NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

Report 16

Estimating Incremental Costs of Bus Route Service Changes

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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Administrators, engineers, and many others in the transit industry are faced with a multitude of complex problems that range between local, regional, and national in their prevalence. How they might be solved is open to a variety of approaches; however, it is an established fact that a highly effective approach to problems of widespread commonality is one is which operating agencies join cooperatively to support, both in financial and other participatory respects, systematic research that is well designed, practically oriented, and carried out by highly competent researchers. As problems grow rapidly in number and escalate in complexity, the value of an orderly, high-quality cooperative endeavor likewise escalates.

Recognizing this in light of the many needs of the transit industry at large, the Urban Mass Transportation Administration, U.S. Department of Transportation, got under way in 1980 the National Cooperative Transit Research & Development Program (NCTRP). This is an objective national program that provides a mechanism by which UMTA's principal client groups across the nation can join cooperatively in an attempt to solve near-term public transportation problems through applied research, development, test, and evaluation. The client groups thereby have a channel through which they can directly influence a portion of UMTA's annual activities in transit technology development and deployment. Although present funding of the NCTRP is entirely from UMTA's Section 6 funds, the planning leading to inception of the Program envisioned that UMTA's client groups would join ultimately in providing additional support, thereby enabling the Program to address a large number of problems each year.

The NCTRP operates by means of agreements between UMTA as the sponsor and (1) the National Research Council as the Primary Technical Contractor (PTC) responsible for administrative and technical services, (2) the American Public Transit Association, responsible for operation of a Technical Steering Group (TSG) comprised of representatives of transit operators, local government officials, State DOT officials, and officials from UMTA's Office of Technical Assistance.

Research Programs for the NCTRP are developed annually by the Technical Steering Group, which identifies key problems, ranks them in order of priority, and establishes programs of projects for UMTA approval. Once approved, they are referred to the National Research Council for acceptance and administration through the Transportation Research Board.

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The needs for transit research are many, and the National Cooperative Transit Research & Development Program is a mechanism for deriving timely solutions for transportation problems of mutual concern to many responsible groups. In doing so, the Program operates complementary to, rather than as a substitute for or duplicate of, other transit research programs.

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FOREWORD

By Staff
Transportation Research Board

This report will be of particular interest to public transit officials responsible for controlling operating costs. Three manual methods and a computerized version of one of the manual methods are presented; each is used to estimate the costs of bus route changes. Most transit agencies use very simple, one- or two-variable cost allocation methods having limited accuracy. More complex models are available that are too difficult and time-consuming to apply and, therefore, are not used by U.S. transit agencies. In view of this situation, this research focused on filling the gap between simple but inaccurate methods and the seldom used complex models. To this end, the research has developed techniques which should produce more reliable and accurate results and, because of the unique features incorporated in each method, should be used by particular transit agencies for particular applications.

NCTRP Project 40-2, "Estimating Incremental Costs of Bus-Route-Service Changes," was initiated to satisfy the need to assess and validate available or improved techniques to provide simple, but more reliable and accurate, methods for estimating the incremental costs stemming from service changes on bus routes. Building on and extending previous cost analysis studies, the research team has developed three manual procedures and one computer model. Each fills a need by providing relatively easy calibration and application procedures while offering substantial improvements in accuracy over simple cost allocation methods. Each seeks to incorporate in the model structure a sensitivity to work rules and pay provisions that affect temporal variations in incremental operating costs. Each of the three manual procedures has been tested at three diverse transit agencies by comparing "true" changes in operating costs with changes predicted by the three models for 20 different test cases representing a full spectrum of the types of changes in service made by transit agencies.

The cost estimating techniques provided in this report can assist transit agencies in many service planning and related functions. Some example applications include:

- Planning changes in service in response to changes in ridership patterns.
- Responding to petitions for changes in service.
- Reorienting service to provide feeder service to new rail lines.
- Planning modifications to service for seasonal changes in demand patterns.
- Refining the scheduling process by using the cost estimating techniques in tandem with runcutting models or manual scheduling techniques.
- Reducing service as required by cutbacks in funding for transit.
- Allocating deficits among local jurisdictions on a route-by-route basis.
- Providing cost estimates for proposed changes in union contract pay provisions and work rules.

The cost estimating methods developed in this project should be used with other related planning and budgeting tools. One important example is the use of the techniques to forecast changes in ridership and revenue in addition to operating cost changes, so that net changes in deficits can be estimated directly.

In response to the need for more reliable procedures to estimate ridership, a follow-up to Project 40-2 has been initiated. Commencing in late 1988, NCTRP Project

40-2A, "Forecasting Incremental Ridership Impacts from Bus Route Service Changes," will develop methods to predict changes in ridership and the impacts on revenues resulting from service changes. Thus, the methods of NCTRP Project 40-2, used in combination with those procedures expected to result from the research conducted under Project 40-2A, will play an important part in overall transit system performance evaluation.

CONTENTS

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The research reported herein was performed under NCTRP Project 40-2 by Sydec, Inc. and Abrams-Cherwony & Associates. The principal investigators were Dr. Harry S. Cohen and Dr. Joseph R. Stowers, Sydec, Inc. (Dr. Cohen is now at the Transportation Research Board). Walter Cherwony, P.E., Abrams-Cherwony & Associates, was co-principal investigator. Lewis Polin, Lewis Polin & Associates, served as a special consultant throughout the project. The authors wish to express their gratitude to the three transit agencies and their staffs who participated in the calibration and testing of the models: Lehigh and Northhampton Transportation Authority (LANTA), San Antonio: VIA Metropolitan Transit (VIA), Orange County Transit District (OCTD).

In addition, sincerest thanks are extended to Long Beach Transit and its staff for participating in the calibration phase of the model testing program.

ESTIMATING INCREMENTAL COSTS OF BUS ROUTE SERVICE CHANGES

SUMMARY

In the face of continuing financial pressures on and within the transit industry it is increasingly important to allocate resources in the most effective manner. Accordingly, a better understanding of the cost changes accompanying both service expansions and reductions is required.

To this end, various techniques have been developed and used by transit agencies to estimate the incremental costs that stem from service changes. The reliability, accuracy, and applicability of these techniques have been questionable, especially with respect to bus route (as opposed to systemwide) changes. A need was identified for assessing and validating available or improved techniques to provide simple, but more reliable and accurate, methods for estimating the incremental costs stemming from service changes on bus routes.

In contrast, most transit systems rely on very simple cost estimating procedures, if any. In many instances, a single unit cost factor is employed (e.g., cost per vehicle-hour). Such an approach is simple to apply and numerous service changes can be analyzed within a relatively short timeframe with little staff effort. However, the positive features of the simple unit cost approach are obtained at the expense of accuracy in most applications. Since this technique is based on systemwide costs, it lacks sensitivity and reliability over the range of service changes normally contemplated.

The objective of this research was to develop simple, reliable procedures that permit transit agencies to estimate the incremental cost of various bus route service changes in a variety of operating environments (e.g., those of differing system size, peak-base ratios, service types, and labor agreements). The procedures are applicable to expanding, curtailing, or eliminating routes, and are sensitive to differences in costs associated with different times of the day and days of the week.

This research effort builds upon and extends previous cost analysis studies. In contrast to previous studies, this research effort has placed substantially more emphasis on simplicity and ease of use, although accuracy is still regarded as a principal criterion. Another distinguishing feature of this study is that tests have been conducted at three transit agencies to quantify the strengths and weaknesses of each cost estimating procedure.

Findings

As a result of a survey of the transit industry (see Appendix A), it is clear that there is a wide disparity between methods appearing in the literature and procedures employed in the industry. All agencies responding to the survey use relatively simple cost estimating procedures. None of the agencies surveyed use models that distinguish between the cost of providing service by time of day and day of the week. However, many recognize that temporal variation in the cost of providing service can have a

substantial effect on the incremental cost of service changes, and view the lack of practical procedures to account for temporal variation as a deficiency of current methods.

Another common theme in the survey results was the need for relatively simple and quick cost estimation techniques. This finding suggests that complicated procedures with numerous variables and computation steps are unlikely to be widely adopted by the industry. In view of the present state of the art, the greatest payoff can be achieved by an incremental advancement of prevailing practice.

These conclusions from the survey are reinforced by the results of the assessment of more complex models, as reported in Appendix C. The more complex models that have been developed in previous research (e.g., the Adelaide and Booz, Allen and Hamilton models) are somewhat more accurate than the simpler cost estimating procedures available prior to this research, but they have not been used by any U. S. transit agency. They are too difficult and time-consuming to both calibrate and apply. Moreover, the modest improvement in accuracy that they might provide does not appear to warrant the additional level of effort required.

In accord with the conclusions reached as a result of the review of industry practice and the assessment of existing models, three cost estimating techniques have been developed, each of which seeks to achieve accuracy, temporal sensitivity, and ease of use. A brief description of these methods—Pay-to-Platform Ratio, Schedule-Based, and Worksheet—is given in the paragraphs that follow.

Pay-to-Platform Ratio (PPR) Method. The premise underlying the PPR method is that each type of run (straight, split, trippers, etc.) produces different hours of pay per hour of actual operation (platform-hours). Further, the types of runs and their proportion of total runs during any given hour of the day vary widely. To reflect this, a PPR value is computed by hour for typical weekdays, Saturdays, and Sundays. Another multiplier is defined, which for want of a better name, has been called the vacancy rate. The vacancy rate is the systemwide ratio of pay-hours from the payroll distribution to the pay-hours for work assignments. Two remaining statistics are computed—the average wage rate and the fringe benefit multiplier—which are self-explanatory.

The calibration of the PPR method requires estimation of the three systemwide parameters (the vacancy rate, the average wage rate, and the fringe benefit multiplier) and the PPR values for each hour. Application of the method involves estimation of changes in platform-hours for each hour of service and multiplication of these by the four multipliers.

The proposed method assumes that the service change and the resulting system will be scheduled similar to present practice. In view of the dimensions of most service changes in comparison to the present system, this assumption appears to be reasonable in most instances.

Schedule-Based Method. In the Schedule-Based method, the effects of service changes on driver costs are taken into account through the application of unit costs factors to changes in platform (vehicle) hours. Separate unit costs are defined for weekday peak periods, weekday off-peak periods, Saturdays, and Sundays and holidays.

The method is based on a set of simple assumptions about how schedulers will respond to peak and off-peak service changes. During peak periods, schedulers will handle service increases by increasing the number of split runs and trippers. The number of straight runs operated will not be affected significantly by service increases that occur only during peak periods. Then, during the off-peak period schedulers will handle service increases by increasing the number of straight runs and decreasing the number of split runs and trippers. The reduction in the number of split runs and trippers occurs because each straight run provides service in both peak and off-peak periods. Thus, some peak period by split runs and trippers can be eliminated when the number of straight runs is increased.

The four unit costs needed to apply the Schedule-Based model are calculated from the following data, which are identical to those for the PPR method except for the definition of the periods for the PPR values: average wage rate (AWR) in dollars per pay-hour; vacancy rate (VR); fringe benefit multiplier (FBM); and PPR values, based on pay-hours and platform-hours by day of the week (weekday, Saturday, and Sunday) and, for weekdays, by type of assignment (straight runs, split runs, and trippers).

Worksheet Method. In the Worksheet method, a set of worksheets are filled out in order to calibrate the model for driver costs. The items that must be estimated on the worksheets include the changes in vehicle-hours for weekdays, Saturdays, and Sundays respectively; the change in the number of vehicles operated during weekday AM and PM peak periods; and three unit costs produced by the worksheet calibration—for weekdays, weekends, and peak vehicles.

Input data required for these worksheets include breakdowns of pay-hours by category for weekdays and weekends; fringe benefits broken down by wage-based and nonwage-based; average wage rate; guarantee hours of pay per run; average report, turn-in, and travel time per run; number of vehicles operated in weekday peak periods; and vehicle-hours per weekday and weekend day.

The model provides a simple procedure for estimating the effects of bus route service changes on driver costs that is sensitive to differences in driver costs associated with different times of day (peak vs. off-peak) and days of the week (weekday vs. weekend).

Service changes are specified in terms of changes in the number of weekday vehicle-hours, changes in the number of weekend vehicle-hours, and changes in the maximum number of buses operated during the AM and PM peak periods. The cost associated with the service change is then calculated by applying incremental cost factors to changes in each of these service measures.

The model is calibrated by filling out four worksheets and two attachments. The first worksheet and the attachments list all of the data required for the calibration procedure.

Assessment of Simple Cost Models

Accuracy. Root mean squared error (RMSE) and percent root mean squared error (%RMSE) are the principal criteria used to assess the overall accuracy of the simple cost models. Use of these measures at three test sites, LANTA (Allentown, Penn.), VIA (San Antonio, Texas), and OCTD (Orange County, Cal.) yielded the following results.

At LANTA, the Schedule-Based method is the most accurate, in terms of both RMSE and %RMSE. At VIA, the Schedule-Based method is most accurate in terms of RMSE, by a slight margin over the Pay-to-Platform Ratio method. In terms of %RMSE, the Pay-to-Platform, the Schedule-Based, and the Two-Variable methods are tied for most accurate. At OCTD, the Schedule-Based method is the most accurate in terms of both RMSE and %RMSE, with the Pay-to-Platform Ratio method a close second, and the Two-Variable method a close third.

In terms of overall accuracy, the Schedule-Based method outperformed the other models. In addition to the analysis of overall accuracy, the methods were examined in terms of how well they reproduced true costs for different types of service changes (e.g., increases vs. decreases in service; large, medium, and small changes; and changes in different time periods). No simple method consistently outperformed the others for different types of changes.

Ease of Use. An important criterion in the evaluation of alternative cost estimating procedures and the likelihood of their use is the ease of using the methods. In this analysis, the ease of use is quantitatively measured in terms of time required to calibrate and apply each procedure.

The time required for each method is presented below based on the results at the test sites:

Method	Calibration (Hours)	Application (Minutes)
Worksheet	4.5	7
Schedule-Based	2.0 plus 1 min/Work Assignment	10
Pay-to-Platform Ratio	4.0 plus 4 min/Work Assignment	30

The time requirements for model application are somewhat similar to the calibration requirements. Models that have limited calibration time requirements also can be applied relatively quickly. However, the range of time values for application is considerably less than that for the calibration phase.

Summary highlights of the findings from the testing program are as follows:

- No single model performed best in terms of accuracy for all types of service change strata and test site locations.
- For the temporally sensitive models, the Schedule-Based approach is more accurate in one test site and approximately the same at the other two systems. The Worksheet method tends to apply too great a penalty to peak period service and is the least accurate of the three models.
- Overall, the results show that a temporally sensitive model offers improved accuracy over the other simpler procedures. This is less true where work rules and pay provisions have little effect on peak period costs, such as at VIA.
- The three models developed as part of the current study all provide sensitivity to the time period of the service change. Also, the models distinguish incremental cost by day of the week. This latter point represents a substantial enhancement over models in current general use.
- None of the models is onerous in terms of its ease of use. Overall, the Schedule-Based procedure appears the most attractive in terms of level of resources required for both calibrations and applications.
- In view of the foregoing discussion, the preferred approach for most applications is the Schedule-Based method. It achieves high ratings in terms of accuracy, sensitivity, and ease of use.
- For small transit agencies with relatively flat peaking profiles, the results of applying the Schedule-Based model will not differ much from the Two-Variable model and, thus, the latter may be the preferred model for such agencies because it is easier to calibrate and apply.

Recommendations for Applications

How can the recommended cost estimating techniques assist transit agencies in service planning and related functions? The answer to this question lies in several specific types of activities for which these techniques may be of assistance:

- Planning changes in service in response to changes in ridership patterns.
- Responding to petitions for changes in service.
- Reorientation of service to provide feeder service to new rail lines.

- Extensions or reorientation of routes to serve major new developments.
- Planning of modifications to service to adapt to seasonal changes in demand patterns.
- Refinements in the scheduling process by using the cost estimating techniques in tandem with runcutting models or manual scheduling techniques.
- Reductions in service required as a result of cutbacks in funding for transit.
- Allocations of deficits among local jurisdictions on a route-by-route basis.
- Provision of cost estimates for proposed changes in union contract pay provisions and work rules.

In addition to these specific types of applications, the experience of this project indicates that transit agencies can benefit from the use of improved cost estimating techniques in less tangible ways. Most transit agencies are either not using cost estimating techniques or are using simple cost allocation methods that do not effectively deal with factors that affect costs. The recommended improved techniques all deal more effectively with these factors. They all attempt to be sensitive to the manner in which drivers' compensation and work rules affect costs during different time periods.

Perhaps most importantly, because these recommended techniques will be appreciated by transit agency staff as being more accurate than techniques now in use in most agencies, they will tend to be used more frequently and for a wider variety of types of applications. This should lead to improvements in the efficiency and effectiveness of many planning, scheduling, and budgeting functions.

No single technique can be recommended for application in all transit agencies because of the variety of conditions and capabilities among agencies. Even within a single transit organization, different cost estimating techniques may be appropriate for different applications. The simple methods that have been developed and tested are intentionally diverse so that they can satisfy the needs of transit agencies having a wide range of capabilities and conditions. The most appropriate method may depend on several factors, including:

- The general compatibility of the assumptions built into each method with the work rules, pay provisions, and type of operations of the transit agency.
- The importance placed on having a very simple to apply method in terms of data and time required, which may indicate preference for the Worksheet method.
- The extent to which schedule-makers are able to optimize the planning of new service or service reductions, in the manner assumed in the Schedule-Based method.
- The importance of hourly variations in factors affecting pay-to-platform ratios, which may indicate preference for use of the PPR method.
- Computer capabilities of planning staff and availability of microcomputers, which may indicate preference for the computer program documented in Appendix E.

Computerization of cost estimating techniques may be desirable in most cases where transit agencies have computer capabilities. The exceptions would be in smaller cities where few service changes and few routes are involved and where the simplest of the recommended cost estimation techniques are known to be adequate.

Nonetheless, despite the potential benefits of computerization, the use of the improved manual techniques in a more rigorous planning process can offer substantial improvements over current practice. Computerization would simply make it easier to expand the range of application of the techniques in improving the management of transit resources.

These cost estimating techniques should be used in tandem with other related planning and budgeting tools. One important example is that the evaluation of major changes in service should include the use of techniques to forecast changes in ridership and revenue in addition to operating cost changes, so that net changes in deficits can be estimated directly.

Conclusions

It is concluded that ease of use is an important consideration in developing new and assessing existing cost estimating procedures. Any proposed model must have a simple structure and be relatively easy to calibrate and apply. This is in contrast to previous research efforts that led to complex techniques. In placing significant emphasis on ease of use, temporally sensitive cost models should receive wider acceptance and use. In contrast with present practices, this can result in much wider use of these methods in the preparation of cost estimates and more accurate forecasts.

This study has produced several new cost models that attempt to satisfy the criteria cited above. They differ in terms of the variables considered and the algorithms by which they attempt to replicate the incremental costs of service changes. For the planner, this represents a two-fold benefit. First, it provides an enhanced menu of techniques that are available and increases the likelihood that one matches the specific needs of the individual and transit agency. Second, the diversity of techniques provides greater insights into scheduling and labor issues that influence bus operating costs.

The final set of conclusions relates to the assessment of the proposed models and other previously used techniques. No single model is best for all types of service changes and operating environments. Overall, the Schedule-Based model attains the highest overall rating in accuracy, sensitivity, and ease of use. In view of this, the authors suggest that planners experiment with the different simple procedures and select the one best suited to their transit agency's unique set of circumstances. A corollary benefit of such an approach is that it may help planners gain greater insights into scheduling and labor issues.

Suggested Research

First, there is a need to upgrade present transit industry practice with respect to cost estimating as well as other planning functions. The simple procedures developed as part of the current analysis, combined with previously developed models, provide planners with a wide array of cost estimating techniques. The challenge is to encourage use of these methods as part of a rational planning framework. To achieve this, a high priority research effort is the preparation of case studies at a few selected transit systems. The case studies would document "hands-on" experience in using the cost models and their integration within the planning framework. It is also proposed that training in cost estimation techniques be initiated. This report provides all the necessary information for the development and conduct of training seminars.

A second priority research effort is an extension of the test site approach used in the current study. It is recommended that simple cost models be calibrated at several transit agencies in order to investigate further the effects of various factors on incremental costs. The unit costs and other parameters from the estimating procedures should be related to various measures that reflect the transit agency's environment. This should include measures of service characteristics and elements in the collective bargaining agreement. As part of this recommended research effort, it is also suggested that a larger number of service changes be tested to enhance the statistical validity of the results. Both the service changes and the transit agencies should be selected to cover a broad range of conditions.

Next in priority is further research on the cost consequences of increasing and decreasing service. The models tested in this study all incorporate the assumption that costs are reversible, i.e., that the incremental costs of increases and decreases are identical. However, the test case results indicate that this assumption may not be valid, perhaps because of the tendency of schedule-makers to attempt to optimize the use of manpower in the schedule for major revisions in schedules, but to use "patches" for minor revisions in schedules, thus resulting in suboptimal schedule changes. Because of this, the procedures generally overestimate cost savings with service reductions and underestimate the cost increase with service expansion. This is counter to a conservative planning approach which would seek to avoid underestimating deficits. Further research on this facet of incremental costs should focus on strategies actually used by schedule-makers for changes of various types and magnitudes. A possible product of this research might be different assumptions and separate procedures to be used in calibrating submodels for increases and decreases in service, or alternatively and perhaps preferably, recommendations should be made for improvements in the approaches used by schedule-makers.

