noted that the service changes at MTC involved routes with irregular headways even during specific time periods. After testing several options for determining headways and round-trip time (i.e., including "first glance," point-in-time, integer and real numbers), it was found that using the mean for each time period, expressed as a real number, produced the most

EXHIBIT 4-16

MODEL APPLICATION
INFORMATION REQUIREMENTS BY MODEL

PROPOSED MODEL

- Net Change in Platform Hours
  - Early A.M.
  - A.M. Peak
  - Midday
  - P.M. Peak
  - Evening
- Net Change in Vehicle Hours
- Net Change in Vehicle Miles

MODIFIED ADELAIDE MODEL

- Average Round-Trip Time
  - Early Morning
  - Morning Peak
  - Day Base
  - Evening Peak
  - Night Base
- Mean Headway
  - Early Morning
  - Morning Peak
  - Day Base
  - Evening Peak
  - Night Base
- Net Change in Vehicle Miles
- Net Change in Vehicle Hours

PEAK / BASE MODEL

- Net Change in Peak Vehicle Hours
- Net Change in Base Vehicle Hours
- Net Change in Vehicle Miles

COST ALLOCATION MODEL

- Net Change in Vehicle Hours
- Net Change in Vehicle Miles

accurate results. Opting for a different approach to application of the modified Adelaide model may reduce relative time requirements significantly and sacrifice some degree of accuracy.

As indicated previously, the level of effort involved in model application may vary among transit systems. Key factors influencing the level of effort needed include data processing capabilities, and the technical capabilities of the individuals involved.

Summary

While no model exhibited superior performance throughout all analysis screens, each had specific strengths and weaknesses. Model performance is briefly summarized below.

Proposed Method - The proposed method, while not the best performer in all cases, exhibited significant strengths in the techniques' test. In regard to model accuracy, no methodology was consistently accurate for minute service changes (i.e., changes of less than one percent of total division hours). For these changes, the proposed method performs nearly as well as the less complex models (i.e., two variable and peak/base cost allocation models), and it performs significantly better than these techniques on the larger of the small service changes (i.e., one to three percent of division hours). Further, the proposed method ranks highest in overall model accuracy, demonstrating consistency in incremental cost estimating performance. Finally, the proposed method exhibits a relatively small aggregate deviation from MTC's estimates over the entire test.

The proposed method is relatively sensitive to the unique cost characteristics of a variety of service modifications, as shown by its coefficient of variance over the 12 service changes. In this measure, the proposed method comes closer than any other model to replicating the mean unit cost, standard deviation, and coefficient of variance produced by MTC's best estimates.

The proposed method requires a relatively high level of effort to calibrate and apply, as compared to the simplistic statistical techniques (i.e., two-variable and peak/base cost allocation models). The proposed method is deterministic in nature, and estimates cost impacts by examining cost elements against the independent variable driving each respective cost element. While all of the calculations are simple and mechanistic, the proposed method has a greater number of computations to complete for each application. In the techniques' test, the proposed method required between 35 and 50 minutes to apply -- automation of model processes could substantially reduce application time.

Overall, the proposed method was a strong performer in the techniques' test. While it was relatively accurate in the techniques' test, it also required a relatively high level of effort to apply. However, it is important to note that the proposed method is quite flexible and can be modified to reduce overall time requirements. In particular, the first application step could be eliminated and the net change in hours distributed to run types based on system average characteristics, rather than route-specific attributes. Further, some elements of the third and fourth steps could be compressed to reduce the overall number of calculations needed. While these modifications are expected to reduce time requirements in application, it is anticipated that some degree of accuracy would also be forfeited. The extent to which each would be impacted is difficult to ascertain based on currently available data.

Modified Adelaide Model - The Adelaide model, as modified for use in the techniques' test, exhibited several significant strengths and weaknesses. In terms of accuracy (measured against MTC's best estimates), the modified Adelaide model was the best performer in six of twelve scenarios. However, it should also be noted that the technique was the poorest performer on five of the remaining six scenarios. While the modified Adelaide was inconsistent on a disaggregate basis, it still ranked first or second on all of the aggregate measures of accuracy in the techniques' test.