Another recommended priority research project, which could be combined with one or more of the foregoing recommendations, is a more detailed examination of the actual use of particular resources in relation to changes in costs of service. Fine-grained analysis is likely to lead to a better understanding of the specific elements of cost increases or decreases that occur in different time periods, and thus to refinements in the models. As an example, very small changes in off-peak service may frequently involve no changes in actual driver compensation; whereas, at some threshold values, additional drivers and/or other operating personnel may be required. This may suggest the development of step functions, similar to one aspect of the new cost allocation model developed at SCRTD (described briefly in Appendix A). However, such a model should be applied within the context of temporally sensitive models, such as those proposed in this report, for the purpose of estimating the cost of bus route service changes.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT

In the face of continuing financial pressures on and within the transit industry it is increasingly important to allocate resources in the most effective manner. Accordingly, a better understanding of the cost changes accompanying both service expansions and reductions is required.

To this end, various techniques have been developed and used by transit agencies to estimate the incremental or extra transit costs that stem from either service reductions or increases. The reliability, accuracy, and applicability of these techniques have been questionable, especially with respect to bus route (as opposed to systemwide) changes. A need was identified for assessing and validating available or improved techniques to provide simple, but more reliable and accurate, methods for estimating the incremental costs stemming from service changes on bus routes.

Some transit agencies rely on a "budget" approach where the impact of a service change is estimated for each individual line item of expense. Typically, this approach requires an extensive investigation of proposed schedules and pay hours resulting from service changes. This technique has the potential of producing detailed and reliable projections of incremental costs. Such a degree of accuracy is achieved only through considerable cost and staff effort devoted to estimating the incremental costs. For this reason, this approach is used by a limited number of transit agencies. Another disadvantage of this rather cumbersome technique is that a full range of service options is not (and cannot be) explored. Because of the time and effort required to assess the cost implications of each service change alternative, the number of options is severely limited.

In contrast, most transit systems rely on very simple cost estimating procedures, if any. In many instances, a single unit cost factor is employed. The cost factor is normally computed by dividing system cost by either total vehicle-hours or vehicle-miles. The change in the transit system resource level (e.g., miles or hours) is multiplied by the unit cost to estimate incremental costs of service changes. Such an approach is simple to apply and numerous service changes can be analyzed within a relatively short timeframe with little staff effort. However, the positive features of the simple unit cost approach are obtained at the expense of accuracy in most applications. Because this technique is based on systemwide costs, it lacks sensitivity and reliability over the range of service changes normally contemplated.

In many transit agencies, cost estimating models are developed by allocating all agency costs to two or more factors, typically miles and hours of bus operation. Often a third variable is added, typically the number of peak vehicles in operation.

Although such cost allocation models may provide somewhat greater accuracy than one variable, average cost factors, transit professionals are in general agreement that they are less than satisfactory for estimating the costs of bus route service changes.

In usual practice, the application of cost allocation models fails to distinguish between variable costs and fixed costs. This approach is adequate for cost estimating for large scale, longer term changes in bus systems, such as for annual budget estimating. However, fixed costs such as management salaries and costs associated with office space and garages are not affected in the short term by smaller scale changes in bus service. Therefore, methods designed for estimating costs of bus route service changes should distinguish fixed and variable costs and omit the former from the estimates.

Cost allocation models also have the shortcoming of failing to recognize the fact that peak period unit costs are generally significantly greater than off-peak costs. Costs also vary considerably by day of the week for most systems. Since bus route service changes frequently involve different amounts of change in service for different time periods, methods used for estimating the cost of such changes should reflect actual differences in costs by time period.

The objective of this research was to develop simple, reliable procedures that permit transit agencies to estimate the incremental cost of various bus route service changes in a variety of operating environments (e.g., those of differing system size, peak-base ratios, service types, and labor agreements). These procedures should provide a means for helping to address the question: If a specific service should be changed, what is the incremental cost of the change? The procedures should identify the incremental short-run costs to transit agencies for a variety of route level changes. This should include common modifications such as changes in frequencies, alignment, and speeds. The procedures should be applicable to expanding, curtailing, or eliminating routes, and should be sensitive to differences in costs associated with different times of the day and days of the week.

RESEARCH APPROACH

This research effort builds upon and extends previous cost analysis studies, most notably a recently completed study of bus route costing procedures performed for UMTA by Booz, Allen and Hamilton, Inc. (*1*). That study produced a procedure that was found to be somewhat more accurate than methods currently used in the industry, based on testing at one transit agency. The procedure, however, is very complex and time-consuming, and has not been adopted by the industry. In contrast to that recently completed study, this research effort has placed substantially more emphasis on simplicity and ease of use, although accuracy is still regarded as a principal criterion. Another distinguishing feature of this study is that tests have been conducted at three transit agencies to quantify the strengths and weaknesses of each cost estimating procedure.

Because of the emphasis on ease of use and because of the orientation of this project toward providing methods that are likely to lead to improvements in current practice, the testing program focused on simpler models—both ones in current use and new models developed to meet the objectives of the project.

More complex methods that were tested in the previous UMTA-sponsored research project are evaluated in detail in Appendix C. No further accuracy testing of these more complex models was conducted as part of this project because of the previous testing and the fact that none of these models has ever been applied in a U.S. transit system. Based on previous research, further testing of the more complex models was not expected to lead to future use of them by transit agencies. Moreover, such testing would have required special funding by UMTA to support data preparation work at the test sites, and such funding was not made available.

This research effort was organized under eight tasks:

A. Identify and evaluate existing cost models.

B. Review and update current industry practice.

C. Develop simplified incremental cost estimation procedures.

D. Prepare interim report.

E. Develop and implement a testing method for validating the proposed procedures and comparing the results with those for existing procedures.

F. Identify planning and policy implications and develop typical applications.

G. Prepare draft final report.

H. Prepare final report.

The major activities in each of the tasks are summarized in Figure 1.

The first three tasks were carried out in parallel and were closely coordinated. The development of simplified procedures in Task C relied heavily on the Task A evaluation of existing methods and the Task B review of existing practices, needs, and capabilities of transit agencies.

The emphasis in Task C was on the development of an analytical framework that: (1) incorporates those variables that are the principal determinants of transit costs for various types of service changes; (2) reflects the difference between average costs (as might be obtained from a simple cost allocation approach) and true marginal costs; and (3) provides flexibility in terms of the resources required for calibration and application.

As shown in Figure 1, an Interim Report documented the results of Tasks A, B, and C, and also served to further structure and define the testing of procedures accomplished in Task E.

The procedures developed in Task C were tested and refined in Task E for a variety of service changes. Cost estimates pro-

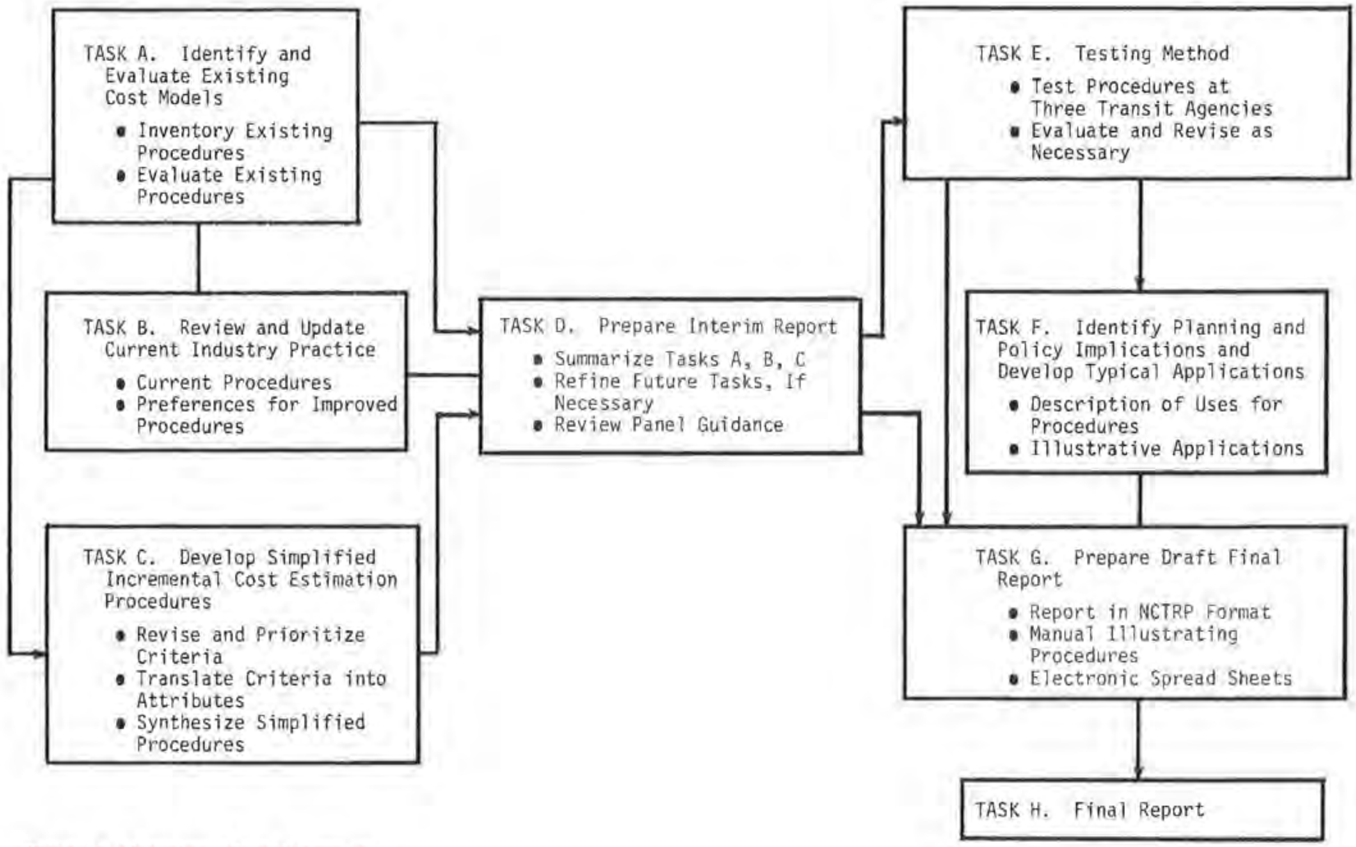


Figure 1. Overview of work program.

duced by the simple procedures were compared with results obtained after runcutting. Cost estimates were also compared with other procedures from transit industry practice. In Task F, the implications of the simplified procedures for bus service planning and policies have been described.

This final report documents the work accomplished in all of the tasks. The results of the Task B survey of transit industry practice are documented in Appendix A, taking into account comments received on the Interim Report. The development of the simple cost estimating methods and their testing (Tasks C and E) are described in detail in Appendix B. The assessment of more complex models that are not recommended for general transit industry application is contained in Appendix C. Detailed guidelines for application of suggested manual procedures are contained in Appendix D and a suggested computer-based procedure is documented in Appendix E.

CHAPTER TWO

FINDINGS

As a result of a survey of the transit industry (see Appendix A), it is clear that there is a wide disparity between methods appearing in the literature and procedures employed in the industry. All agencies responding to the survey use relatively simple cost estimating procedures. None of the agencies surveyed use models that distinguish between the cost of providing service by time of day and day of the week. However, many recognize that temporal variation in the cost of providing service can have a substantial effect on the incremental cost of service changes, and view the lack of practical procedures to account for temporal variation as a deficiency of current methods.

Another common theme in the survey results was the need for relatively simple and quick cost estimation techniques. This finding suggests complicated procedures with numerous variables and computation steps that are unlikely to be widely adopted by the industry. In view of the present state of the art, the greatest payoff can be achieved by an incremental advancement of prevailing practice.

These conclusions from the survey are reinforced by the results of the assessment of more complex models, as reported in Appendix C. The more complex models that have been developed in previous research (e.g., the Adelaide and Booz, Allen and Hamilton models) are somewhat more accurate than the simpler cost estimating procedures available prior to this research, but they have not been used by any U.S. transit agency. They are too difficult and time-consuming to both calibrate and apply. Moreover, the modest improvement in accuracy that they might provide does not appear to warrant the additional level of effort required. The tradeoffs between accuracy and other considerations, particularly ease of use, are described in detail in Appendix C for these more complex models and a simpler cost allocation model.

Cost estimating procedures can be divided into two broad categories depending on their temporal sensitivity. That is, they can be stratified in terms of whether or not they measure incremental cost consequences by time of day and day of the week. Time is an important distinction because drivers' compensation (wages and fringe benefits) comprises the single largest expenditure. Further, a complex set of work rules and collective bargaining provisions have evolved which affect the use and payment of drivers. Because of these provisions and the typical peaking and service span characteristics of bus service, temporal sensitivity is an important consideration in developing cost estimation procedures.

The first group of incremental cost models makes no attempt to reflect drivers' pay and work rule provisions. The unit cost factors are applied uniformly for all time periods and service days. The consequence of this approach is that the cost estimate for either adding or subtracting an hour of service is the same for all components of the operating span. The lack of sensitivity reflects the simplicity of the model and ease of calibration and application. In the current research effort, the two most commonly used simple models were documented and analyzed. The first procedure is termed a One-Variable model where a single unit cost per vehicle-hour is determined. The second, a Two-Variable model, consists of both vehicle-hour and vehicle-mile cost factors. Models of this type are being used in the majority of U.S. transit agencies, as reported in Appendix A. The only other type of model in common use is a cost allocation model with three factors, most commonly including the number of buses in use in the peak period plus those factors used in the Two-Variable model. However, such a three-factor cost-allocation model is not recommended for bus route change cost estimating because the third factor is associated primarily with fixed costs.

The second type of incremental cost procedure attempts to reflect the various factors that influence drivers' compensation and the cost of implementing service changes. A common feature of these models is that the costs of drivers' wages and fringe benefits are analyzed separately. Nondriver costs are estimated using a traditional cost allocation model. The procedures for accommodating drivers' compensation and temporal sensitivity vary substantially.

The introduction of somewhat more complex models involves the distinction between average unit costs, which cost allocation models use, and marginal costs, which are the unit costs of small increments of change in service. The marginal costs of off-peak service may be quite low because buses, drivers, and other resources are available at little or no extra cost, particularly for small increments of change in service. Peak-period increases in service, on the other hand, may involve payment of premiums for split runs or overtime, and may involve placing of additional buses in service and hiring a new driver.

Close examination of the costs of service changes shows that the problem is one of predicting how well schedulers and other managers utilize available capacity and resources. As will be seen in the descriptions of the new models developed in this project as well as in their evaluation, evidence points to the fact that available resources are being managed fairly efficiently for the test systems used in this study.

In accord with the conclusions reached as a result of the review of industry practice and assessment of existing models, three cost estimating techniques have been developed, each of which seeks to achieve accuracy, temporal sensitivity, and ease of use. These methods—Pay-to-Platform Ratio, Schedule-Based, and Worksheet—are contrasted in the sections that follow with the simpler models whose principal virtue is ease of use.

This chapter presents a description of the cost estimating procedures evaluated in detail during the current research effort. It also presents an assessment of the performance of each procedure for key criteria that will influence the selection and use of the methods in the transit industry. In particular, the final sections of this chapter describe the project research team's evaluation of the comparative accuracy, ease of use, and other criteria for the several models. Additional detail on these evaluations is presented in Appendix B. This chapter also presents recommendations on the use of this next generation of cost estimating models.

For reasons noted in Chapter One, the more complex models that have been tested in previous UMTA-sponsored research, but have not been used in U.S. transit agencies, were not tested in this project. However, their previous testing is documented in Appendix C, along with more detailed explanations of why they are not recommended for current practice.

DESCRIPTION OF COST MODELS

Each of the five cost models tested in this study is described in this section. A more detail description of model calibration at the test sites is presented in Appendix B. A detailed presentation of model application for a sample service change is presented in Appendix D. This section provides an overview of each model in terms of the rationale and key features as well as calibration and application steps.

One-Variable Model

This is by far the simplest method to calibrate and apply. Similar to all cost models examined, fixed expenditures are excluded. The model includes only variable expenses that would either increase or decrease with service changes. A single unit cost factor is computed by dividing total variable expenses by the vehicle-hours operated. The resulting model is merely a single vehicle-hour unit cost factor. It should be noted that the traditional cost yardstick in the transit industry was a vehicle-mile unit cost. With labor cost contributing an increasing proportion of transit expenditures and drivers being paid on an hourly basis, the use of a vehicle-hour unit cost model is more appropriate.

In applying the One-Variable model, a transit planner merely multiplies the unit cost factor by the anticipated change in vehicle-hours for the proposed service proposal. As noted previously, no attempt is made to analyze drivers' compensation separately. Further, the unit cost is assumed to be constant for all operating periods and days of the week. The cost of a vehicle-hour of service is the same for weekday peak period operations and midday weekend operations.

Two-Variable Model

To develop a Two-Variable model, each line item of variable expense is assigned to either vehicle-hours or vehicle-miles. Expenditures such as drivers' wages and fringe benefits would be assigned to vehicle-hours along with other costs that may vary with the hours of service provided. Expenses allocated to vehicle-miles would include line items such as fuel, tires, and tubes, and various maintenance costs. The costs assigned to each variable are summed and divided by the appropriate operating statistic to derive two unit cost factors—costs per vehicle-hour and per vehicle-mile. This is the model calibration process.

In application, a two-step process is employed. First, the changes in operating statistics with the service proposal under consideration are estimated. The net changes in both vehicle-hours and vehicle-miles are estimated. Second, the unit cost factors are multiplied by the appropriate operating statistic and summed. The resulting value represents the incremental cost of the service change.

This cost estimating method can be viewed in two ways. It represents an evolution of the One-Variable model because it includes a second factor, vehicle-miles, that also affects incremental costs. Another perspective is that it represents the traditional fully allocated cost model adopted for incremental cost estimating. The fixed outlays are eliminated from the analysis with the deletion of peak vehicles as an explanatory variable.

Because of the two variables used in this approach, it is sensitive to the speed of operation. However, the model is similar to the one-variable approach in that it affords no temporal sensitivity. Given the same number of vehicle-hours and vehicle-miles, a service change will have the same incremental cost estimate regardless of the time period and service day. The two-variable approach was followed for the nondriver cost component of the more sophisticated models that specifically focus on drivers' compensation. With these techniques, the nondriver cost model has the same vehicle-mile unit costs, but the vehicle-hour cost factor is reduced by eliminating expenses for drivers' wages and fringe benefits.

Pay-to-Platform Ratio (PPR) Method

The premise underlying the PPR method is that each type of run (straight, split, trippers, etc.) produces different hours of pay per hour of actual operation (platform-hours). Further, the types of runs and their proportion of total runs during any given hour of the day vary widely. To reflect this, a PPR value is computed by hour for typical weekdays, Saturdays, and Sundays. Another multiplier is defined, which for want of a better name, has been called the vacancy rate. The vacancy rate is the systemwide ratio of pay-hours from the payroll distribution to the pay-hours for work assignments. Two remaining statistics are computed—the average wage rate and the fringe benefit multiplier—which are self-explanatory.

The calibration of the PPR method requires estimation of the three systemwide parameters (the vacancy rate, the average wage rate, and the fringe benefit multiplier) and the PPR values for each hour. Application of the method involves estimation of changes in platform-hours for each hour of service and multiplication of these by the four multipliers.

In mathematical terms, the change in driver cost for a given service change is calculated as :

$$D = AWR * VR * FMB * (PPR_i * PH_i)$$

where: D is the predicted change in driver cost for the service change under consideration; AWR is the average wage rate; VR is the vacancy rate, i.e., the ratio of systemwide pay-hours from the payroll distribution to the pay-hours for the work assignments; FBM is a multiplier used to account for fringe benefits; PPR_i is the ratio of pay-hours to platform-hours for existing service during hour i (separate values of PPR_i are developed for each hour during which service is provided for a typical weekday, Saturday, and Sunday); and PH_i is the change in platform (vehicle) hours for hour i associated with the service change under consideration.

To simplify the application of the model, the quantity $AWR * VR * FBM * PPR_i$ can be calculated for each hour during calibration. In the current analysis, the preferred approach was to compute the value of the summation term because it represents the change in pay-hours for the proposed change.

The PPR method is a new method developed as part of this project. Other methods developed recently have somewhat similar characteristics. In an unpublished paper by Anne Herzenberg, driver wages per platform hour are calculated for individual runs and averaged over one-half hour time intervals (*2*). In a procedure presented in a recent UMTA handbook, ratios of pay-hours to platform-hours are calculated for individual runs, and then a weighted average ratio is calculated, based on the number of platform-hours in the time period under consideration (*3*). This weighted average pay-to-platform ratio is then adjusted to include pay-hours to the extraboard during the subject time period, and used together with wage and fringe benefit rates to calculate driver cost.

The proposed method assumes that the service change and the resulting system will be scheduled similar to present practice. In view of the dimensions of most service changes in comparison to the present system, this assumption appears to be reasonable in most instances. Alternative approaches would be to assume a schedule "patch" or "opportunity." The differences can best be understood with an example in which increased service would be provided during the peak period with an additional bus. With a schedule "patch," a driver would be added which may not represent a cost-effective solution. Under the "opportunities" approach, an existing extraboard driver would be used with little or no increased driver cost. By assuming that the present schedule practices will be maintained, the methodology avoids both extreme approaches.

Model Calibration

Calibration of the PPR method involves quantifying four factors or set of factors: (1) average wage rates (AWR), (2) pay-hours to platform-hours ratio (PPR), (3) vacancy rate (VR), and (4) fringe benefit multiplier (FBM).

The initial step is the development of wage rates that can be used in conjunction with pay-hours to determine drivers' pay. Since all premium and penalty payments will be incorporated into the PPR as equivalent straight pay-hours, only two wage rates need to be considered to reflect the type of driver—full time and part time. At most transit systems, the base wage rate for drivers varies by length of service (i.e., seniority). At transit systems that do not use part-time drivers or where the base hourly pay is the same for all drivers, only a single average wage rate would be established based on payroll and personnel data for both categories of drivers. Where there is a substantial difference in wage rate by driver category, a simple approach is to compute the average wage rate for full-time drivers and compute PPR values in terms of equivalent full-time driver pay-hours.

The next step in the process is the development of pay-hour to platform-hour ratios by time of day and day of week. This phase of the calibration attempts to measure the different types of assignments and the average pay for these types of assignments. For a typical peaking situation there are different distributions for pay-hours and platform-hours. Platform-hours, which includes deadhead, revenue, and layover time, is merely the vehicle in-service profile. This distribution is based on vehicle pull-out and pull-in data. Within each hour or time period, the number and proportion of driver assignment by type varies. During peak periods, service is typically provided by straight runs, splits, and trippers. Foremost of the day outside the peaks, service is provided primarily by straight runs with some split assignments. As noted previously, the number of driver assignments varies to respond to demand for service. Also, the prevailing labor agreement provisions and scheduling practices establish the types of assignments by hour or time period.

Since the composition of assignment types differs by hour, the PPR values vary considerably by the time of day and day of week. Average PPR values are computed by driver assignment type and then summed to arrive at a systemwide average. Averages are computed for each hour of the operating service days—weekday, Saturday, and Sunday. An attractive feature of this approach is that the user does not have to define the start, end, or duration of the peak period.

Each driver run is examined in terms of both pay-hours and platform-hours. This ratio for the entire run is assigned to all hours between pull-out and pull-in times. Typically, the PPR would include report time, overtime, spread premium, and night differentials, to cite only a few. All pay-hours would be specified in terms of equivalent straight pay time. For example, 40 min of overtime at time-and-a-half would be computed as one hour of straight time.

The next step in the process is to quantify the vacancy rate, which is the ratio of pay-hours from the payroll distribution to the pay-hours for the work assignments. All hours covered by fringe benefits are excluded from the analysis, including sick leave, holidays, vacation, etc. Absenteeism not covered by fringe benefits, as well as all other unproductive pay-hours, are included in the calculation of the vacancy rate.

The concluding step is to estimate the fringe benefit multiplier. From the previous analysis, the total wages paid will be determined. This amount is compared to fringe benefits to compute the fringe benefit multiplier. For simplicity, no distinction is made between either fixed or variable benefits. While some benefits represent a fixed amount for each driver and others are a function of wages, only a single ratio is used.

Model Application

After establishing the various measures during the calibration phase, the model can be applied to service changes. Incremental costs are estimated as follows:

1. Determine platform-hours for the service change by time of day and day of week. This should reflect the number of vehicles in service and span of the change.
2. Apply PPR values for each hour and day covered by the change to compute pay-hours for the assigned work.
3. Multiply pay-hours by the vacancy rate to reflect standby and nonoperating time.
4. Multiply the total number of pay-hours from Step 3 by the average wage rate.
5. Apply fringe benefit multiplier from Step 4 to determine total driver compensation.

The foregoing steps are relatively few and straightforward and satisfy the criteria established. The procedure can accommodate situations where there is some knowledge of how the service change will be scheduled. For example, if it is known that a peak-period service is to be operated by split runs, the PPR values for that type of assignment would be used. These values would be obtained during calibration as part of the accumulation of platform-hours and pay-hours. The other indices (vacancy rates and fringe benefit multiplier) would be applied without modifications. Without this information on scheduling of the service change—which is the most common situation—the systemwide measures by hours and time of day should be used.

Schedule-Based Method

In the Schedule-Based method, the effects of service changes on driver costs are taken into account through the application of unit cost factors to changes in platform (vehicle) hours. Separate unit costs are defined for weekday peak periods, weekday off-peak periods, Saturdays, and Sundays and holidays. (It is noted that separate unit costs should also be developed for Saturday peak and off-peak periods if a high peak-to-base ratio occurs on Saturday, as is often the case for larger transit systems and for some moderate size systems in older eastern cities. Sunday and holiday peak-to-base ratios might also be high enough to warrant the development of separate unit cost factors in a few large transit systems.)

The method is based on a set of simple assumptions about how schedulers will respond to peak and off-peak service changes:

- Schedulers will handle service increases during peak periods by increasing the number of split runs and trippers. The number of straight runs operated will not be affected significantly by service increases that occur only during peak periods.

• Schedulers will handle service increases during the off-peak period by increasing the number of straight runs and decreasing the number of split runs and trippers. The reduction in the number of split runs and trippers occurs because each straight run provides service in both peak and off-peak periods. Thus, some peak period service by split runs and trippers can be eliminated when the number of straight runs is increased.

These assumptions are similar to the assumptions that underlie the Adelaide model and the cost estimating method currently being used by the Chicago Transit Authority.

The four unit costs needed to apply the Schedule-Based model are calculated form the following data: average wage rate (AWR) in dollars per pay-hour; vacancy rate (VR); fringe benefit multiplier (FBM); and pay-hours and platform-hours by day of the week (weekday, Saturday, and Sunday) and, for weekdays, type of assignment (straight runs, split runs, and trippers).

The first three items are estimated in the same way as for the PPR method. However, in the actual calibration process it is not necessary to estimate these three parameters separately because only the product of the three is needed for the application. This product is the fully loaded drivers' compensation per platform-hour.

Figure 2 shows the equations used to calculate unit costs for the driver-cost component of the Schedule-Based model.

The peak period unit cost (C_{pp} in Figure 2) is based on the pay-to-platform ratio (PPR) for split runs and trippers, since it is assumed that the number of straight runs will not be affected significantly by peak period only service increases.

The off-peak unit cost (C_{op} in Figure 2) is based on two times the PPR for straight runs minus the PPR for split runs and trippers. This is consistent with the assumption that service increases during the off-peak will result in an increase in the number of straight runs and a decrease in the number of split runs and trippers.

$C_{pp} = AWR \times VR \times FBM \times P_1$

$C_{op} = AWR \times VR \times FMB \times (2 P_2 - P_1)$

$C_{Sat} = AWR \times VR \times FBM \times P_3$

$C_{Sun} = AWR \times VR \times FBM \times P_4$

where

C_{pp} is the unit cost per weekday peak period platform hour.

C_{op} is the unit cost per weekday off-peak platform hour.

C_{Sat} is the unit cost per platform hour on Saturday.

C_{Sun} is the unit cost per platform hour on Sunday.

P_1 is the pay-to-platform ratio for split runs and trippers.

P_2 is the pay-to-platform ratio for all straight runs.

P_3 is the pay-to-platform ratio for all Saturday runs.

P_4 is the pay-to-platform ratio for all types of Sunday runs.

AWR is the average wage rate.

VR is the vacancy rate.

FBM is the fringe benefit multiplier.

Figure 2. Calibration equations for the schedule-based model.

Unit costs for Saturdays and Sundays (C_{Sat} and C_{Sun} in Figure 2) are based on PPR for all runs operated on those days.

With the Schedule-Based method, the change in pay-hours for a given service change can be less than the change in platform-hours. Figure 3 illustrates how this can occur.

The top part of the figure shows the calculation of pay-hours

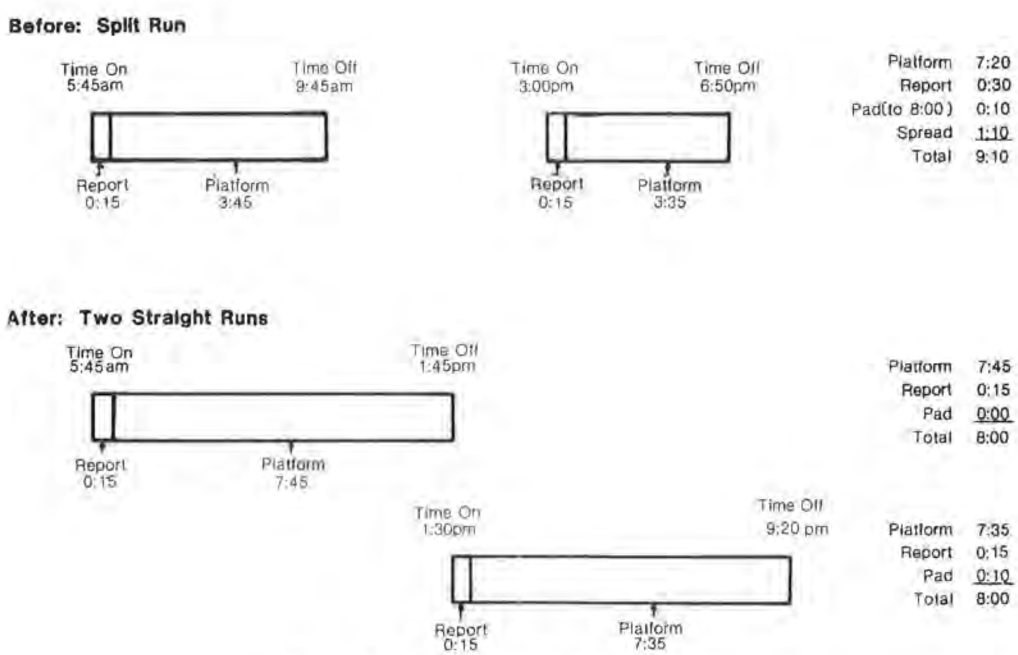


Figure 3. Example of off-peak service increase.

for a split run which provides 3:45 hours of platform time during the AM peak and 3:35 hours during the PM peak. If midday and evening services are increased, this split run might be replaced by two straight runs. The bottom part of the figure shows the calculation of pay-hours for these straights. Note that in replacing the split run by the two straight runs, 8:00 platform-hours have been added but only 6:50 pay-hours have been added.

Worksheet Method

The Worksheet method reduces the following analytical steps to an easy-to-follow sequence of simple calculations on four worksheets plus two attachments (see Appendix B):

- Split the various categories of wages paid for an audit period among weekdays, Saturdays, and Sundays.
- Split wages paid for full-time drivers from wages paid for part-time drivers.
- Allocate fringe benefits among weekdays, Saturdays, and Sundays (separately for wage-based and nonwage-based fringe benefits).
- Calculate total weekday, Saturday, and Sunday driver-related costs for the audit period.
- Calculate vehicle-hours and total driver-related cost for a straight run at the minimum guarantee.
- Calculate marginal costs per peak vehicle and per vehicle-hour for weekdays and weekends.

This sequence of calculations is necessary to provide data in the form needed for the model, which assumes that schedulers will handle increases in off-peak service by reducing make-up time on existing straight runs and by replacing some split runs and trippers with straight runs at the minimum guarantee. Other assumptions are built into the model as described below.

The worksheets are designed to calibrate the following model for driver costs:

$$D = C_{PV} * PV + C_{WD} * VH_{WD} + C_{WE} * VH_{WE}$$

where: D is the predicted change in driver cost for the service change under consideration; VH_{WD} and VH_{WE} are the changes in vehicle-hours for weekdays, Saturdays, and Sundays respectively; PV is the change in the number of vehicles operated during weekday AM and PM peak periods; and C_{WD}, C_{WE}, and C_{PV} are the three unit costs produced by the Worksheet calibration.

The model provides a simple procedure for estimating the effects of bus route service changes on driver costs that is sensitive to differences in driver costs associated with different times of day (peak vs. off-peak) and days of the week (weekday vs. weekend).

Service changes are specified in terms of changes in the number of weekday vehicle-hours, changes in the number of weekend vehicle-hours, and changes in the maximum number of buses operated during the AM and PM peak periods. The cost associated with the service change is then calculated by applying incremental cost factors to changes in each of these service measures. The cost factors are developed through a calibration procedure that might be performed once a year, or whenever driver wage rates and pay provisions are changed significantly.

The model is calibrated by filling out four worksheets and two attachments. The first worksheet and the attachments list all of the data required for the calibration procedure.

Data Requirements

Incremental costs for the Worksheet method are calculated using cost data and operating statistics for an "audit" period of approximately 4 weeks in length, although longer periods could be used. Driver's wages and premiums for weekdays and weekends during the audit period are readily available from driver payroll records. Audit period wages and premiums must be broken down in several categories and split between weekdays and weekends on the first attachment to the worksheet.

Fringe benefits are divided into two general categories for the purpose of calculating incremental costs: (1) wage-based fringe benefits, such as FICA, which are directly related to the amount of total pay earned by full-time and part-time drivers; and (2) nonwage-based fringe benefits, such as vacation time and paid holidays, for which the cost to the transit agency is determined primarily by the number of full-time drivers. Data on fringe benefits are usually available only on an annual basis. Fringe benefits for the audit period are therefore estimated based on fringe benefit multipliers that are developed from annual data in the second of the two attachments to the worksheets.

The average base wage rate for full-time drivers in effect during the audit period is obtained based on the ratio of total wages to total pay-hours for full-time drivers. Alternatively, the wage rate can be estimated by counting the number of full-time drivers in each wage class (wage classes are usually based on seniority) and then calculating a weighted average of the base wage rate for each class. Minimum guarantee hours of pay per run (8 hours for most agencies) can be obtained from the labor agreement. For most agencies, there is a fixed allowance for report and turn-in time for all straight runs, which can also be taken directly from the labor agreement. Travel time, if applicable to the agency, generally varies by run, with many runs having no travel time.

Data on weekday, Saturday, and Sunday vehicle-hours and weekday AM and PM peak vehicles are obtained from schedules, terminal sheets, or run guides in effect during the audit period. To reduce the effort in assembling data on vehicle-hours, it is important to avoid selecting an audit period during which there were significant schedule changes.

The next step after assembling data required for input to the worksheets is to allocate costs for fringe benefits between weekdays and weekends. All of the data items needed to perform these calculations are listed in the first worksheet. Wage-based fringes for the audit period are allocated between weekdays and weekends in direct proportion to the weekday/weekend split of total wages and premiums. The allocation is made on the total wages and premiums of both full-time and part-time drivers.

Nonwage-based fringes are allocated between weekdays and weekends in direct proportion to the weekday/weekend split of full-time drivers' wages at the base rate. Overtime, spread premiums, other premiums, and part-time drivers' costs are not used in this allocation because it is assumed that costs for nonwage-based fringes depend primarily on the number of full-time drivers, and that increased expenditures for overtime, other premiums, and part-time drivers will not significantly affect the amount of nonwage-based fringe benefits.

Total weekday driver costs for the audit period are then calculated by adding weekday wages and premiums, and the weekday shares of wage-based and nonwage-based fringe benefits. Total weekend driver costs for the audit period are calculated similarly.

Incremental costs for weekday service are calculated based on the assumption that schedulers will handle increases in off-peak service by reducing make-up time on existing straight runs and by replacing some split runs and trippers with straight runs at the minimum guarantee. Thus, prior to estimating weekday changes in costs, it is necessary to estimate the cost (including fringe benefits and associated nonoperating time) for straight runs, as well as vehicle-hours for these runs.

Nonoperating time is included in estimating the cost for a straight run based on the assumption that (1) nonoperating time varies with total (AM + PM) peak vehicles operated by the agency, and (2) that each straight run provides service in one peak period. The cost for nonoperating time is included in the cost for a straight run because, even if the agency provided only straight runs at the minimum, some costs for stand-by and other nonoperating time would still be incurred, if only to cover driver absences.

Calculation of Incremental Costs

The incremental cost for weekday vehicle-hours is then calculated. The equation used in this calculation can be interpreted in terms of a comparison between actual weekday service and an idealized "flat" service consisting of straight runs at the minimum guarantee and providing the same number of peak vehicles as actual weekday service.

The numerator of the weekday vehicle-hour incremental cost equation is the difference between the cost per weekday of the idealized flat service and the actual cost per weekday; and the denominator is the difference between vehicle-hours under the flat service and actual vehicle-hours per weekday. Because the number of peak vehicles is the same in both cases, the incremental cost for weekday vehicle-hours can be interpreted as an estimate of the added cost per vehicle-hour if the number of peak vehicles is held constant (i.e., if the increase in service does not add to the maximum number of vehicles in operation during the AM or PM peak periods).

The incremental cost for peak vehicles is calculated based on the assumption that there are no appreciable economies of scale in weekday driver costs; so that:

Driver Cost Per Weekday =
(Driver Cost Per Vehicle-Hour) × (Vehicle-Hours)
+ (Driver Cost Per Peak Vehicle) × (Peak Vehicles)

The last step is the calculation of the incremental cost for weekend vehicle-hours. The denominator of this equation is total vehicle-hours on weekends (including holidays) during the audit period. Because only vehicle-hours (not peak vehicles) is used in calculating the effects of weekend service changes on driver costs, the incremental cost for weekend vehicle-hours can be estimated directly as the ratio of weekend cost (from the weekday/weekend cost allocation) to weekend vehicle-hours.

ASSESSMENT OF SIMPLE COST MODELS

Accuracy

Root mean squared error (RMSE) and percent root mean squared error (%RMSE) are the principal criteria used to assess the overall accuracy of the simple cost models.

The mathematical definition of root mean squared error is:

$$RMSE = \left((1/N) \sum_i (P_i - T_i)^2\right)^{1/2}$$

where: N is the number of test cases; P_i is the predicted cost for test case i, T_i is the "true" cost for test case i, and $I_i \sum_i$ is the summation over all test cases.

Following is an example of how to calculate root mean squared error using predicted and true costs for five hypothetical service change test cases:

Case	Predicted Cost Change	True Cost Change	Error	Squared Error
1	1,450	1,980	−530	280,900
2	−1,570	−1,470	−100	10,000
3	−740	−680	−60	3,600
4	−6,830	−7,470	640	409,600
5	730	710	20	400

Note that Cases 2, 3, and 4 are service decreases, so that both predicted and true cost changes are negative.

The average squared error for the example is:

$$(280{,}900 + 10{,}000 + 3{,}600 + 409{,}600 + 400)/5 = 140{,}900$$

The root mean squared error is the square root of 140,900 or 375. The definition of percent root mean square error is:

$$\%RMSE = \left((1/N) \sum_i ((P_i - T_i)/T_i)^2\right)^{1/2}$$

where all variables are as defined previously.

Following is the calculation of percent root mean squared error for the same example that was presented above:

Case	Predicted Cost Change	True Cost Change	Percent Error	Squared Error
1	1,450	1,980	−26.8%	716.5
2	−1,570	−1,470	−6.8%	46.3
3	−740	−680	−8.8%	77.9
4	−6,830	−7,470	8.6%	73.4
5	730	710	2.8%	7.9

The average squared percent error for the example is:

$$(716.5 + 46.3 + 77.9 + 73.4 + 7.9)/5 = 184.4$$

The percent root mean squared error is the square root of 184.4 or 13.6 percent.

The difference between the two accuracy criteria is that RMSE measures errors in absolute terms and %RMSE measures errors in percentage terms. In the above example, Case 4 is the largest contributor to RMSE because it has the largest error—

1. Root Mean Squared Error[1/]

Cost Method	LANTA	VIA	OCTD
One Variable	129.55	238.12	635.62
Two Variable	102.24	198.97	316.18
Pay-to-Platform Ratio	101.49	147.75	308.75
Schedule-Based	86.47	144.66	301.79
Worksheet	119.36	154.43	524.96

2. Percent Root Mean Squared Error[1/]

Cost Method	LANTA	VIA	OCTD
One Variable	21.63%	18.57%	15.87%
Two Variable	14.53	17.12	9.00
Pay-to-Platform Ratio	15.68	17.15	8.85
Schedule-Based	11.91	17.21	8.82
Worksheet	15.80	18.40	21.04

[1/]Lower values of RMSE and %RMSE mean that a method is more accurate. All accuracy measures include overall variable cost differences from "true" costs of driver plus non-driver costs; however, non-driver costs were estimated with the same two variable cost allocation model in all cases except the One Variable model.

Figure 4. Overall accuracy of simple cost methods.

Test Site and Cost Method	Peak	Off-Peak	Weekend	Mixed
LANTA				
True Costs	28.78	24.85	27.95	28.37
One Variable	27.28	27.28	27.28	27.28
Two Variable	27.80	26.80	27.33	27.83
Pay-to-Platform Ratio	29.22	27.32	27.69	29.01
Schedule-Based	29.75	24.54	27.82	28.05
Worksheet	33.31	23.40	26.01	29.64
VIA				
True Costs	25.49	26.76	23.55	23.98
One Variable	22.83	22.83	22.83	22.83
Two Variable	24.95	23.03	22.43	20.75
Pay-to-Platform Ratio	26.68	24.63	23.96	22.43
Schedule-Based	26.70	24.39	23.96	22.29
Worksheet	26.98	23.28	23.97	22.07
OCTD				
True Costs	45.15	38.54	36.63	39.78
One Variable	38.00	38.00	38.00	38.00
Two Variable	43.08	36.57	37.78	39.48
Pay-to-Platform Ratio	43.58	36.57	37.61	39.85
Schedule-Based	44.37	35.84	37.53	39.58
Worksheet	55.05	28.71	36.04	41.29

Figure 5. Cost per vehicle-hour for service changes by time period.

$640. Case 1 is the largest contributor to %RMSE because it has the largest percentage error—26.8 percent.

The same estimates of nondriver costs were used for "true" costs in each of the simplified procedures except the one-variable model. Thus, except for the one-variable model, errors are due to differences between true driver costs and estimates of driver costs developed using the simple procedures.

Figure 4 shows the root mean squared error and percent root mean squared error of the simple procedures for each of the three test sites.

At LANTA, the Schedule-Based method is the most accurate, in terms of both RMSE and %RMSE. At VIA, the Schedule-Based method is most accurate in terms of RMSE, by a slight margin over the Pay-to-Platform Ratio method. In terms of %RMSE, the Pay-to-Platform, Schedule-Based, and Two-Variable methods are tied for most accurate. At OCTD, the Schedule-Based method is the most accurate in terms of both RMSE and %RMSE, with the Pay-to-Platform Ratio method a close second, and the Two-Variable method a close third. In terms of overall accuracy, the Schedule-Based method outperformed the other models.