The modified Adelaide model was quite sensitive to the unique characteristics of a variety of service modifications, as demonstrated by its high coefficient of variance in the techniques' test. While the modified Adelaide closely replicated the MTC's best estimate in mean hourly cost, it exceeded the baseline standard deviation by more than 70 percent. This is partly attributable to accurate sensitivity and partially the result of some inaccurate cost estimates. It is difficult to ascertain the degree to which each is reflected in the technique's high coefficient of variance.

The modified Adelaide model requires a relatively high level of effort in model calibration and application. In regard to the calibration time required, the modified Adelaide falls between the proposed method and the cost allocation models. This procedure requires about 30 to 40 minutes per scenario. It should be noted that the Adelaide model requires headway and trip length information by time of day, while all other models require only the net change in service hours and miles. In order to allow an equitable comparison with other methods, the time to generate this additional data was included. As adjusted, the modified Adelaide model required between one and one-half hours and three and one-half hours to apply -- depending on the proposed service change. It should be noted, however, that the modified Adelaide can be simplified and time requirements reduced substantially. Determination of headways and trip length can be conducted using "first glance" or "point in time" methods rather than determining the mean of each for all five time periods. This alone can reduce application times by between 30 minutes and three hours. Utilization of integers, rather than real numbers, in driver estimation should also reduce application times. While these modifications are expected to reduce the level of effort needed to apply the method, some degree of accuracy may be lost as well.

Peak/Base Model - The peak/base model, a statistical method adjusted to reflect the cost implications of peak and base period services, exhibited several interesting strengths and weaknesses in the techniques' test. As compared to the two previous methodologies, the peak/base model performed slightly better on the minute changes (i.e., less than one percent of vehicle hours), albeit performance on the more substantive changes was significantly lower. The peak/base model experienced less variability than the more complex models, even on the minute changes. In all of the aggregate measures of accuracy, the peak/base model ranks third or fourth in a field of four.

By relying on a limited number of indices and variables, model sensitivity to a variety of service changes is reduced. In the techniques' test, both the peak/base and cost allocation models achieved the lowest overall sensitivity. The peak/base model significantly underestimated the mean hourly cost and achieved a low standard deviation as compared to MTC's best estimate. However, it should be noted that the coefficient of variance was not significantly below that achieved by the proposed method.

The peak/base model is easy to use and requires relatively minor application times -- approximately five to ten minutes per scenario. Model calibration, however, still requires a significant amount of analysis of scheduling practices to develop peak and base period productivity indices. Once calibrated, the model can be applied to numerous service changes with a minimal level of effort.

Overall, the peak/base model was a good performer in the techniques' test. It appears most applicable to situations where some degree of model accuracy and sensitivity can be sacrificed for the attributes of simplicity and expediency.

<u>Cost Allocation Model</u> - The two-variable, cost allocation model exhibited performance trends similar to those of the peak/base model. As compared to the more complex techniques, the cost allocation model performed slightly better on the minute changes and did not perform as well on the more substantive measures. The model experienced less variability in performance overall, chiefly a result of its reliance on only two variables. In most of the aggregate measures of accuracy, the cost allocation model achieved the lowest level of performance.

As can be expected, the cost allocation model exhibited relatively low sensitivity to a variety of service changes. This is attributable to the fact that the two-variable model relies on system average statistics for all service periods, and does not explicitly deal with the nuances of labor and scheduling practices which vary cost by type of service and time of day.

The cost allocation model attains the highest level of performance in regard to ease of use. The model is very simple to calibrate and does not require analysis of scheduling practices and pay provisions. The model is easy to understand and apply -- application requires a mere five to ten minutes per service change.

Overall, the model was a reasonably good performer in the techniques' test. While some degree of accuracy and sensitivity in cost estimation is sacrificed, substantial benefits in ease of use are gained. The model provides a quick response tool for any route-level cost analysis project. The methodology can be calibrated, applied, and results evaluated in a very short time span.