In addition to the analysis of overall accuracy presented above, the simple methods were examined in terms of how well they reproduced true costs for different types of service changes. To make this comparison for different types of service changes, the average incremental costs per vehicle-hour were calculated for true costs and for cost estimates developed using each of the simple methods. For a given service change, incremental cost per vehicle-hour is calculated as the change in cost divided by the change in vehicle-hours.

Service Changes by Time Period

Figure 5 shows the estimated average incremental cost per vehicle-hour for service changes by time period. At LANTA and OCTD, the true incremental costs for weekday peak period changes are higher than those for weekday off-peak service changes. This is consistent with the general perception that it is more expensive to add service in the peak period than in the off-peak period and, conversely, that greater operating cost savings can be realized from peak period service reductions.

The Pay-to-Platform Ratio, Schedule-Based, and Worksheet methods—each distinguishes among service changes by time period, with weekday peak period changes having the highest cost per hour, weekday off-peak changes having the lowest cost per hour, and weekend and mixed changes falling between weekday peak and off-peak.

At LANTA, the difference between weekday peak and off-peak average cost per vehicle-hour is $3.93 for the true cost. For the other methods, the differences are:

- No difference for the One-Variable method, because cost per vehicle-hour is assumed to be constant under this method.
- $1.00 for the Two-Variable method, reflecting only the fact that speeds are generally lower in the peak period. (The cost per hour factor outweighs the cost per mile factor in the cost estimating formula.)
- $1.90 for the Pay-to-Platform Ratio method, reflecting higher PPR ratios in peak periods.
- $5.21 for the Schedule-Based method, reflecting the as-

sumptions about how schedulers use different types of runs in making changes in the peak and off-peak periods.

- $9.91 for the Worksheet method, reflecting the assumptions about how schedulers use different types of runs, as well as assumptions about the use of part-time vs. full-time drivers and differences in their compensation.

At OCTD, the difference between weekday peak and off-peak average cost per vehicle-hour is $6.61 for the true cost. Three of the methods—the Two Variable, Pay-to-Platform, and Schedule-Based—do a good job of reproducing this difference. The difference for the Worksheet method is much greater—$26.34.

The weekday peak versus off-peak comparison at LANTA and OCTD highlights the principal shortcoming of the Worksheet method in terms of accuracy—it overstates the incremental cost for peak service changes and understates the cost for off-peak changes.

In contrast to the other two test sites, VIA peak period incremental costs are not higher than its off-peak costs. This is primarily because, at the time the true costs were developed for the service changes, VIA generally did not pay overtime premiums to its drivers. Since the additional buses required for peak periods are frequently used for trippers on overtime, the fact that VIA generally did not pay overtime premiums allowed them to provide peak period service at a lower cost.

Service Increases and Decreases

Figure 6 shows average incremental costs per vehicle-hour for service increases and decreases. At each of the three test sites, the true incremental costs for service increases are greater than those for service decreases. This is probably because schedulers have fine-tuned schedules to take maximum advantage of the number of drivers and current pay provisions. That is, in figuring out how much service to provide on a given route, schedulers tend to set service levels at the point where any increase would cause a disproportionate increase in cost (e.g., by requiring that an additional driver be hired). In none of the service change test cases has an attempt been made to optimize the revised schedules. Rather, changes were made by adjusting service levels as part of a set of 20 predetermined changes, without making refinements to take full advantage of all resources.

Each of the simple procedures, with the exception of the one-variable method, has estimated higher per vehicle-hour costs for service increases than for service decreases, although the differences are generally less than those observed for true costs. However, the fact that the procedures produce higher costs for service increases than for service decreases could be the result of chance because none of the simple procedures distinguishes service increases from service decreases in terms of how costs are calculated. If one of the procedures predicts that a service increase of 20 vehicle-hours will increase costs by $500, it will predict that a service decrease of 20 vehicle-hours (for the same time period) will decrease costs by $500.

A more likely explanation, however, is that the original schedules were more nearly optimized than the revised schedules. The original schedules were fine-tuned to make full use of available vehicles, drivers, and other operating personnel. The revised schedules involved tests of predetermined levels of changes in service, but little effort was made to refine the schedules to take full advantage of the adjusted manpower and other resources.

In actual practice, something like this tends to happen for minor schedule changes, but that for more major revisions schedule-makers tend to put more effort into the planning of resource utilization, often with the aid of automated runcuts. If this is true, then further investigation would show that for larger scale service changes, costs would be approximately reversible, to the extent that optimization occurred. However, for small service changes, schedulers are likely to make "patches" without serious attempts at optimization, this resulting in somewhat higher costs for service increases and lower costs for service decreases, as occurred in our test cases.

Further testing, along with detailed analysis of strategies used by schedule-makers, will be required to determine which of these hypotheses is most valid. If the second hypothesis proves to be valid, the appropriate recommendation might be to improve the manner in which schedule-makers prepare "patches," rather than revising the models to attempt to more accurately predict the results of a process that results in suboptimal schedules for small changes in service levels.

This further research should also analyze in more depth possible systematic biases in costs depending on whether service is increased or decreased and to determine how cost estimation procedures might be adjusted to account for this bias, if it is proven to exist.

Test Site and Cost Method	Service Increases	Service Decreases
LANTA		
True Costs	28.92	25.35
One Variable	27.28	27.28
Two Variable	27.39	27.28
Pay-to-Platform Ratio	28.34	27.95
Schedule-Based	27.40	26.97
Worksheet	28.31	27.62
VIA		
True Costs	28.07	21.88
One Variable	22.83	22.83
Two Variable	23.19	22.83
Pay-to-Platform Ratio	24.81	24.46
Schedule-Based	24.72	24.37
Worksheet	24.40	24.06
OCTD		
True Costs	42.04	37.76
One Variable	38.00	38.00
Two Variable	40.09	37.78
Pay-to-Platform Ratio	40.29	37.86
Schedule-Based	40.34	37.58
Worksheet	43.60	34.42

Figure 6. Cost per vehicle-hour for service increases and decreases.

Test Site and Cost Method	Size of Service Change[1/]		
	Large	Medium	Small
LANTA			
True Costs	28.67	26.85	26.37
One Variable	27.28	27.28	27.28
Two Variable	27.53	27.70	26.78
Pay-to-Platform Ratio	28.66	28.70	27.14
Schedule-Based	27.60	27.54	26.48
Worksheet	28.42	29.15	26.29
VIA			
True Costs	22.71	27.34	25.01
One Variable	22.83	22.83	22.83
Two Variable	20.86	24.74	23.17
Pay-to-Platform Ratio	22.48	26.44	24.72
Schedule-Based	22.33	26.38	24.64
Worksheet	21.85	26.26	24.28
OCTD			
True Costs	43.13	42.95	34.13
One Variable	38.00	38.00	38.00
Two Variable	41.35	39.86	36.37
Pay-to-Platform Ratio	41.74	40.10	36.23
Schedule-Based	41.70	40.16	35.84
Worksheet	45.30	42.35	31.12

1/For each test site, the test cases were divided into these three groups. The ranges used for each size category vary among the three sites because the overall ranges vary among the sites and because the breakpoints were chosen to be where there were wide gaps betwen small and medium changes and between medium and large changes. See Figure B-22 for a list showing the distribution of the size of changes for each site.

Figure 7. Cost per vehicle-hour for large, medium, and small service changes.

Large, Medium, and Small Service Changes

Figure 7 shows average incremental costs per vehicle-hour for large, medium, and small service changes. Differences among large, medium, and small service changes appear to be the result of chance rather than any systematic effect.

At LANTA, the "true" incremental cost per vehicle-hour is greater for large service changes than for medium and small changes. However, at LANTA four of the five large service changes are service increases which, as noted above, tend to have a higher average cost per hour than service decreases. Thus, the observation that large service changes have a greater incremental cost appears to be the result of the fact that a disproportionate share of the large service changes were service increases.

At VIA, the incremental cost per vehicle-hour is greater for medium service changes. Following the same logic as above, this can be explained by the observation that at VIA, five of the seven medium service changes are service increases.

At OCTD, the incremental cost per vehicle-hour is less for small service changes. Again following the same logic, this can be explained by the observation that at OCTD, five of the seven small service changes are service decreases.

Ease of Use

An important criterion in the evaluation of alternative cost estimating procedures and the likelihood of their use is the ease of using the methods. In this analysis, the ease of use is quantitatively measured in terms of time required to calibrate and apply each procedure. A qualitative assessment has also been prepared which attempts to gauge the level of difficulty of required computations. Consistent with the evaluation of current cost estimating procedures, it has been assumed that model calibration and application rely solely on manual techniques. This reflects the desire to compare cost models within the context of the general lack of computers for planning purposes at many transit agencies. Of course, certain models lend themselves to computer processing, which may offset the greater manual time required and the difficulty of required computations for those agencies that choose to computerize such models.

The time required for each method is presented below based on the results at the test sites:

	Calibration (Hours)	Application (Minutes)
One Variable	0.5	5
Two Variable	1.0	5
Worksheet Method	4.5	7
Schedule-Based Method	2.0 plus 1 min/ Work Assignment	10
Pay-to-Platform Ratio	4.0 plus 4 min/ Work Assignment	30

The calibration results reflect experience with the final three test sites as well as with Long Beach Transit. As noted earlier, the calibration time requirements vary with the number of driver assignments for two of the methods.

By far the simplest technique is the one-variable approach. The calibration time is the time required for data assembly and minimal validation. The two-variable model requires approximately one hour of an analyst's time—principally the time required to assign cost elements to either vehicle-hours or miles.

The remaining three models distinguish costs by time of day and day of the week. Not surprisingly, these models required considerably more time. The Worksheet method is relatively simple once all data input is provided for the first page and the attachments. Computations of drivers' costs based on payroll and platform-hour data are the time-consuming steps. The last two methods share certain similarities in that the vacancy rate, average wage rate, and fringe benefit multiplier all must be computed. The time-consuming work is the development of data from drivers' work assignment records. In the case of the Schedule-Based method, pay-hours and platform-hours are tallied by type of driver assignment. This results in a time requirement that varies by work assignment. The PPR approach calibration time also is a function of the number of work assignments. Greater time requirements reflect the need to compute ratios for each assignment and then compute averages by hour of the day and day of the week.

The time requirements for model application are somewhat similar to the calibration requirements. Models that have limited calibration time requirements also can be applied relatively quickly. However, the range of time values for application are considerably less than those for the calibration phase.

The two average cost models (one and two variable) require only 5 min to apply to a service change. This includes the time required to compute vehicle-hours and miles as well as the multiplication of unit costs. The Worksheet method is also not time-consuming since the peak service surcharge is applied by a peak vehicle unit costs. The vehicle-hour unit cost is the same for peak and off-peak periods. In contrast, the Schedule-Based method requires estimates of vehicle-hours by time period, which increases the application time. The PPR method is the most time-consuming because vehicle-hours of the service change must be disaggregated by hour of day.

The foregoing estimates indicate the average time requirements to calibrate and apply each procedure under typical conditions. The overall staff time required at a particular agency will reflect the frequency of calibration and the number of service changes to be costed. The former is of lesser importance inasmuch as calibrations might be warranted no more often than once or twice per year. Recalibration would be needed with significant changes in work rules, pay provisions, driver utilization, and cost escalation.

The concluding element of the assessment is the difficulty and complexity of computations. For the most part, time requirements are also good surrogate measures of complexity. An important exception is that the calibration calculations are relatively simple for the Schedule-Based method and PPR methods, although they are time-consuming. Numerous computations are required, but they are mechanical and repetitive in nature, and can be performed by less experienced staff. For this reason they also lend themselves to computerization. This should be kept in mind when reviewing the test site results for ease of use.

SUMMARY

Summary highlights of the findings from the testing program are as follows:

- No single model performed best in terms of accuracy for all types of service change strata and test site locations.
- For the temporally sensitive models, the Schedule-Based approach is more accurate in one test site and approximately the same at the other two systems. The Worksheet method tends to apply too great a penalty to peak period service and is the least accurate of the three models.
- Overall, the results show that a temporally sensitive model offers improved accuracy over the other simpler procedures. This is less true where work rules and pay provisions have little effect on peak period costs, such as at VIA.
- The three models developed as part of the current study all provide sensitivity to the time period of the service change. Also, the models distinguish incremental cost by day of the week. This latter point represents a substantial enhancement over models in current general use.
- None of the models is onerous in terms of its ease of use. Overall, the Schedule-Based procedure appears the most attractive in terms of level of resources required for both calibrations and applications.
- In view of the foregoing discussion, the preferred approach for most applications is the Schedule-Based method. It achieves high ratings in terms of accuracy, sensitivity, and ease of use.
- For small transit agencies with relatively flat peaking profiles, the results of applying the Schedule-Based model will not differ much from the Two-Variable model, and thus the latter may be the preferred model for such agencies because it is easier to calibrate and apply.

CHAPTER THREE

RECOMMENDATIONS FOR APPLICATIONS

How can the recommended cost estimating techniques assist transit agencies in service planning and related functions?

Several specific types of activities can be identified for which these techniques may be of assistance:

- Planning changes in service in response to changes in ridership patterns.
- Responding to petitions for changes in service.
- Reorientation of service to provide feeder service to new rail lines.
- Extensions or reorientation of routes to serve major new developments.
- Planning of modifications to service to adapt to seasonal changes in demand patterns.
- Refinements in the scheduling process by using the cost estimating techniques in tandem with runcutting models or manual scheduling techniques.
- Reductions in service required as a result of cutbacks in funding for transit.
- Allocations of deficits among local jurisdictions on a route-by-route basis.
- Provision of cost estimates for proposed changes in union contract pay provisions and work rules (e.g., proportion of part-time operators allowed, or proportion of runs that must be straight runs).

In addition to these specific types of applications, the experience of this project indicates that transit agencies can benefit from the use of improved cost estimating techniques in less tangible ways. As documented in Appendix A, most transit agencies are either not using cost estimating techniques or are using simple cost allocation methods that do not effectively deal with factors that affect costs. The recommended improved techniques all deal more effectively with these factors, except perhaps

	Time Required	
	Calibration (Hours)	Application (Minutes)
Recommended Methods:		
Worksheet	4.5	7
Schedule-Based	2.0 plus 1 minute/ work assignment	10
Pay-to-Platform Ratio	4.0 plus 4 minutes/ work assignment	30
More Complex Methods:		
Modified Adelaide	18	150
Booz, Allen and Hamilton	24	43

Figure 8. Comparison of ease of use of recommended methods and more complex models.

The recommended techniques all require far less staff time to calibrate and apply as compared to the Adelaide and Booz, Allen and Hamilton methods. Figure 8 provides a summary comparison of the simple vs. complex methods in terms of ease of use. In addition to the time savings indicated in the figure, the recommended techniques can all be applied without the need for runcuts; whereas the more complex methods would require certain portions of the scheduling process to be performed.

The simple methods that have been developed and tested are intentionally diverse so that they can satisfy the needs of transit agencies having a wide range of capabilities and conditions. The most appropriate method may depend on several factors, including:

- The general compatibility of the assumptions built into each method with the work rules, pay provisions, and type of operations of the transit agency.
- The importance placed on having a very simple to apply method in terms of data and time required, which may indicate preference for the Worksheet method.
- The extent to which schedule-makers are able to optimize the planning of new service or service reductions, in the manner assumed in the Schedule-Based method.
- The importance of hourly variations in factors affecting pay-to-platform ratios, which may indicate preference for use of the PPR method.
- Computer capabilities of planning staff and availability of microcomputers, which may indicate preference for the computer program documented in Appendix E.

A critical factor in choosing the method is that it must accurately reflect the ways in which work rules of the transit agency affect costs in different time positions—either explicitly or implicitly. All of the recommended methods attempt to do this in one form or another without the need to prepare schedules. The computer-based method described in Appendix E does so in more explicit terms than the other simple methods. A transit agency that has unusual or particularly stringent work rules or pay provisions may wish to consider modifying the assumptions built into the methods to better match its conditions.

The vast majority of transit agencies currently do not now use computer facilities to assist in cost estimating as part of regular route service planning activities (28 of 30), as documented in the survey results reported in Appendix A. However, 25 of the 30 agencies responding to the survey do have computers available in the agency and three of the remaining five have plans to add computer facilities. Computers are in relatively widespread use for scheduling, particularly in larger cities.

Good schedule-makers appear to be quite proficient at devising schedules that make effective use of guaranteed pay-hours, i.e., in developing near optimal work assignments within the constraints of work rules and pay provisions. The Adelaide and Schedule-Based methods explicitly assume a form of optimality in their structure.

This contrasts with the use of average cost or simple cost allocation models for estimating driver-related costs, which is the current practice at the vast majority of transit agencies. These overly simplified approaches are not recommended for most transit agencies because they generally produce less accurate results, as documented in Appendix B. The exceptions in small transit agencies with very flat peaking profiles where simple two variable cost allocation models may provide nearly equal accuracy with less effort in terms of both calibration and application.

All of the recommended models attempt to be sensitive to the manner in which drivers' compensation and work rules affect costs during different time periods. Some of the techniques deal explicitly with work rules that affect costs in important ways. Some of the techniques recognize, either explicitly or implicitly, that the use of split runs, trippers, and part-time operators can substantially affect costs. Transit agency staff can benefit from regularly working with techniques that provide a better basis for understanding how these various factors affect costs.

Planning staff are often not familiar with the schedule-making process. Working with the recommended techniques will help them understand this process, and can draw them into a closer working relationship with schedule-makers, so that the planning process will lead to more cost-effective refinements in service.

Perhaps most importantly, because these recommended techniques will be appreciated by transit agency staff as being more accurate than techniques now in use in most agencies, they will tend to be used more frequently and used for a wider variety of types of applications. This should lead to improvements in the efficiency and effectiveness of many planning, scheduling, and budgeting functions.

No single technique can be recommended for application in all transit agencies because of the variety of conditions and capabilities among agencies. Even within a single transit organization, different cost estimating techniques may be appropriate for different applications.

As extensively documented in Appendix A in the survey of current practice, and in Appendix C in the assessment of more complex models, very few, if any, transit agencies are likely to use more complex techniques such as the Adelaide or Booz, Allen and Hamilton methods. Only methods that are simple to calibrate and apply will be extensively used. Even though an agency may be able to obtain greater accuracy with the more complex techniques, the added time and cost of doing so will outweigh the benefits of potentially greater accuracy for most, if not all agencies. For the industry as a whole, as concluded in Appendix C, there is no doubt that the use of simpler techniques offers far greater overall benefit.

are in very small urban areas with low peak-to-base ratios and work rules that do not result in significantly higher peak period costs. Simple two variable cost allocation models may produce satisfactory results in such areas.

A major problem in current practice is that many transit agencies are using poor cost estimating techniques without knowing how much in error their estimates are. Most agencies do not check their cost estimates against actual subsequent cost experience as affected by the service changes, nor do they check their estimates from the very simple methods with more accurate cost estimates based on runcuts (as was done in estimating "true" costs in this study). Transit agencies need to recognize that they are probably getting poor estimates of costs from the oversimplified average cost or simple cost allocation methods (except for very small urban areas as noted above). Appendix B provides comparative measures of error for these methods and the recommended manual methods, and Appendix E provides comparative measures of error for the computer-based method and the other methods.

The project research team would advise transit agencies to perform similar comparisons between results obtained from one or more of the recommended techniques and their "true" costs based on runcuts made before and after the service changes have been made. This type of feedback from the use of cost estimating models and "actual" experience is necessary to realize the value of improvements in these techniques and to understand what types of refinements may be needed.

Computerization of cost estimating techniques may be desirable in most cases where transit agencies have computer capabilities. The exceptions would be in smaller cities where few service changes and few routes are involved and where the simplest of the recommended cost estimation techniques are known to be adequate. All of the recommended techniques could benefit from being automated, particularly the PPR method, because it is the most time-consuming and may be the most attractive in some larger systems. Computerization would save time for most agencies in both calibration and application, and would facilitate its use for a wider variety of the types of applications identified at the beginning of this chapter. Computerization of the calibration process for the Schedule-Based method would also be beneficial if the input data are available in machine-readable form.

Nonetheless, despite the potential benefits of computerization the use of the improved manual techniques in a more rigorous planning process can offer substantial improvements over current practice. Computerization would simply make it easier to expand the range of application of the techniques in improving the management of transit resources.

Each of the cost estimating techniques should be recalibrated periodically, perhaps annually under average conditions. Recalibration is desirable when any major changes occur that may affect the basic relationships, such as revisions in work rules or pay provisions in new contracts, substantial changes over time in the peak-to-base ratio, major reorientation of bus routes to provide feeder service to new rail lines, major changes in the mix of vehicles in the bus fleet, or major changes in fuel or other prices.

A key factor that has been defined and used in the PPR and Schedule-Based method is a ratio that, for want of a better term, has been called the "vacancy rate"—the ratio of pay-hours from the payroll distribution to the pay-hours for the work assignments. This is a useful measure of the efficiency of transit operations because it essentially measures the proportion of operators' time that is in productive use. Transit managers should be interested in periodically reviewing estimates of the agency's vacancy rate and in comparing it with such measures for similar transit systems.

As noted previously, one of the potential applications of the recommended techniques is that they can be used in tandem with runcutting to aid in optimizing schedules. Ideally, computerized use of improved cost estimating techniques should be in regular use at transit agencies for most of the applications identified at the beginning of this chapter. These techniques should be used in tandem not only with automated scheduling techniques as discussed previously, but also with other related planning and budgeting tools.

One important example is that the evaluation of major changes in service should include the use of techniques to forecast changes in ridership and revenue in addition to operating cost changes, so that net changes in deficits can be estimated directly. Computerized techniques are now available for making these forecasts, and could be linked to provide transit managers with a complete financial impact assessment of potential changes in service.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The major conclusions of this research fall into three areas. First, the requirements for incremental cost estimating procedures have been identified that can achieve wide acceptance and use in the transit industry. Second, new techniques have been developed to estimate the cost impacts of route level service changes. Third, tests have been performed at three sites and the performance of the procedures using several relevant criteria have been evaluated. Each of these conclusions is presented in this section.

The survey results clearly indicate a wide disparity between the simple methods being used by transit agencies and more complex techniques that are available. Moreover, many transit systems do not prepare cost estimates of service changes. In part, this reflects the current state of the art in that previously available models that attempt to be sensitive to temporal variations in factors affecting costs are complex in structure and time-consuming to calibrate and apply. Research has revealed that the substantial additional effort required for the Modified Adelaide and Booz, Allen and Hamilton models does not produce a corresponding increase in model accuracy and reliability.

On the basis of the foregoing, it is concluded that ease of use is an important consideration in developing new and assessing existing cost estimating procedures. Any proposed model must have a simple structure and be relatively easy to calibrate and apply. This is in contrast to previous research efforts that led to complex techniques. In placing significant emphasis on ease of use, it is anticipated that temporally sensitive cost models will receive wider acceptance and use. In contrast with present practices, this can result in much wider use of these methods in the preparation of cost estimates and more accurate forecasts.

This study has produced several new cost models that attempt to satisfy the criteria cited above. They differ in terms of the variables considered and the algorithms by which they attempt to replicate the incremental costs of service changes. For the planner, this represents a two-fold benefit. First, it provides an enhanced menu of techniques that are available and increases the likelihood that one matches the specific needs of the individual and transit agency. Second, the diversity of techniques provides greater insights into scheduling and labor issues that influence bus operating costs.

The final set of conclusions relates to the assessment of the proposed models and other previously used techniques. These results were presented in Chapter Two and are only highlighted here. No single model is best for all types of service changes and operating environments. Overall, the Schedule-Based model attains the highest overall rating in accuracy, sensitivity, and ease of use. In view of this, it is suggested that planners experiment with the different simple procedures and select the one best suited to their transit agency's unique set of circumstances. A corollary benefit of such an approach is that it may help planners gain greater insights into scheduling and labor issues. These and other benefits of the improved simple methods were discussed in Chapter Three.

SUGGESTED RESEARCH

Based on the results of the current analysis and previous studies, further research is suggested in several areas. They are listed in priority order.

First, there is a need to upgrade present transit industry practice with respect to cost estimating as well as other related planning functions. The simple procedures developed as part of the current analysis, combined with previously developed models, provide planners with a wide array of cost estimating techniques. The challenge is to encourage use of these methods as part of a rational planning framework. To achieve this, a high priority research effort is the preparation of the case studies at a few selected transit systems. The case studies would document 'hands-on" experience in using the cost models and their integration within the planning framework. It is also proposed that training in cost estimation techniques be initiated. This report provides all the necessary information for the development and conduct of training seminars.

A second priority research effort is an extension of the test site approach used in the current study. The calibration of the simple cost models is recommended at several transit agencies in order to investigate further the effects of various factors on incremental costs. The unit costs and other parameters from the estimating procedures should be related to various measures that reflect the transit agency's environment. This should include measures of service characteristics and elements in the collective bargaining agreement. As part of this recommended research effort, it is also suggested that a larger number of service changes be tested to enhance the statistical validity of the results. Both the service changes and the transit agencies should be selected to cover a broad range of conditions.

Next in priority is further research on the cost consequences of increasing and decreasing service. The models tested in this study all incorporate the assumption that costs are reversible, i.e., that the incremental costs of increases and decreases are identical. However, the test case results indicate that this assumption may not be valid, perhaps because of the tendency of schedule-makers to attempt to optimize the use of manpower in the schedule for major revisions in schedules, but to use "patches" for minor revisions in schedules, thus resulting in suboptimal schedule changes. Because of this, the procedures generally overestimate cost savings with service reductions and underestimate the cost increase with service expansion. This is counter to a conservative planning approach which would seek to avoid underestimating deficits. Further research on this facet of incremental costs should focus on strategies actually used by schedule-makers for changes of various types of magnitudes. A possible product of this research might be different assumptions and separate procedures to be used in calibrating submodels for increases and decreases in service, or alternatively and perhaps preferably, recommendations should be made for improvements in the approaches used by schedule-makers.

Another recommended priority research project, which could be combined with one or more of the above recommendations, is a more detailed examination of the actual use of particular resources in relation to changes in costs of service. Fine-grained analysis is likely to lead to a better understanding of the specific elements of cost increases or decreases that occur in different time periods, and thus to refinements in the models. As an example, very small changes in off-peak service may frequently involve no changes in actual driver compensation; whereas, at some threshold values, additional drivers and/or other operating personnel may be required. This may suggest the development of step functions, similar to one aspect of the new cost allocation model developed at SCRTD (described briefly in Appendix A). However, such a model should be applied within the context of temporally sensitive models, such as those proposed in this report, for the purpose of estimating the cost of bus route service changes.

Another avenue of suggested research is computer programming of the models developed in this study incorporating refinements suggested above. This would be valuable because of the wide availability of microcomputers and spread sheet programs, and because it is likely to lead to more widespread use of the models within transit agencies as discussed in Chapter Three. All of the recommended techniques could benefit from being automated, particularly the PPR method, because it is the most time-consuming and may be the most attractive in some larger systems. The Schedule-Based method should also be computerized because of the time required for its calibration and application and because it is the most accurate of all techniques evaluated under a wide range of applications.

As discussed on Chapter Three, it is recommended that transit agencies adopt these improved simple techniques for use in tandem with automated scheduling techniques and other related planning and budgeting tools. A very useful research project would be to demonstrate in one or more transit agencies the use of such techniques in tandem. One important application of this type cited was that the evaluation of major changes in service could include the use of techniques to forecast changes in ridership and revenue in addition to operating cost changes, so that net changes in deficits can be estimated directly. Available computerized techniques could be used for making these forecasts. The demonstration should show how transit managers could be provided with complete financial impact assessments of potential changes in service. A cost estimating model that is sensitive to changes in ridership was recently developed and tested at SCRTD, as described in Appendix A.

Finally, efforts should be directed to developing cost models for other modes such as demand response transit, rapid transit, light rail, and commuter rail systems. The suitability of these techniques for other modes should be tested and refinements made as appropriate.

REFERENCES

1. "Bus Route Costing Procedures: Final Report." Prepared for the Urban Mass Transportation Administration by Booz, Allen and Hamilton, and Abrams-Cherwony and Associates (April 1984).
2. HERZENBERG, A., "Methods of Estimating the Costs of Drivers' Wages for Bus Service" (May 1982).
3. UMTA Technical Assistance Program. Office of Service and Management Demonstration, *Report DOT-TSC-1752* (November 1984).
4. "Bus Route Costing Procedures: A Review." Prepared for the Urban Mass Transportation Administration by Booz, Allen and Hamilton (May 1981).

APPENDIX A

SURVEY OF CURRENT PRACTICE

This appendix describes a survey of transit operators that was conducted in this study and discusses the implications of survey findings for the development of improved procedures for incremental cost estimating.

SURVEY PROCEDURE

The survey of transit operators was conducted to obtain information on:

- Procedures, models, or rules of thumb currently being used to estimate the effects of bus route service changes on operating costs.
- Special adjustments, if any, for handling service changes by time of day.
- Special problems encountered in past efforts to estimate service change costs.
- Suggestions for how the procedures and documentation developed in this study might be structured to be most useful in overcoming these problems.
- Whether agencies have access to microcomputers or other computer facilities on which a program for cost estimation could be installed.

Figure A-1 is a copy of the form that was used in this survey. The survey form was sent to 58 transit agencies, ranging in size from less than 50 to over 2,000 peak vehicles; and 30 of the forms were completed and returned. Figure A-2 shows the survey coverage and response rate by size class (as measured by peak bus requirements). As indicated in this figure, the response rate generally increased with system size.

SURVEY RESULTS

The responses of transit agencies to each question in the survey are described below.

Question 1. *Please describe the procedures, models, or rules of thumb your agency uses to estimate the effects of bus route service changes on operating costs, prior to performing run cuts and driver assignments.*

The procedures used by agencies responding to the survey fell into four general categories: (1) average cost per hour; (2) a two variable cost allocation approach in which costs are allocated to vehicle-hours and vehicle-miles; (3) a three variable cost allocation approach in which costs are usually allocated to vehicle-hours, vehicle-miles, and peak vehicles (with overhead or fixed costs allocated to peak vehicles); and (4) a more complex method used by CTA (Chicago) involving estimates of vehicle-hours (stratified by five weekday time periods and three periods each for Saturday and Sunday), vehicle-miles, number of buses required by period (same periods), breakdown between straight runs and swing runs, and miscellaneous costs.

1. Please describe the procedures, models, or rules of thumb your agency uses to estimate the effects of bus route service changes on operating costs, prior to performing run cuts and driver assignments.

   ____

   If possible, please provide copies of reports or memoranda which describe these procedures.

2. Do these procedures include special adjustments for handling service changes by time of day? If so, please describe.

   ____

3. Does your agency own or have access to a microcomputer or other computer facilities on which a program for cost estimation could be installed? If so, please indicate the system configuration.

   ____

4. Please describe any special problems encountered by your agency in past efforts to estimate service change costs. Also, please provide suggestions for how the procedures and documentation developed in our study might be structured to be most helpful to you in overcoming these problems.

   ____

5. May we contact you for additional information on how available procedures might be improved to make them more useful to your agency? ____

   Contact Person: __________ Telephone Number: __________
   Agency: ____________________

Figure A-1. Transit agency survey form.

Figure A-3 shows a tabulation of agencies by system size and general approach used. Figure A-4 shows the two-page worksheet used by CTA for preparing cost estimates. As noted in Figure A-3, the more complex method used by CTA was brought to our attention after the survey was completed. The use of such detailed procedures is atypical of the transit industry and may be unique to CTA.

Other important variations on the generalizations shown in Figure A-3 have been developed by individual agencies. NYCTA (New York) develops average costs per bus-hour and per pay-hour for driver costs. The unit cost per pay-hour is used in situations, such as swing runs, with an unusual relationship of pay-hours to bus-hours.

GCRTA (Cleveland) uses a minimum cost per day for buses and operators, to account for the relatively high cost per hour of short runs in the peak period. SCRTD (Los Angeles) uses pull-outs, as well as vehicle-hours and miles, in estimating changes in costs. The cost coefficients are established using regression analysis. (Since completion of this survey, SCRTD has completed a research project involving the testing of a new cost allocation model, which is described at the end of this section.)

SEMTA (Detroit) uses a system average cost per hour for quick cost estimates and a three variable cost allocation model for more rigorous cost calculations. RTD (Denver) uses mar-

Size Class: Peak Bus Requirements	Number of Agencies Surveyed	Number of Agencies Responding	Total Number of Agencies[1/]	Sample Size (%)	Response Rate (%)
25-49	10	2	64	16	20
50-99	10	4	41	24	40
100-249	10	5	35	29	50
250-499	11	7	15	73	64
500-999	12	8	12	100	67
1,000 & Over	5	4	5	100	80
Total	58	30	172	34	52

[1/] As tabulated from UMTA, A Directory of Regularly Scheduled, Fixed Route, Local Public Transportation Service in Urbanized Areas Over 50,000 Population, August 1981. Private operations are excluded from this tabulation.

Figure A-2. Survey coverage of transit agencies by size class.

ginal cost per bus hour by type of service (local, express, circulator, etc.).

TARC (Louisville) distinguishes between fixed, variable, and semivariable costs. The semivariable costs are dependent on hours operated and include most fringe benefits. It is TARC's experience that these expenses do not vary directly with hours operated, nor are they completely fixed.

Two smaller systems (Bridgeport and Santa Barbara) make judgmental adjustments to cost per hour based on contract provisions and likely effects of service changes on run cuts.

Question 2. *Do these procedures include special adjustments for handling service changes by time of day? If so, please describe.*

None of the agencies surveys indicated any formal procedures for adjusting the unit costs for vehicle-hours or vehicle-miles to account for peak vs. off-peak service changes. Three of the smaller agencies, however, indicated that judgmental adjustments to unit costs per vehicle-hour are sometimes made, depending on the magnitude of the change and possibilities for covering the service change using existing pad or make-up time paid to satisfy minimum daily guarantees to drivers.

Four of the agencies indicated that their estimated costs for peak vs. off-peak service changes will vary, because fixed costs are allocated to peak vehicles in their cost estimation procedures. Thus, cost for off-peak service changes will be estimated using unit costs for vehicle-miles and vehicle-hours only, while costs for peak period service changes will also include the effect of changes in peak vehicle requirements on fixed costs.

Question 3. *Does your agency own or have access to a microcomputer or other computer facilities on which a program for cost estimation could be installed? If so, please indicate the system configuration.*

	General Approach to Cost Estimation			
Size Class: Peak Bus Requirements	Cost per Hour	Two Variable Approach	Three Variable Approach	More Complex Method
25-49	0	2	0	0
50-99	0	3	1	0
100-249	0	1	4	0
250-499	3	1	3	0
500-999	2	4	2	0
1,000 & Over	0	2	2	1
Total	5	13	12	1
Percent	16	42	39	3

Source: Responses to survey of a representative sample of transit agencies conducted for this study, plus information separately supplied to the research team by the Chicago Transit Authority (regarding the use of the more complex method) during the review of the interim report.

Figure A-3. General approach to cost estimation by system class.

In response to this question, 25 (of the 30 agencies responding to the survey) indicated that they had computer facilities on which a program for cost estimation could be installed; 3 agencies indicated that microcomputer purchases were in process or planned; and 2 agencies indicated no computer facilities or any plans to acquire such facilities.

Chicago Transit Authority
General Operations Division
Operations Planning Department
Routes/Systems

Cost Estimate for Service Change | OP-x77203
9/20/77

Source

I. Hours of service:

a. Weekday ____
b. Saturday ____
c. Sunday ____

II. Estimated round trip distance/time:

a. Total R.T. distance ____ mile(s)
b. Est. round trip running time ____ minutes

III. Average headways:

	Weekday	Saturday	Sunday	Source
a. A.M. rush =	____			____
b. Base =	____	____	____	____
c. P.M. rush =	____			____
d. Evening =	____	____	____	____
e. Owl =	____	____	____	____

IV. Buses required: (Running time ÷ headway) = Units required

	Weekday	Saturday	Sunday	Source
a. A.M. rush =	____			____
b. Base =	____	____	____	____
c. P.M. rush =	____			____
d. Evening =	____	____	____	____
e. Owl =	____	____	____	____

V. Estimated number of runs -- pay hours: (A.M. + base = 1 straight run/bus; P.M. + evening = 1 straight run/bus; and additional buses A.M. + P.M. = 1 swing run/bus)

a. Weekday --
A.M. straight ____ @ ____ hrs.= ____ hrs. ____
P.M. straight ____ @ ____ hrs.= ____ hrs. ____
Swing ____ @ ____ hrs.= ____ hrs. ____
Total ____ ____ hrs. ____

b. Saturday --
A.M. straight ____ @ ____ hrs.= ____ hrs. ____
P.M. straight ____ @ ____ hrs.= ____ hrs. ____
Total ____ ____ hrs. ____

c. Sunday --
A.M. straight ____ @ ____ hrs.= ____ hrs. ____
P.M. straight ____ @ ____ hrs.= ____ hrs. ____
Total ____ ____ hrs. ____

Figure A-4. Chicago Transit Authority form for cost estimates.

VI. Operator expense: Source

Pay hrs. x (wage rate + overhead) = operator expense
(per OP-x76301)

a. Weekday ____ x ($____ + ____%) = ____ ____
b. Saturday ____ x ($____ + ____%) = ____ ____
c. Sunday ____ x ($____ + ____%) = ____ ____

VII. Miles operated:

trips/day x r.t. distance + PO/FI miles = miles operated

a. Weekday ____ x ____ + ____ = ____ ____
b. Saturday ____ x ____ + ____ = ____ ____
c. Sunday ____ x ____ + ____ = ____ ____

VIII. Mileage expense:

miles operated x (maintenance + fuel + injury reserve)/mile = mileage exp./day

a. Weekday ____ x (____¢ + ____¢ + ____¢) = $____ ____
b. Saturday ____ x (____¢ + ____¢ + ____¢) = $____ ____
c. Sunday ____ x (____¢ + ____¢ + ____¢) = $____ ____

IX. Out-of-pocket costs:

operator exp./day + mileage exp./day = cost/day

a. Weekday ____ + ____ = ____ ____
b. Saturday ____ + ____ = ____ ____
c. Sunday & Hol. ____ + ____ = ____ ____

X. Annual out-of-pocket costs:

cost/day x days/year = cost/year

a. Weekday $____ x 255 = $____ ____
b. Saturday $____ x 52 = $____ ____
c. Sunday (& Hol.) $____ x 58 = $____ ____
Total = $____ ____

XI. Miscellaneous costs:

____ ____
____ ____
____ ____
____ ____

By: ____
Date: ____

Figure A-4. Continued

Figure A-5 shows computer availability by type of computer and system size. More than half of the agencies responding to the survey have one (or more) microcomputers on which a program for cost estimation could be installed. It should be recognized that availability of computers does not necessarily indicate wide use for the planning function. Only two agencies indicated the use of computer programs to perform cost estimation.

Question 4. *Please describe any special problems encountered by your agency in past efforts to estimate service change costs. Also, please provide suggestions for how the procedures and documentation developed in our study might be structured to be most helpful to you in overcoming these problems.*

Many of the agencies identified problems with current procedures and opportunities for improvements. NYCTA (New York) indicated that problems include (1) accounting for time of day cost variations, (2) costing service requiring overtime versus straight time with fringe benefits, and (3) how overhead should be considered for various levels of service increases and decreases. They suggested that procedures should be logical and easy to apply, and that documentation should clearly identify the types of data required, whether sample data are adequate, and, if so, how sample sizes should be determined.

Metro (Seattle) cited the lack of feedback on actual effects of past service changes as a problem. They suggested that results from recent service changes be built into the process of "calibrating" to local conditions. GCRTA (Cleveland) and PAT (Pittsburgh) noted problems in developing good estimates of unit costs, due to the lengthy calculations required. Both systems are looking forward to computer assistance in performing these calculations in the near future.

Pierce Transit (Tacoma) noted that existing models may overestimate both the cost of service additions and the savings of service reductions, because the number of drivers and fleet size are relatively fixed in the short term and contractual obligations (most notably "guarantees") limit the effects of service changes. They suggested that more exact procedures be developed that take advantage of the scheduling and runcutting software that is now available for microcomputers.

WMATA (Washington, D.C.) noted that variations in bus costs throughout the year were a problem in developing unit costs for evaluation service changes. SCRTD (Los Angeles) said that most of the cost estimating issues that they face involve marginal service adjustments and that a systemwide average cost model is not adequate for addressing these adjustments. SORTA (Cincinnati) suggested that procedures be kept simple, so that they can readily be understood and applied by most agencies.

RTD (Denver) said that special problems include distinguishing peak and off-peak costs, time required for existing procedures, and the lack of standardization for these procedures. SEMTA (Detroit) said that the three variable cost allocation model that they use does not enable them to properly determine weekend costs, particularly the portion of overhead costs that should be allocated to weekends. In that model, overhead costs are allocated to peak vehicles. Since changes in weekend service do not affect peak vehicles, the model does not account for overhead costs that are, nonetheless, incurred for weekend service.

PENTRAN (Hampton-Newport News) said that the greatest difficulty in cost estimating involved the net effect on overhead of service changes and accounting for differences between peak and off-peak service changes. MTC (Twin Cities) said that driver costs are very hard to isolate because a given piece of work may involve part-time, overtime, or straight time drivers along with varying penalty pay. AC Transit (Oakland) noted the need for refinements to distinguish peak vs. off-peak costs and costs for express vs. local service.

SCRTD has recently completed a research project involving the development and testing of a new cost allocation model involving some interesting features (Peter R. Stopher et al., "Development of a UTPS-Compatible, Cost Allocation Model of Bus Operating Cost," paper prepared for presentation to the 1987 TRB Annual Meeting, August 1986, revised January 1987). The model uses threshold values for various resources (e.g., specified man-hours of particular categories of labor) as step functions, rather than the traditional use of continuous unit cost factors. These step functions are used to estimate costs for each of SCRTD's several bus operating divisions. Costs are assigned at a flat amount for any fraction of a specified threshold amount up to that amount (e.g., half a man-year for part-time drivers or a man-year for full-time operating personnel). Another feature of the model that has been incorporated in some other cost allocation models is that one of the factors is annual passenger boardings, thus making the cost model at least theoretically sensitive to ridership forecasts. This could be used to develop net cost estimates of proposed service changes if a patronage estimating methodology was coupled with the model. However, no basis for forecasting the effects of service changes on ridership was incorporated in the model as reported in the paper.

System Size: Peak Bus Requirements	Number of Systems Reporting	Microcomputer Available	Minicomputer Available	Mainframe Available
25-49	2	2	0	0
50-99	4	3	1	0
100-249	5	4	0	0
250-499	7	3	2	2
500-999	8	4	3	5
1,000 & Over	4	1	1	3
Total	30	17	7	10
Percent		57	23	33

Figure A-5. Computer availability by system size.

FINDINGS

The survey results present a picture of the prevailing practice and current problems or deficiencies with cost estimation procedures. While comments varied by transit agency, a common theme was expressed that leads to the following conclusions:

• There is a wide disparity between methods appearing in the literature and procedures employed in the industry. All agencies responding to the survey use relatively simple cost estimating procedures.