CHAPTER 5
CONCLUSIONS

The Twin Cities test case provided only a limited basis for assessing the relative strengths and weaknesses of the four costing procedures. Because only 12 service changes were considered, the models' capabilities, with respect to a wide range of service modifications, were not explored. Also, testing at a single transit system makes it difficult to extrapolate findings to the entire industry. While the MTC is not an untypical bus system, there may be unique attributes with respect to labor provisions, system characteristics, and cost experience which preclude far-reaching conclusions. For these reasons, the findings of the current analysis should be viewed as an interim research effort which can provide pertinent guidance for future studies.

Further, the study has served a useful purpose by providing increased documentation on this complex and timely subject. The inventory of several dozen costing procedures provides a useful reference of available techniques.(1) It describes a variety of techniques and issues involved in estimating incremental bus costs associated with small-scale service changes. Also, the specification of evaluation criteria should prove useful to transit planners as they consider methods for estimating incremental bus costs. Another benefit of the current research is its documentation of the four tested methods. In particular, the Adelaide model has been modified and adapted to reflect U.S. transit industry schedule and labor practices. For this reason, the research has provided a "menu" of preferred techniques that are available for use by transit planners.

Although the techniques' test was limited in scope and a true value for incremental costs was not available, several interesting conclusions are suggested by the test results. First, none of the costing techniques appear to be accurate or consistent for extremely small service changes (i.e., less than one percent of total division hours). Each of the cost models experience high variability and substantial deviation from the MTC's baseline cost estimate for service changes of this magnitude. Second, the size of the estimated cost implications of minute service changes (i.e., less than one percent) is so small that transit properties may not wish to expend the resources necessary to estimate these costs. It may be more productive to focus service planning resources on more substantive, although still small, service changes.

While the limited testing program and subsequent evaluation results do not clearly identify a single incremental costing method as the preferred technique, key insights were realized concerning the relative strengths and weaknesses of each model. Both the proposed method and modified Adelaide model represent more sophisticated attempts to simulate the complex factors driving incremental driver wage and benefits cost. The peak/base and cost allocation models, on the other hand, utilize a statistical approach where systemwide average characteristics determine the extent to which incremental costs are impacted. The accuracy, sensitivity, and ease of use evaluation measures suggest that no single model is preferred for all situations.

The use of a particular model would be a function of the extent of the service changes and the use of the cost estimates. For example, investigation of the cost consequences of a relatively minor service change would suggest the use of the peak/base or cost allocation model. The increased sensitivity and complexity of the other procedures does not appear to increase relative model accuracy for minute bus service modifications. This may be attributable to the numerous intermediate solutions (e.g., number of trippers and drivers) possible. For more substantial service changes, the proposed and modified Adelaide models may be preferred. In cases where the cost impacts are expected to be relatively high, use of a more rigorous, and potentially more accurate evaluation tool may be warranted.

Another issue related to the selection of an incremental costing procedure is the intended use of the resulting cost estimates. For a preliminary investigation of a wide range of bus service options, the simplistic techniques may be appropriate. In this case, the resources required to apply the technique would not unduly constrain the number of service changes that could be investigated. If a relatively limited number of changes were considered for implementation, a more accurate, but more time-consuming, model may be appropriate. Such an approach is consistent with other transportation analyses in which sketch planning techniques are applied initially and then followed by more rigorous and detailed procedures.

It should be noted that automation of the more sophisticated techniques has the potential to significantly reduce the level of effort required in both calibration and application phases. In addition, automation can enhance reliability as the potential for error in completing repetitive algorithms is effectively reduced. Progress has been made on automating both the proposed method and the Adelaide model in efforts outside of this study. It is believed that these efforts represent progress in furthering bus route incremental cost estimation.

CHAPTER 5
FOOTNOTES

(1) Walter Cherwony, Greg Gleichman, and Ben Porter, Bus Route Costing Procedures: A Review, Washington, (D.C.): U.S. Government Printing Office, 1981.

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