• None of the agencies use temporal variation models that distinguish between the cost of providing service by time of day and day of the week. However, many recognize that temporal variation in the cost of providing service can have a substantial effect on the incremental cost of service changes, and view the lack of practical procedures to account for temporal variation as a deficiency of current methods.

• Another common theme in the survey results was the need for relatively simple and quick cost estimation techniques. This finding suggests that complicated procedures with numerous variables and computation steps are unlikely to be widely adopted by the industry.

• In view of the present state of the art, the greatest research payoff can be achieved by an incremental advancement of prevailing practice.

• Several agencies indicated issues related to fixed and variable expenditures. In some cases, comments were related to equitable allocations of total (fixed and variable) cost to present service. Other operators, however, noted the need for a better understanding of how those costs that are considered to be fixed in prevailing practice are affected by different size service changes.

The foregoing observations should be useful in formulating cost estimating methods. Further, they provide another prospective to gauge the appropriateness of existing procedures appearing in the literature.

APPENDIX B

TESTING OF SIMPLE COST MODELS

OVERVIEW OF TESTING PROCESS

This appendix describes the testing of simple cost models at three transit agencies: LANTA (Allentown, Pennsylvania); OCTD (Orange County, California); and VIA (San Antonio, Texas). In addition, each of the models was calibrated, but not tested with data for Long Beach, California.

Five simple cost models were tested: one variable (vehicle-hours), two variable (vehicle-hours and vehicle-miles), pay-to-platform ratio (PPR), schedule-based, and worksheet.

The first two models, which are in common use among transit agencies, are intended as bases for comparison of the accuracy of the three newer models developed as part of this project. The first two models are used to estimate overall variable operating costs; whereas, the latter three models are each designed to provide a better basis for estimating costs associated with drivers, which are the overwhelming majority of operating costs. Nondriver costs can be estimated in conjunction with these three driver cost models using one or two variable cost models. The five models were calibrated and applied to 20 service change test cases at each of the agencies. "True" costs were also developed for each service change test case, as the agency's best estimate of the increase or decrease in costs if the service change were to be implemented. For all test sites, a detailed runcutting exercise was used to estimate actual driver-related costs. Various factors used in some of the procedures, such as average pay rates and fringe benefit multipliers, were used to convert pay-hours from the runcuts to "true" driver-related costs.

A two variable cost allocation model was used to estimate nondriver costs in the testing process in conjunction with each of the three driver cost models, so that total (driver plus nondriver) costs could be estimated for each of the service changes using each of the methods. The form of the cost allocation model used is:

$$\text{Change in Nondriver Cost} = C_{VH} * VH + C_{VM} * VM$$

where: VH and VM are changes in vehicle-hours and vehicle-miles and C_{VH} and C_{VM} are unit costs.

The same two variable cost allocation model was used in calculating nondriver cost changes to be added to each agency's best estimate of changes in driver costs in order to provide the best estimate of total cost. Thus, differences between "true" costs and the costs estimated using each of the four methods are due solely to differences in the driver cost component.

Each of the simple cost models is described in Chapter Two along with the rationale for each. The testing process and findings are presented in this appendix.

TEST SITES

From the outset of the project, the testing program was anticipated to be carried out at three transit agencies—a large agency (over 200 buses), a medium-sized agency (100 to 200 buses), and a small agency (less that 100 buses). The original study design called for cost estimates to be made for 60 service changes at each bus system using a variety of procedures and models. In total, 180 individual service changes would be analyzed and conclusions drawn regarding the advantages and disadvantages of each method based on a variety of criteria. Because of the considerable level of effort required of the staff at each agency, UMTA funding was to be provided. Unfortunately, UMTA funding did not become available and transit systems that were originally slated for participation declined. In some cases, availability of staff and scheduling conflicts precluded participation regardless of UMTA funding. Each of the original transit systems was contacted and invited to participate at a reduced level of effort. However, all of the systems declined and the search for three new systems was initiated.

A preliminary list of approximately a dozen systems was developed. The primary consideration at this preliminary stage was that the systems include all size categories. Contacts were made with each agency to explain the study objectives and work program, responsibilities and level of staff required, and the schedule for the testing program. At the time, information was obtained on the general characteristics of the system, scheduling process, and cost estimating procedures in current use. While all agencies expressed an interest in the study, several declined to participate due to staff and schedule conflicts.

After the initial contacts, the three test sites were selected on the basis of their willingness to participate without compensation as well as the following technical criteria:

- *Size*—The systems should be representative of the three sizes defined previously.
- *Geography*—The systems should reflect a good geographic distribution.
- *Scheduling*—Different runcutting procedures should be used ranging from manual to computer-generated schedules.
- *Driver Types*—At least one system should utilize part-time operators.
- *Work Rules*—The selected systems should not have atypical collective bargaining provisions regarding driver compensation and utilization.

Based on the foregoing criteria, the following three transit systems were selected initially: LANTA—Allentown, Pennsylvania; Long Beach—California; and VIA—San Antonio, Texas.

Certain tradeoffs were made among the various criteria. For example, VIA is unusual among transit agencies in that it does not pay drivers scheduled overtime for hours worked in excess of 8 hours a day or 40 hours a week. On the other hand, VIA's completely automated scheduling process made it an attractive test site. For this reason, it was selected as one of the test sites.

Each of the cost models was calibrated at each of these three transit agencies. Unfortunately, Long Beach withdrew from the testing program prior to the application phase due to the press of other staff commitments. Fortunately, a transit agency meeting approximately similar criteria, Orange County Transit District (OCTD), agreed to participate in both the calibration and application phases. OCTD is considerably larger than Long Beach, but is similar in terms of geography, the use of part-time drivers, and other factors.

Key characteristics of the four systems are presented in Figure B-1.

	LANTA	VIA	Long Beach[1]	OCTD
System Dimensions				
Vehicle Miles (000s)	1,825.5	15,853.0	6,025.8	18,182.8
Vehicle Hours (000s)	137.9	1,118.3	518.6	1,178.9
Operating Costs ($000s)	4,422.0	34,465.0	18,253.4	60,905.5
Number of Divisions	2	1	1	3
Measures				
Cost per Vehicle Hour	32.07	30.82	35.20	51.66
Operating Speed	13.24	14.18	11.62	15.42
Vehicle Requirements (Peak/Base)				
Weekday	48/27	355/160	124/95	375/258
Saturday	29/27	160/160	63/63	171/171
Sunday	0	70/70	53/53	133/133
Span of Service				
Weekday	5:30 AM - 12:30 AM	4:30 AM - 12:40 AM	4:30 AM - 2:10 AM	4:50 AM - 11:30 PM
Saturday	5:30 AM - 7:35 PM	4:30 AM - 12:40 AM	5:00 AM - 2:10 AM	5:15 AM - 10:00 PM
Sunday	----------	4:30 AM - 12:40 AM	5:10 AM - 2:10 AM	6:00 AM - 10:00 PM
Driver Contract Provisions				
Spread (Hours)				
Premium	11	12	10	10.5
Maximum	14	13	12	12
Report/Turn-in (Minutes)	15	10	15	15
Guarantee (Hours)				
Regular	40	40	40	40
Extraboard	16	40	40	40
Part-Timers (%)	0	0	10	10
Overtime	1.5	1.0	1.5	1.5
Run Type (% Straights/Splits/Trippers)				
Weekday	38/58/4	28/50/22	54/17/29	66/23/11
Saturday	66/31/3	42/46/12	76/24/0	80/20/0
Sunday		32/54/14	76/24/0	80/20/0
Scheduling Process	Manual	Computer	Computer-assisted	Computer-assisted
Future Changes	Stable	Growth	Stable	Stable
Costing Method	Modified cost build up	None, remain within budget	None or allocation model	Cost allocation model, remain within budget

[1] Did not participate in model application.

Figure B-1. Characteristics of test sites.

Expense Account	Total	Fixed Costs: Peak Vehicles Required	Variable Costs: Vehicle Miles	Variable Costs: Vehicle Hours: Non-driver	Variable Costs: Vehicle Hours: Driver
Vehicle Operations					
Operator Salaries & Wages	$1,686,933	0	0	0	$1,686,933
Other Salaries & Wages	89,097	0	0	$89,097	0
Fringe Benefits	716,232	0	0	35,931	680,301
Fuel & Lubricants	419,580	0	$419,580	0	0
Tires & Tubes	37,943	0	37,943	0	0
Taxes	480	0	0	480	0
Subtotal	$2.950,265	0	$457,523	$125,508	$2,367,234
Vehicle Maintenance					
Other Salaries & Wages	$367,288	0	$367,288	0	0
Fringe Benefits	148,241	0	148,241	0	0
Services	6,208	0	6,208	0	0
Fuel & Lubricants	9,991	0	9,991	0	0
Tires & Tubes	15	0	15	0	0
Other Materials & Supplies	185,380	0	185,380	0	0
Casualty and Liability	2,980	0	2,980	0	0
Subtotal	$720,103	0	$720,103	0	0
Non-Vehicle Maintenance					
Other Salaries & Wages	$50,156	$50,156	0	0	0
Fringe Benefits	21,269	21,269	0	0	0
Services	38,849	38,849	0	0	0
Other Materials & Supplies	14,886	14,886	0	0	0
Subtotal	$125,160	$125,160	0	0	0
General Administration					
Other Salaries & Wages	$197,326	$197,326	0	0	0
Fringe Benefits	80,220	80,220	0	0	0
Services	46,300	46,300	0	0	0
Other Materials & Supplies	34,127	34,127	0	0	0
Utilities	94,069	94,069	0	0	0
Casualty & Liability	92,009	0	$92,009	0	0
Taxes	5	5	0	0	0
Miscellaneous	38,639	38,639	0	0	0
Expense Transfer	43,822	43,822	0	0	0
Subtotal	$626,517	$534,508	$92,009	0	0
TOTAL	$4,422,045	$659,668	$1,269,635	$125,508	$2,367,234

Figure B-2. Cost allocation process—LANTA.

CALIBRATION PROCESS FOR EACH MODEL

This section describes in detail the data sources and computational steps followed in the calibration of the existing and proposed cost models. To aid in this, the procedure and data for the Allentown division of LANTA are presented as an example. The initial step is the development of a cost allocation model which identifies both the fixed and variable cost components. The variable costs are assigned to either driver or nondriver related categories. The assignment of individual expense account items to variables follows the traditional cost allocation model process. For those models that attempt to reflect temporal variation in transit costs, more detailed analysis is performed on data from the payroll distribution and drivers' work assignments.

Cost Allocation Process

This phase of the cost model calibration results in the development of three separate models as follows: (1) a simple one variable unit cost model, (2) a traditional two variable cost allocation model, and (3) a two variable model that excludes driver costs. As shown in Figure B-2, each cost item for the LANTA system is assigned to one of four items. The first column (after the totals to be allocated) is the fixed cost components that typically are assigned to peak vehicle requirements in a traditional fully allocated model. The remaining categories are expenses that vary with the level of service provided. The costs assigned to vehicle-miles and hours are treated in the same manner as for the traditional two-variable model except that costs normally allocated to vehicle-hours are further stratified by driver and nondriver expenses. Driver-related items include only two expenditures—wages and fringe benefits.

Based on the allocation of expense accounts and the appropriate operating statistics, the unit cost coefficients are computed as shown in Figure B-3.

Pay-to-Platform Ratio Method

The premise underlying the PPR method is that each type of run produces different hours of pay. Further, the types of runs and their proportion of total runs during any given hour of the day vary widely. To reflect this situation, a PPR value is computed by hour which is a "floating" average by time of day. Because of unscheduled and miscellaneous activities, drivers' payroll during any period exceeds that which would be computed from the driver runs. In the PPR method, this multiplier is termed the vacancy rate. The two remaining statistics that are computed are the average wage rate and the fringe benefit multiplier, which are self-explanatory. Presented below are the steps necessary to calibrate the PPR method using the Allentown operating division of LANTA.

Basis For Allocation	Amount	Percent	Operating Statistic	Unit Cost[1]
Variable				
Vehicle Miles	$1,269,635	28.7%	1,825,500	0.70
Vehicle Hours				
Non-driver	125,508	2.8	137,900	0.91
Driver	2,367,234	53.6	137,900	17.17
Subtotal	$2,492,742	56.4	137,900	18.08
Total Variable	$3,762,379	85.1	---	---
Fixed				
Peak Vehicles	$659,668	14.9	48	13,743
Total Variable & Fixed	$4,422,045	100.0%	---	---

Cost Models

Fully Allocated Costs: C = 0.70M + 18.08H + 13,743V

Variable Costs:

Two Variable: C = 0.70M + 18.08H

One Variable:[2] C = 27.28H

Non-driver Costs: C = 0.70M + 0.91H

where:
C = Operating Cost
M = Vehicle Miles
H = Vehicle Hours
V = Peak Vehicles Required

[1] Column one divided by column three.

[2] Unit cost is total variable cost from column one divided by vehicle hours from column three.

Figure B-3. Development of cost allocation model—LANTA.

Step 1—Compute PPR Values for Each Run

Transit agencies have a listing of all runs (i.e., work assignments) that are to be operated each service day. Separate listings are prepared for each day—weekday, Saturday, and Sunday. It includes all scheduled service whether or not it is biddable. As shown in Figure B-4 for LANTA, the work assignment lists on and off times, platform-hours and pay-hours and the basis of compensation. In the PPR method, the ratio of pay-to-platform hours is computed. In most systems, this statistic varies widely reflecting the various provisions of the collective bargaining agreement. The necessary calculation is simple and is repeated for all runs or work assignments for each service day.

One additional point should be noted regarding systems that have part-time operators. If the wage rates are the same for both regular and part-time operators (e.g, in Long Beach), no additional calculations are required. In the event a differential wage scale exists, an equivalent PPR value must be computed for all scheduled runs assigned to part-time operators. The equivalent PPR value is merely the product of the value obtained from the work assignments times the ratio of wage rates, as shown below:

$$PPR_{eq} = PPR_w \frac{W_p}{W_r}$$

where: PPR_{eq} = equivalent ratio; PPR_w = ratio obtained from work assignments; W_p = wage of part-time operators; and W_r = wage of regular operators.

Times		Basis For Pay Computation							
On	Off	Platform	Report	Pad	Spread	Travel	Overtime	Pay	PPR
STRAIGHTS									
5:55 AM	2:18 PM	8:23	15	0	0	0	19	8:57	1.068
5:15 AM	1:00 PM	7:45	15	0	0	0	0	8:00	1.032
2:18 PM	10:10 PM	7:52	15	0	0	0	4	8:11	1.040
SPLITS									
5:45 AM	9:20 AM								
3:00 PM	6:50 PM								
		7:15	30	10	1:10	0	0	9:10	1.250
5:20 AM	11:05 AM								
3:40 PM	5:40 PM								
		7:45	30	0	48	0	0	9:11	1.185
6:00 AM	12:48 PM								
3:40 PM	4:40 PM								
		7:48	30	0	0	0	9	8:27	1.083
TRIPPERS									
7:04 AM	9:49 AM	2:45	15	0	0	0	0	3:00	1.091
2:55 PM	7:35 PM	4:40	15	0	0	0	0	4:55	1.054

Figure B-4. Sample calculations of work assignment PPR values.

If part-time operators' work assignment had a PPR value of 1.05 and their wages were three-quarters of regular drivers, the equivalent ratio would be 0.79. Because of the substantial wage differential in this example, it is possible to obtain equivalent PPR values less than one for part-time operators.

Step 2—Compute PPR Values For Each Hour

At the conclusion of Step 1, each run has a computed PPR value. The hours for which each work assignment's PPR values are included are then determined using the on and off times. In those cases where less than 30 min of an hour are worked, the PPR value is not included in that one-hour period. For example, the first straight run listed in Figure B-4 would have PPR values assigned to the eight one-hour periods form 6 AM to 2 PM. Because only 5 min are worked between 5 AM and 6 AM, that hour is not included. Similarly, the PPR value would not be applied to the hour beginning at 2 PM because 18 min is less than 30 min. On the other hand, the second straight run (5:15 AM to 1:00 PM) would include the 5:00 AM to 6:00 AM calculation because more than 30 min are worked. The half-hour rule would apply to all types of runs.

To compute the average PPR value for each hour, the PPR values that apply are summed and divided by the number of runs for that hour. Two methods are available to perform this calculation. One approach is to construct a table of work assignments (rows) vs. hours of the day (columns). The PPR value for a particular run is entered into all the cells for the appropriate hours (row). The average PPR values are computed as the average of a column which corresponds to a particular hour. This approach is best suited to systems that have fewer than 50 work assignments in a particular service day. An alternate approach is to select an hour period and record the PPR values from the work assignments. The total and average are then computed and the process repeated for each service hour.

Pay Category	Amount	Hours
RUNS OPERATED		
Scheduled Pay Time	$88,944	8,012
Unassigned Runs	1,662	153
Report	4,599	414
Pad	430	38
Travel Time	16	2
Subtotal	$95,651	8,691
PREMIUMS		
Spread	$5,090	459
Late-In	103	9
Over Workday	2,408	217
Day Off Premium	981	89
Out Early	95	9
Subtotal	$8,677	783
STANDBY & NON-OPERATING		
Unscheduled Service	$ 187	17
Dispatch, Supervision	1,006	90
Excused	93	9
Protection	456	42
Working Day Off	141	13
Subtotal	$1,884	171
TOTAL	$106,212	9,573

Figure B-5. Payroll distribution.

Step 3—Compute Vacancy Rate

The vacancy rate is determined for an audit period that corresponds to the agency payroll. In the case of LANTA, drivers are paid every 2 weeks and a 4-week period was used in model calibration (i.e., two pay periods). As shown in Figure B-5, LANTA's accounting system records the hours and amounts paid to drivers during the audit period. Excluded from the analysis are charter and various fringe benefit payments (e.g., holiday, vacation, and jury duty). As shown in Figure B-6, this total number of hours for which drivers are paid (9,573, as shown at the bottom of Figure B-5) is the numerator of the vacancy rate. The denominator is obtained by multiplying the pay-hours per week from the work assignments by the appropriate number of weeks in the audit period. The ratio of pay-hours from the payroll distribution to the pay-hours of the work assignments is the vacancy rate.

One point that should be noted about the vacancy rate is that it is not directly related to the number of the extraboard drivers, but rather to their use. This is attributable to the definition of wage and fringe benefit payments. For example, if a regular driver calls in sick and is paid a fringe benefit, while the extraboard driver is paid a wage, the vacancy rate is not affected because the unproductive time is considered a fringe benefit. The absenteeism is costly, but the unproductive time appears as a higher fringe benefit payment rather than a higher vacancy rate.

VACANCY RATE (Allentown)

Work Assignments

Days	Payhours per Week	Number of Weeks	Audit Period Payhours
Monday-Friday(5 days)	2,040.67	4	8,162.68
Saturday	254.02	4	1,016.08
	2,294.69	4	9,178.76

Payroll Distribution Audit Period Payhours	9,573

$$\text{Vacancy Rate} = \frac{9,573}{9,178.76} = 1.043$$

AVERAGE WAGE RATE (Allentown and Easton)

Pay Period	Payhours	Amount
7/22	6,866	$75,615
8/5	6,788	75,519
Audit Period	13,654	$151,134

$$\text{Average Wage Rate} = \frac{\$151,134}{13,654} = \$11.07$$

FRINGE BENEFIT MULTIPLIER (Allentown and Easton)

Expense	Amount
Wages	$1,686,933
Fringe Benefits	680,301
Total	2,367,234

$$\text{Fringe Benefit Multiplier} = \frac{2,367,234}{1,686,933} = 1.403$$

Figure B-6. Computation of vacancy rate, average wage rate, and fringe benefit multiplier.

Step 4—Compute Average Wage Rate

LANTA is similar to most transit systems in that the hourly wage rate is based on years of service. To determine an average value, the hours and payroll amount of the audit period are used. Because both the Allentown and Easton Divisions are covered by a single labor agreement, one average wage rate was computed for the system.

Step 5—Compute Fringe Benefit Multiplier

Because the fringe benefit payments vary by month (e.g., many vacations are taken in summer), annual statistics from the Section 15 Report were used. As shown in Figure B-6, the multiplier is merely the ratio of total compensation to wages. In some systems, the Section 15 data include two listings of wages, one for drivers and one for other personnel, while only a single value is presented for fringe benefits. For these systems, the wage amounts should be used to proportion the fringe benefits to drivers and other personnel involved in vehicle operations.

Schedule-Based Method

This method is an adaptation of the Adelaide model that is simple to calibrate and apply. It assumes a simple scheduling algorithm as to the use of straight versus split runs and trippers. The run that is scheduled depends on the time of day of the service change. Similar to the Pay-to-Platform Ratio method, PPR values are computed. One major difference is that the PPR values are calculated by type of run and day of the week rather than individual values by hour. In this sense, the Schedule-Based method may be viewed as a simplified version of the PPR method. The other parameters (i.e., vacancy rate, average wage rate, and fringe benefit multiplier) are identical with the PPR method. The calibration of the method is explained in the following using the Allentown data.

Step 1—Compute PPR Values for Each Run Type

The total number of platform-hours and pay-hours are summed by run type using the work assignment data for weekdays. As shown in Figure B-7, hours are computed for straights, splits, and trippers. For weekend service (i.e., Saturday only for Allentown), the hours for all runs are computed with no distinction between types of runs. This reflects the common situation where service is relatively uniform throughout the day. In the event peaking does exist during the weekend, a similar tabulation as that for weekdays could be performed.

Step 2—Compute Other Cost Parameters

The vacancy rate, average wage rate, and fringe benefit multiplier are estimated in the same way as for the PPR method. However, in the actual calibration process it is not necessary to estimate these three parameters separately because only the product of the three is needed for the application. This product is the fully loaded drivers' compensation per platform-hour.

Run Type	Platform Hours	Payhours	PPR
WEEKDAY			
Straight	145.37	152.98	1.05[1]
Split	214.27	252.75	1.18
Trippers	5.50	6.00	1.09
Splits & Trippers	219.77	258.75	1.18[1]
Total	365.14	411.73	1.13
SATURDAY			
All	232.22	254.02	1.09[1]

1/ PPR value used in model.

Figure B-7. Computation of PPR values by run type and day.

Step 3—Compute Unit Cost Values

The unit cost values are computed using the equations presented in Figure B-8. All unit costs are per platform-hour and differ only by time of day (weekday peak and off-peak) and service day. In the event either Saturday or Sunday service exhibits peaking, the peak and off-peak approach should be applied to weekend service days as appropriate.

Worksheet Method

As the name implies, this cost model requires a series of

$Cpp = AWR \times VR \times FBM \times P_1$

$Cop = AWR \times VR \times FBM \times (2P_2 - P_1)$

$C_{sat} = AWR \times VR \times FBM \times P_3$

where:

Cpp =	unit cost per weekday peak period platform hour
Cop =	unit cost per weekday off-peak period platform hour
C_{sat} =	unit cost per Saturday platform hour
P_1 =	pay-to-platform ratio for split runs and trippers
P_2 =	pay-to-platform ratio for all straight runs
P_3 =	pay-to-platform ratio for all Saturday runs
AWR =	average wage rate
VR =	vacancy rate
FBM =	fringe benefit multiplier

The three required PPR values were estimated in Figure B-7 and the other three required factors are the same as for the PPR Method, as estimated in Figure B-6. Based on these data, the three unit cost values are:

C_{pp} = (\$11.07) (1.043) (1.403) (1.18) = \$19.11 per platform hour

C_{op} = (\$16.20) [2(1.05) - 1.18] = \$14.90 per platform hour

C_{sat} = (\$16.20) (1.09) = \$17.66 per platform hour

Figure B-8. Computation of unit cost values for the Schedule-Based method.

Number of Days in Audit Period

Weekdays	20
Saturdays	4
Sundays and Holidays	0

Wages and Premiums During Audit Period (from Attachment A)

	Weekdays	Saturdays	Sundays
Full-Time Drivers			
Wages for Runs Operated	84,897	10,755	0
Wages for Standby & Other Non-Operating Time	1,670	214	0
Subtotal--Wages	86,567	10,969	0
Premiums	7,867	810	0
Part-Time Drivers			
Wages and Premiums	0	0	0
Total Wages and Premiums	94,434	11,779	0

Fringe Benefits During Audit Period (from Attachment B)

Wage-Based Fringe Benefits (e.g. FICA)	10,484
Non-Wage-Based Fringe Benefits	32,351

Wage Rates and Guarantee Hours for Straight Runs

Average Base Wage for Full-Time Drivers ($/Hour)	11.07
Guarantee Hours of Pay Per Run (Hours)	8
Ave. Report, Turn-In, and Travel Time Per Run (Min.)	15

Number of Vehicles Operated During Peak Periods

AM Peak	36
PM Peak	38
Total Peak Vehicles	74

Vehicle Hours Per Day

Weekdays	365.13
Saturdays	232.20
Sundays and Holidays	0

Figure B-9. Worksheet 1—required data.

1. Allocate wage-based fringes in proportion to total wages and premiums

$$\text{WBF Factor} = \frac{\text{(Wage-Based Fringe Benefits)}}{\text{(Weekday + Saturday + Sunday Wages \& Premiums)}} = \frac{10{,}484}{94{,}434 + 11{,}779 + 0} = 0.0987$$

Weekday Share = (WBF Factor) x (Weekday Wages & Premiums) = 0.0987 x 94,434 = 9,321

Saturday Share = (WBF Factor) x (Saturday Wages & Premiums) = 0.0987 x 11,779 = 1,163

Sunday Share = (WBF Factor) x (Sunday Wages & Premiums) = 0.0987 x 0 = 0

2. Allocate non-wage-based fringes in proportion to wages for full-time drivers

$$\text{NWBF Factor} = \frac{\text{(Non-Wage-Based Fringe Benefits)}}{\text{(Weekday + Saturday + Sunday Full-Time Driver Wages)}} = \frac{32{,}351}{86{,}567 + 10{,}969 + 0} = 0.3317$$

Weekday Share = (NWBF Factor) x (Weekday Full-Time Driver Wages) = 0.3317 x 86,567 = 28,713

Saturday Share = (NWBF Factor) x (Saturday Full-Time Driver Wages) = 0.3317 x 10,969 = 3,638

Sunday Share = (NWBF Factor) x (Sunday Full-Time Driver Wages) = 0.3317 x 0 = 0

3. Calculate total weekday, Saturday, and Sunday costs (including fringe benefits) for audit period.

	Weekday	Saturday	Sunday
Wages and Premiums	94,434	11,779	0
Wage-Based Fringes	9,321	1,163	0
Non-Wage-Based Fringes	28,713	3,638	0
Total	132,468	16,580	0

Figure B-10. Worksheet 2—weekday/weekend cost allocation.

calculations that can be made using a set of tables in a fixed sequential format (Figures B-9 through B-16). All data required for model calibration are listed on the first page. For certain data items, information is taken directly from the transit operator's files, while some entries require intermediate calculations. These operations are listed separately as attachments to the four worksheets. The calibration steps are described in terms of the required input data in the seven steps described as follows.

Step 1—Number of Days in Audit Period

In the Allentown example, a 4-week period was selected that corresponds to two pay periods. As indicated at the top of Figure B-9, this results in 20 weekdays and 4 Saturdays, because no Sunday service is operated.

Step 2—Wages and Premiums during Audit Period

As shown in Attachment A of the worksheet (Figures B-13 to 15), the wages paid drivers from the work assignment sheets can be stratified into various categories by service day. The first page of Attachment A (Figure B-13) shows the categories of audit period wages and premiums required. The second page (Figure B-14) shows the breakdown of hours required by weekday and weekend, and the third page (Figure 15) shows the calculations required to get a stratification of wages and premiums by category for weekdays and weekends. Because payroll distributions do not provide wages paid by day of the week during the audit period, certain intermediate calculations are required. As shown in Figure B-14, pay-hours by categories are available from the weekday and Saturday work assignments.

1. Calculate cost (including fringe benefits and associated non-operating time) for a straight run at the minimum guarantee (CPSR):

$$\text{CPSR} = \left(\text{GH} \times \text{BWR} + \frac{\text{CNOT}}{\text{TPV} \times \text{NWD}}\right) \times (1 + \text{WBFF} + \text{NWBFF}) = \left(8 \times 11.07 + \frac{1670}{74 \times 20}\right) \times (1 + 0.0987 + 0.3317) = 128.29$$

where

GH	=	Guarantee hours of pay per day worked from Worksheet 1
BWR	=	Ave. base wage rate for full-time drivers from Worksheet 1
CNOT	=	Wages for standby and other non-operating time during the audit period from Worksheet 1
TPV	=	Total (AM+PM) peak vehicles from Worksheet 1
NWD	=	Number of weekdays in the audit period from Worksheet 1
WBFF	=	Wage-Based Fringe (WBF) Factor from Worksheet 2
NWBFF	=	Non-Wage-Based Fringe (NWBF) Factor from Worksheet 2

2. Calculate vehicle hours for a straight run at the minimum guarantee (VHPSR).

$$\text{VHPSR} = \text{GH} - \frac{\text{ARTT}}{60} = 8 - \frac{15}{60} = 7.75$$

where

GH	=	Guarantee hours of pay per day worked from Worksheet 1
ARTT	=	Average report, turn-in, and travel time (minutes) from Worksheet 1

Figure B-11. Worksheet 3—costs and hours for straight runs.

1. Calculate driver cost (including fringes) per weekday (CPWD):

132,468 20

CPWD = TWDC / NWD = 6,623

where

TWDC = Total weekday driver cost (including fringes) for the audit period from Worksheet 2

NWD = Number of weekdays in the audit period from Worksheet 1

2. Calculate marginal cost for weekday vehicle hours (MCWDH):

128.29 74 6,623 7.75 74 365.13

MCWDH = (CPSR x TPV - CPWD)/(VHPSR x TPV - WDVH) = 13.77

where

CPSR = Cost per straight run from Worksheet 3

TPV = Total (AM+PM) peak vehicles from Worksheet 1

CPWD = Cost per weekday as calculated above

VHPSR = Vehicle hours per straight run from Worksheet 3

WDVH = Vehicle hours per day for weekdays from Worksheet 1

3. Calculate marginal cost for total (AM+PM) peak vehicles (MCTPV):

6,623 365.13 13.77 74

MCTPV = (CPWD - WDVH x MCWDH) / TPV = 21.54

where all variables are as defined in Step 2

4. Calculate marginal cost for Saturday vehicle hours (MCSATH):

16,580 4 232.20

MCSATH = TSATC / (NSAT x SATVH) = 17.85

where

NSAT = Number of Saturdays in audit period from Worksheet 1

SATVH = Vehicle hours per day for Saturdays from Worksheet 1

TSATC = Total Saturday driver costs (including fringes) for the audit period from Worksheet 2

4. Calculate marginal cost for Sunday vehicle hours (MCSUNH):

MCSUNH = TSUNC / (NSUN x SUNVH) = 0

where

NSUN = Number of Sundays in audit period from Worksheet 1

SUNVH = Vehicle hours per day for Sundays from Worksheet 1

TSUNC = Total Sunday driver costs (including fringes) for the audit period from Worksheet 2

Figure B-12. Worksheet 4—calculation of marginal costs.

	Audit Period Wages and Premiums
Wages for Runs Operated:	
Scheduled Pay Time	$88,944
Unassigned Runs-Trippers	1,662
Line Service Report In	4,599
Line Service Pad	430
Travel Time	16
Subtotal	$95,651
Premiums:	
Line Service Spread	$5,090
Late In	103
Line Over Workday Premium	2,408
Line Service Day Off Premium	981
Out Early	95
Subtotal	$8,677
Wages for Standby and Other Non-Operating Time:	
Unscheduled Extra Service	$187
Dispatcher, Receiver, Supervisor	1,006
Excused	93
Protection	456
Working on Day Off	141
Subtotal	$1,884
Total Wages and Premiums	$106,212

Figure B-13. Attachment A of worksheet—analysis of payroll distribution—Allentown.

This is the same source information used to compute PPR values for the Pay-to-Platform Ratio and Schedule-Based methods. The weekday results are multiplied by 5 (Monday through Friday) and added to Saturday to obtain weekly totals.

These results are used to compute percentage of pay-hours by category for each service day as shown in Figure B-14. These percentages are then applied to the wages paid from the payroll distribution as shown in Figure B-15, to estimate drivers' wages by service day.

Two points should be noted regarding this step. Allentown has a limited span and does not use part-time operators. For systems that provide service 7 days a week, a third column for Sundays would be required. Also, where part-time operators are used, their wages and premiums would be required separately in addition to wages and premiums for full-time operators. In nearly all cases these expenditures would be for weekday operations.

	Hours			Percent	
	Monday-Friday	Saturday	Total	Weekday	Saturday
Platform Time:					
Assigned Runs	1,775:35	227:33	2,003:08	88.64%	11.36%
Unassigned Runs	33:35	4:40	38:15	87.80	12.20
Report In	93:30	9:30	103:00	90.78	9.22
Pad	10:55	0:35	11:30	94.93	5.07
Spread	95:30	4:54	100:24	95.12	4.88
Over Work Day	31:35	6:49	38:24	82.25	17.75
Total	2,040:40	254:01	2,294:41	88.93%	11.07%

Figure B-14. Attachment A of worksheet—analysis of driver pay and assignment sheets—Allentown.

Step 3—Fringe Benefits During Audit Period

The objective of this step is to compute fringe benefits for the audit period based on annual statistics from the Section 15 Report. As shown in Attachment B of the worksheet (Figure B-16), certain intermediate calculations are required. Similar to the PPR method for the calculation of the fringe benefit multiplier, fringe benefits are computed as a percentage of wages. This percentage is multiplied by the total drivers' wages paid during the audit period.

Nonwage-based fringe benefits are computed as a percentage

Wages for Runs Operated:	Audit Period Wages and Premiums	Percent Weekday	Percent Saturday	Amount Monday-Friday	Amount Saturday
Scheduled Pay Time	$88,944	88.64%	11.36%	$78,840	$10,104
Unassigned Runs-Trippers	1,662	87.80	12.20	1,459	203
Line Service Report In	4,599	90.78	9.22	4,175	424
Line Service Pad	430	94.93	5.07	408	22
Travel Time	16	88.64	11.36	15	2
Subtotal	$95,651			$84,897	$10,755
Premiums:					
Line Service Spread	$5,090	95.12	4.88	4,842	248
Late In	103	88.64	11.36	91	12
Line Over Workday Premium	2,408	82.25	17.75	1,981	427
Line Service Day Off Premium	981	88.64	11.36	869	111
Out Early	95	88.64	11.36	84	11
Subtotal	$8,677			$7,867	$810
Wages for Standby and Other Non-Operating Time:					
Unscheduled Extra Service	$187	88.64	11.36	166	21
Dispatcher, Receiver, Supervisor	1,006	88.64	11.36	892	114
Excused	93	88.64	11.36	83	11
Protection	456	88.64	11.36	404	52
Working on Day Off	141	88.64	11.36	125	16
Subtotal	$1,884			$1,670	$214
Total Wages and Premiums	$106,212			$94,434	$11,778

Figure B-15. Attachment A of worksheet—audit period wages and premiums—Allentown.

Estimation of Total Fringe Benefits for Operators during the Audit Period

From Form 310 (Section 15 Report) for Vehicle Operations:

Operators' Salaries and Wages	$1,686,933
Other Salaries and Wages	89,097
Total Salaries and Wages for Vehicle Operation	$1,776,030
Fringe Benefits for Vehicle Operation	$716,232

Multiplier for Total Fringe Benefits = $716,232/$1,776,030 = 0.4033

	Audit Period Wages & Premiums	Multiplier for Total Fringes	Total Fringes for Audit Period
Allentown	$106,212	0.4033	$42,835
Easton	$27,815	0.4033	$11,218

Estimation of Wage-Based Fringe Benefits during Audit Period

Wage-based fringe benefits (FICA and Workmen's Compensation Insurance) for all employees from Form 331 (Section 15 Report):

FICA or Railroad Retirement	$183,942
Workmen's Compensation Insurance	55,162
Total Wage-Based Fringe Benefits	$239,104

Wages and salaries for all employees from Form 310 = $2,422,285

Multiplier for wage-based fringe benefits = $239,104/$2,422,285 = 0.0987

	Audit Period Wages & Premiums	Multiplier for Wage-Based Fringe Benefits	Wage-Based Fringe Benefits for Audit Period
Allentown	$106,212	0.0987	$10,484
Easton	$27,815	0.0987	$ 2,746

Estimation of Non-Wage-Based Fringe Benefits for Audit Period

Non-wage-based fringe benefits are calculated as the difference between total fringe benefits and wage-based fringe benefits:

	Total	Wage-Based	Non-Wage-Based
Allentown	$42,835	$10,484	$32,351
Easton	$11,218	$2,746	$8,472

Figure B-16. Attachment B of worksheet—analysis of fringe benefits.

of total benefits from Form 331 of the Section 15 Report. This is an approximation because it includes fringe benefits for all employees. By multiplying this percentage by the audit period wages, the amount expended on nonwage-based fringe benefits for drivers is estimated. The difference between total and nonwage-based fringe benefits is the wage-based component of fringe benefits.

Step 4—Wage Rates and Guarantee Hours for Straight Runs

The average wage rate is computed from the payroll distribution for the audit period. This calculation is identical to that described for the PPR method. Guarantee hours, report time, and turn-in time were taken directly from the labor agreement. If a transit system had extensive field relief with relatively high payments for travel time, an average value should be computed from the listing of work assignments and added to the report and turn-in time.

Step 5—Number of Vehicles Operated during Peak Periods

This information should be readily available. In the unlikely event that these data are not available, the pull-out and pull-in information from the work assignments would have to be tabulated.

Step 6—Vehicle-Hours per Day

These statistics correspond to platform-hours on the work assignment sheets.

Step 7—Perform Calculations

Having developed the necessary data base (Steps 1 through 6), the calculations are performed as indicated on the last three worksheets (Figures B-10, 11, and 12).

CALIBRATION OF MODELS AT TEST SITES

An earlier section of this appendix provided a brief description of the test sites in terms of operating characteristics that influence transit costs. Utilizing information provided by the three transit agencies, the research team calibrated each of the cost models for each of the transit agencies. Because LANTA has two operating divisions, separate models were calibrated for Allentown and Easton. The results for both operating divisions are presented here, although the testing program was carried out using service changes for the Allentown operating division. Also, Long Beach calibration results are presented, although that agency did not participate in the application phase of the research.

The first two models (i.e., one and two variable cost models) do not distinguish bus operating cost by driver versus nondriver or time of day. For these simple models, a cost allocation process was used, with the following results:

	One Variable	Two Variable	
	Cost/Hour	Cost/Hour	Cost/Mile
LANTA	27.28	18.08	0.70
VIA	22.83	13.38	0.67
Long Beach	30.42	18.35	1.04
OCTD	38.00	24.62	0.87

The one variable cost model was devised by merely dividing total variable expenses by vehicle-hours operated. The two variable cost model was derived by allocating all budget items to either vehicle-hours or vehicle-miles and then dividing the two subtotals by the totals for these two variables.

The two variable cost model is sensitive to speed because it includes vehicle-hours and vehicle-miles.

A different version of the two variable cost model was developed by eliminating costs associated with drivers' compensation for use as the nondriver cost model for the test sites.

Nondriver Costs

Because all of the proposed techniques estimated variable costs of service changes, an initial step was the allocation of operating expenses into fixed and variable categories, with only the latter being used in the present analysis. As part of this process, variable operating costs were stratified by driver-related (i.e., operator wages and fringe benefits) and nondriver-related expenses. The concluding step for calibration of the nondriver cost models was the allocation of the nondriver expenses to either vehicle-hours or vehicle-miles, as is typically performed in the development of a cost allocation model.

The results of this process for the four test sites are presented in Figure B-17. Because the Section 15 Report was used in the development of the nondriver cost model, a single formula was determined for LANTA. Expenditure data are not compiled by operating division in the Section 15 Report. The allocation of expenses by cost category indicates that fixed expenditures comprise only about 15 percent of system operating expenses at LANTA and Long Beach, but slightly over 25 percent at VIA and OCTD. Driver-related expenses comprise between 41 and 54 percent of total operating costs and between 55 and 64 percent of variable operating costs.

Nondriver-related variable costs account for about one-third of total operating expenses (fixed and variable). By assigning each of the nondriver-related cost items to either vehicle-hours or vehicle-miles and dividing by the appropriate operating statistic, unit cost factors were computed for each of the two variables. The nondriver cost model can be applied and added to the estimate of drivers' wages and fringe benefits from each of the driver cost models to estimate the total (driver and nondriver) incremental cost of a service change.

Driver Costs

Average driver cost per vehicle-hour was calculated from the Section 15 Report for each of the four test sites:

LANTA	$17.17
VIA	$12.50
Long Beach	$18.29
OCTD	$22.25

Category	LANTA Amount (000)	LANTA Percent	VIA Amount (000)	VIA Percent	LONG BEACH Amount (000)	LONG BEACH Percent	OCTD Amount (000)	OCTD Percent
Cost by Category:								
Fixed	$659.7	15%	$8,934.4	26%	$2,478.9	14%	$16,106.7	27%
Variable								
Driver-Related	2,367.2	54	13,982.4	41	9,485.4	52	26,231.6	43
Non-Driver-Related	1,395.1	31	11,548.2	33	6,289.1	34	18,567.2	30
Subtotal	$3,762.3	85%	$25,530.6	74%	$15,774.5	86%	44,798.8	73%
Total	$4,422.0	100%	$34,465.0	100%	$18,253.4	100%	60,905.5	100%
Allocation of Non-Driver-Related Costs:								
Vehicle Hours	125.5	9	986.7	9	30.2	1	2,793.5	15
Vehicle Miles	1,269.6	91	10,561.5	91	6,258.9	99	15,773.7	85
Subtotal	$1,395.1	100%	$11,548.2	100%	$6,289.1	100%	18,567.2	100%
Model Development:								
Operating Statistics:								
Vehicle Hours (000)	137.9		1,118.3		518.6		1,178.9	
Vehicle Miles (000)	1,825.5		15,853.0		6,025.8		18,182.8	
Unit Cost Factors:								
$/Vehicle Hour	0.91		0.88		0.06		2.37	
$/Vehicle Mile	0.70		0.67		1.04		0.87	

Figure B-17. Development of nondriver cost models.

These costs include driver wages, premiums, and fringe benefits.

The use of these annual systemwide average driver costs, together with the cost allocation approach for nondriver costs, is identical to the traditional two-variable model used by many agencies to estimate variable costs.

For the other three methods, driver costs are estimated for an "audit" period of much shorter duration. In the case of LANTA and VIA, this period included 4 weeks' experience (i.e., two pay periods) while for Long Beach the calibration was for a single month. The selection of these audit periods reflects the desire to have information for a long enough period to assure representative data. Accounting practices at each test site determine the precise period used.

Presented below is a brief summary of the calibration results for the participating transit agencies.

PPR Method

As shown in Figure B-18, the key feature of this method is that each vehicle-hour of bus operations produces different pay-hours because of the various provisions in the collective bargaining agreement and the number of proportion of work assignment types. Typically, the weekday peak periods have higher PPR values than weekday off-peak or weekend periods. This reflects the consequences of premium payments such as spread penalties and overtime.

Overall, VIA's PPR values are relatively low and do not exhibit much variation by time of day and day of the week. This reflects the prevailing agreement in which hours in excess of 8 (daily) or 40 (weekly) are paid at straight time.

Long Beach results reflect two countervailing relationships for weekday service. The use of part-time operations with relatively low PPR assignments are offset by trippers at time and a half. Also both regular and part-time drivers receive the same wage rate.

Three other factors are computed as part of the PPR method. Vacancy rate measures the ratio of total pay-hours to pay-hours for actual work assignments, based on the payroll distribution and work assignments used in the PPR computations. Values greater than one reflect payments for training, completion of accident reports, standby time, and unscheduled overtime, to cite only a few.

Because drivers' wages are based on a sliding scale related to years of experience, the average wage rate is computed as the total wages divided by the total pay-hours.

The final factor is the fringe benefit multiplier, which includes payroll taxes, health insurance, vacation, sickness, and similar payments. The PPR method does not distinguish between wage-based (e.g., FICA) and nonwage-based (e.g., life insurance premiums) fringe benefits. One striking point is that the fringe benefit multiplier at all test sites is substantial. Fringe benefits paid to drivers represent a significant expense item in providing bus service.

Worksheet Method

This approach relies on a series of steps that allocate drivers' wages and fringe benefits to different time periods and days of the week. In turn, these costs are divided by the number of vehicle-hours operated. As shown in Figure B-19, separate unit cost values (per vehicle-hour) are computed for weekdays, Saturday, and Sunday. For weekday service, the same vehicle-hour unit cost is used for peak and off-peak periods. The "penalty" for peak period service is computed as the cost per peak vehicle.

One interesting point is that weekday vehicle-hour unit cost is less than the product of the average wage rate, vacancy rate, and fringe benefit multiplier for the three test sites. This reflects the fact that the marginal cost of a service change is not equal to the average cost of present service. This is particularly true at Long Beach Transit and OCTD because of the use of trippers

Hour Beginning	ALLENTOWN Weekday	ALLENTOWN Saturday	EASTON Weekday	EASTON Saturday	VIA Weekday	VIA Saturday	VIA Sunday	LONG BEACH Weekday	LONG BEACH Saturday	LONG BEACH Sunday	OCTD Weekday	OCTD Saturday	OCTD Sunday
	PPR VALUES												
12 AM	1.043							1.046	1.038	1.039			
1 AM								1.067	1.067	1.067			
2 AM													
3 AM													
4 AM													
5 AM	1.106	1.066	1.052		1.038	1.021	1.020	1.055	1.061	1.047	1.117	1.116	1.109
6 AM	1.157	1.113	1.117	1.148	1.046	1.034	1.021	1.088	1.075	1.062	1.165	1.119	1.109
7 AM	1.153	1.124	1.117	1.174	1.049	1.037	1.021	1.127	1.088	1.073	1.179	1.122	1.114
8 AM	1.135	1.116	1.113	1.113	1.051	1.038	1.021	1.081	1.089	1.076	1.160	1.133	1.124
9 AM	1.130	1.112	1.107	1.106	1.048	1.037	1.020	1.073	1.088	1.077	1.162	1.131	1.140
10 AM	1.107	1.085	1.076	1.085	1.038	1.037	1.020	1.064	1.071	1.076	1.152	1.132	1.141
11 AM	1.060	1.066	1.065	1.085	1.036	1.035	1.019	1.062	1.054	1.065	1.135	1.125	1.138
12 NOON	1.060	1.063	1.070	1.080	1.036	1.029	1.018	1.061	1.047	1.055	1.112	1.119	1.123
1 PM	1.108	1.063	1.074	1.077	1.038	1.036	1.019	1.068	1.045	1.046	1.144	1.114	1.125
2 PM	1.131	1.083	1.093	1.077	1.040	1.033	1.018	1.083	1.056	1.058	1.170	1.126	1.129
3 PM	1.148	1.100	1.115	1.077	1.050	1.037	1.018	1.129	1.062	1.061	1.178	1.131	1.138
4 PM	1.145	1.104	1.115	1.077	1.046	1.036	1.021	1.119	1.066	1.063	1.165	1.131	1.143
5 PM	1.150	1.104	1.112	1.098	1.045	1.036	1.021	1.072	1.057	1.058	1.159	1.135	1.144
6 PM	1.132	1.112	1.113	1.101	1.046	1.036	1.022	1.062	1.051	1.051	1.141	1.142	1.144
7 PM	1.066	1.054			1.045	1.030	1.020	1.052	1.038	1.046	1.134	1.132	1.146
8 PM	1.066				1.038	1.028	1.020	1.044	1.039	1.035	1.124	1.132	1.127
9 PM	1.066				1.025	1.032	1.020	1.039	1.041	1.038	1.117	1.135	1.138
10 PM	1.043				1.020	1.028	1.020	1.041	1.040	1.037	1.122	1.138	1.138
11 PM	1.043				1.020	1.032	1.020	1.044	1.040	1.038	1.113	1.139	1.139

	ALLENTOWN	EASTON	VIA	LONG BEACH	OCTD
Vacancy Rate	1.043	1.021	1.099	1.079	1.078
Average Wage Rate	$11.07	$11.07	$9.12	$11.75	$12.45
Fringe Benefit Multiplier	1.403	1.403	1.357	1.427	1.456

Figure B-18. Development of Pay-to-Platform Ratio models.

	Allentown	Easton	VIA	Long Beach	OCTD
Worksheet Method					
Unit Costs:					
Weekday Vehicle Hours	$13.77	$15.29	$12.75	$12.74	$12.97
Weekday Peak Vehicles	21.54	8.00	6.79	43.29	61.11
Saturday Vehicle Hours	17.85	16.54	14.10	17.68	22.55
Sunday Vehicle Hours	-	-	13.86	17.67	22.24
Schedule-based Method					
Average Wage Rate	$11.07	$11.07	$9.12	$11.75	$12.45
Vacancy Rate	1.043	1.021	1.099	1.079	1.078
Fringe Benefit Multiplier	1.403	1.403	1.357	1.427	1.456
PPR Values:					
Weekday Splits & Trippers	1.181	1.139	1.048	1.129	1.193
Weekday Straights	1.053	1.058	1.034	1.058	1.144
Saturday Runs	1.094	1.092	1.035	1.062	1.132
Sunday Runs	-	-	1.020	1.058	1.136
Unit Cost Per Vehicle Hour:					
Weekday Peak	$19.12	$18.08	$14.24	$20.43	$23.31
Weekday Off-Peak	14.91	15.54	13.86	17.86	21.40
Saturday	17.66	17.29	14.08	19.21	22.12
Sunday	-	-	13.87	19.14	22.20

Figure B-19. Development of Worksheet and Schedule-Based methods.

at overtime wage rates. For this reason, the addition of peak period service would be relatively costly. On the other hand, added midday service would be relatively inexpensive because trippers could be converted to straight runs.

Schedule-Based Method

The concluding driver cost model proposed and tested as part of the current analysis attempts to combine features of the Adelaide and PPR methods. The output of the calibration process is separate unit cost values per vehicle-hours for weekday peak and off-peak, Saturday, and Sunday services. For all test systems, the highest unit costs are observed for the weekday peak period (Figure B-19). The relative costs for the other periods differ among the systems, reflecting provisions of the collective bargaining agreement and the proportion of work assignment types.

SERVICE CHANGE TEST CASES

A two-step process was followed in specifying service changes to be costed by the various methods. Initially, a series of generic changes were delineated that would apply at all test sites. Next, each operator was requested to formulate a service proposal that satisfied the generic requirements of the testing program and was reasonable in terms of local conditions. A more detailed description of the process of defining service changes is presented in the remainder of this section.

As shown in Figure B-20, 20 service changes were specified at the outset of the testing program. The objective was to identify a representative mix of service changes typically evaluated by transit agency personnel. As shown in Figure B-21, the 20 test cases were split evenly among increases and decreases. For the most part, the service changes were modifications to existing routes. These involved changes in headway, span, and route alignment. One test case called for the implementation of an entirely new route. Some service changes to existing routes were relatively substantial and comparable to adding a new route. For example, the last test case is a peak-period-only route extended to a full day of service. Because a key element of the analysis is the variation in operating costs by time of day, the test cases were chosen to be representative of all periods. Some test cases cover more than a single time period, as is often the case with actual service changes.

Meetings were held at each of the test sites to develop specific service changes in terms of routing, headway, and span, in accord with the 20 generic service changes listed in Figure B-20. All test cases were reasonable service change options.

As shown in Figure B-22, the service changes vary widely in terms of the number of vehicle-hours and vehicle-miles required. For VIA, results for one of the test cases did not appear reasonable and, for this reason, the case was deleted. For comparison purposes, the corresponding weekly values for the entire transit system are presented. As expected, each test case represents a relatively modest change in service levels in comparison to systemwide totals. This reflects the typical range of system changes evaluated by transit personnel. Nonetheless, the sum of all these changes would involve quite substantial changes in each system. In this analysis, however, the objective is to evaluate a representative sample of test cases (i.e., increases and decreases), rather than to evaluate the effects of all the service changes as a whole.

ESTIMATING INCREMENTAL COSTS

The next step in the testing program was to compute the cost of each service change using the various models and procedures. In addition, the "true" incremental costs were determined. Because the service changes included different service days, all estimates were prepared for a one-week period.

This section provides an overview of the application of the cost estimating methods as well as the resulting cost estimates. The following descriptions summarize the process of applying each method:

- *One Variable*—This approach relies on a single unit cost factor to estimate operating costs. For each test case, the number of vehicle-hours was estimated and multiplied by the appropriate unit cost value. No distinction is made between driver and nondriver costs.
- *Two Variable*—With this approach, the number of vehicle-hours and vehicle-miles with each service change was multiplied by the appropriate unit cost factors. Similar to the previous method, total incremental operating costs are estimated.
- *Pay-to-Platform Ratio Method*—This model estimates each cost component separately—driver and nondriver costs. The results are summed to obtain the incremental operating costs for a service change. Similar to the two-variable model, costs

1. Add new express route during peak periods only.
2. Reduce frequency of local route in peak periods only.
3. Reduce frequency of local route in midday period only.
4. Eliminate route with full span of service.
5. Add Saturday service on route that presently operates Monday through Friday only.
6. Delete weekend service on route that presently has full span of service.
7. Increase span (night service) on existing weekday route.
8. Reduce frequency on existing Saturday service route.
9. Increase frequency on existing Sunday service route.
10. Extend all trips on existing route with full weekday service.
11. Extend selected peak period trips on existing route.
12. Reduce service on existing route to peak-period-only service.
13. Short turn all midday trips on existing route.
14. Increase (double) frequency for weekday service during entire day.
15. Short turn all weekend trips on existing route.
16. Eliminate a peak-period-only route.
17. Increase frequency on local route in peak periods only.
18. Increase frequency on local route in midday period only.
19. Reduce span (night service) on existing weekday route.
20. Extend peak-period-only service to full span of service.

[1]/Because LANTA operates no Sunday service, all weekend changes for that system apply to Saturday only.

Figure B-20. Service change test cases. Because LANTA operates no Sunday service, all weekend changes for that system apply to Saturday only.

Test Case	Direction of Change: Increase	Direction of Change: Decrease	Type of Change: Frequency	Type of Change: Span	Type of Change: Alignment	Type of Change: New	Time Periods Affected: Weekday Peak	Time Periods Affected: Weekday Off-Peak	Time Periods Affected: Weekend
1	X					X	X		
2		X	X				X		
3		X	X					X	
4		X		X			X	X	X
5	X			X					X
6		X		X					X
7	X			X				X	
8		X	X						X
9	X		X						X
10	X				X		X	X	
11	X				X		X		
12		X		X				X	
13		X			X			X	
14	X		X				X	X	
15		X			X				X
16		X		X			X		
17	X		X				X		
18	X		X					X	
19		X		X				X	
20	X			X				X	
Total	10	10	7	8	4	1	8	10	6

Figure B-21. Characteristics of test cases.

other than drivers' wages and fringe benefits are estimated on the basis of vehicle-mile-unit cost factors. Driver costs are determined from a four-step procedure. First, the number of vehicle-hours by hour for each service day is multiplied by the appropriate PPR value. These results are summed to determine the change in pay-hours. Second, the pay-hours are multiplied by the vacancy rate. Next, this product is multiplied by the average wage rate to estimate drivers' wages. Finally, the fringe benefit multiplier is used to convert drivers' wages to total compensation. Estimates are prepared for pay-hours, wages, and fringe benefits.

- *Schedule-Based Method*—Similar to the PPR approach, nondriver costs are estimated using vehicle-hour and vehicle-mile-unit cost factors. Estimates of drivers' compensation rely on separate vehicle-hour-unit costs for weekday-peak, weekday-off-peak, Saturday, and Sunday. For this reason, vehicle-hours by time period and day of the week must be estimated. In turn, these operating statistics are multiplied by the appropriate unit cost factors and summed.
- *Worksheet Method*—In terms of unit cost factors, this method is nearly identical to the schedule-based approach. The nondriver costs use a two variable cost model. Driver costs for off-peak periods (weekday, Saturday, and Sunday) are estimated by multiplying the vehicle-hours and vehicle-hour-unit cost factor for each day. For peak periods, a peak vehicle unit cost is used, which requires an estimate of the change in peak vehicles.

The foregoing discussion indicates the procedures used in applying the proposed cost methods to each test case. The operating statistics that are input, the calibrated unit costs and factors, and the outputs are illustrated in Figure B-23. The figure shows the level of detail and information required by each ap-

Test Case	LANTA Vehicle Hours	LANTA Vehicle Miles	VIA Vehicle Hours	VIA Vehicle Miles	DCTD. Vehicle Hours	DCTD. Vehicle Miles
1	26.7	556	36.5	732	33.3	720
2	(22.5)	(283)	(36.4)	(601)	(40.9)	(648)
3	(32.5)	(393)	(30.9)	(458)	(21.8)	(237)
4	(72.0)	(1,268)	(388.5)	(5,541)	(163.8)	(2,992)
5	6.3	110	20.4	353	19.1	299
6	(12.8)	(196)	(233.6)	(2,462)	(45.0)	(718)
7	15.0	224	20.9	330	38.9	660
8	(8.1)	(88)	(26.7)	(407)	(24.4)	(313)
9	10.8	122	14.6	165	15.8	235
10	81.7	648	65.6	817	60.0	1,050
11	36.3	297	37.9	561	26.3	450
12	(40.0)	(444)	(133.1)	(1,275)	(65.8)	(776)
13	(27.5)	(165)	2/	2/	(26.8)	(156)
14	54.2	880	104.6	656	273.9	4,241
15	(12.6)	(137)	(9.8)	(128)	(1.0)	(16.0)
16	(23.3)	(420)	(41.6)	(791)	(184.3)	(4,182)
17	37.1	363	39.7	634	48.4	1,262
18	37.9	388	27.6	425	51.6	760
19	(18.4)	(310)	(116.3)	(1,611)	(21.3)	(387)
20	38.8	617	25.3	429	154	2,729
System 1/	2,651	35,106	21,508	304,865	22,671	349,668

( ) Denotes service reduction.

1/ Based on annual statistics from Section 15 Report divided by 52.

2/ This service change was not included in the analysis of the VIA test cases.

Figure B-22. Summary of test cases—weekly changes.

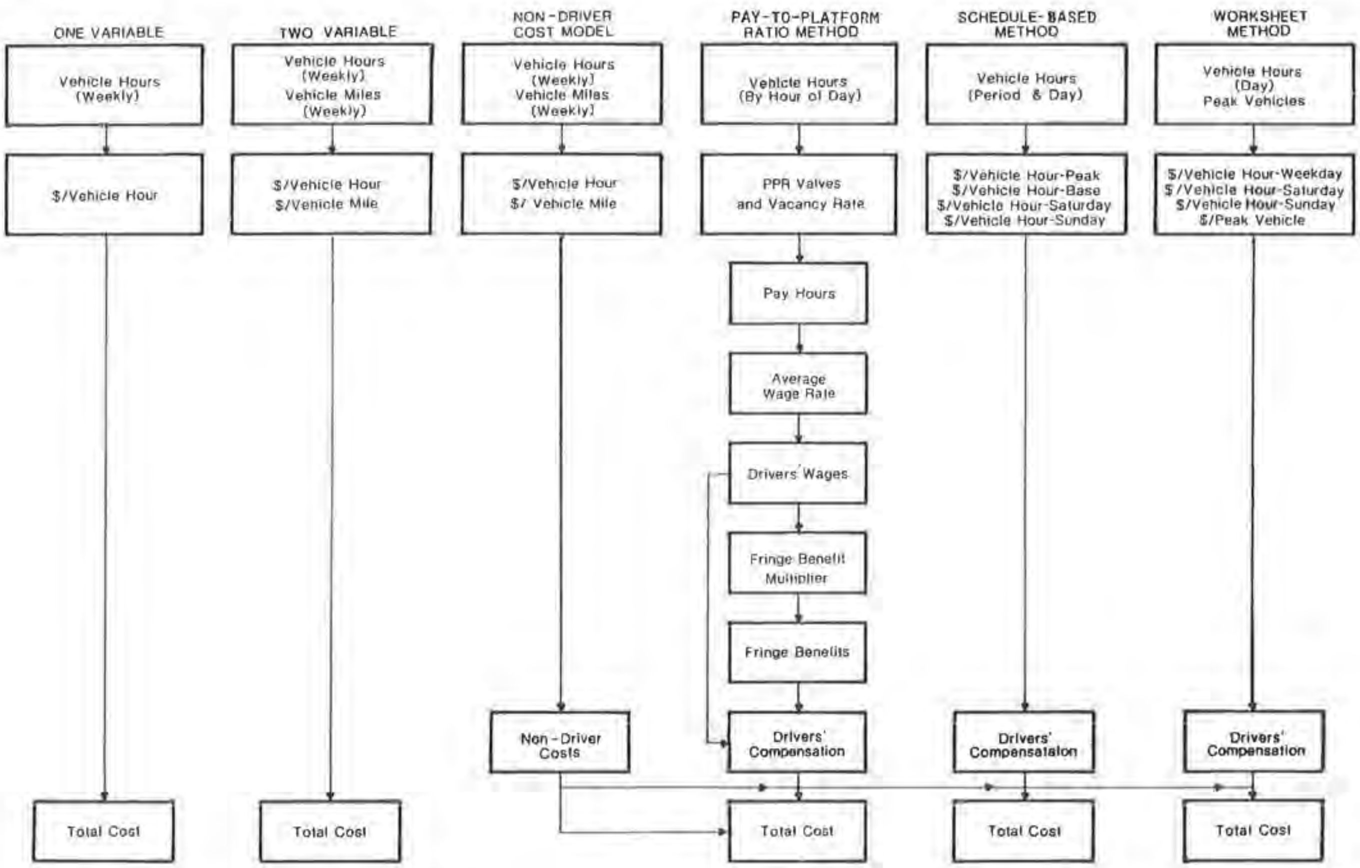


Figure B-23. Flow chart of costing procedures.

proach. As noted previously, the Schedule-Based method does not actually require separate estimates of the three multipliers used in the PPR method (vacancy rate, average wage rate, and fringe benefit multiplier). Only the product of the three, the fully loaded drivers' compensation per platform-hour, needs to be estimated. Therefore, the flow diagram has been shown in simplified form for this method in Figure B-23.

The final element in the preparation of cost estimates was the calculation of "true" costs. It should be recognized that the actual cost of a service change could be determined only by making a single service modification and measuring expenditures before and after the change. In view of the magnitude of the test cases, this approach would be impractical. A transit agency could not participate in such an experimental design. For this reason, a computational procedure was devised to estimate "true" costs. The estimate relies on the approach used for the PPR method. The one difference is that drivers' pay-hours are not computed from the PPR values, but rather is a direct output of the scheduling process. Pay-hours before and after the service changes were estimated by the scheduling department. The before period was based on the schedule in place during the calibration audit period.

For each service change, the test site transit agency prepared a runcut for each service change. Because each test case was analyzed individually, the runcut and schedule preparation was repeated for each of the 20 cases. The schedule department at each system was instructed to prepare a runcut as though the single service change was to be implemented in the next pick. The extent of changes to the schedule was left to the discretion of the scheduling department. The service change could be made by either a "patch," a complete restructuring, or an intermediate approach where schedule opportunities are exploited. In the case of LANTA, which relies on a manual runcut, some changes were made by a "patch" while others resulted in more significant changes to achieve higher efficiency. With an automated approach (as was used at VIA), the entire schedule for all routes and service were constructed. Thus, relatively minor changes in a single route can produce substantial shifts in run types. Regardless of the scheduling method, the resulting pay-hours were viewed as the best basis for estimating "true" costs because the schedule-maker would have the greatest input on incremental operating costs.

The resulting costs of each service change are presented in Figures B-24 through B-26 for the test sites.

CASE (see Figure B-20)	"TRUE" COST CHANGE	ONE VARIABLE	TWO VARIABLE	PAY-TO-PLATFORM RATIO	SCHEDULE-BASED	WORKSHEET
1	933	728	871	910	923	996
2	-517	-614	-605	-638	-649	-744
3	-640	-887	-863	-885	-789	-752
4	-2,107	-1,964	-2,189	-2,275	-2,235	-2,404
5	198	171	190	194	193	194
6	-376	-348	-368	-363	-374	-376
7	438	409	428	430	394	377
8	-208	-222	-209	-212	-213	-214
9	292	293	280	285	285	287
10	2,133	2,228	1,930	2,040	1,946	2,083
11	977	989	863	917	934	1,171
12	-891	-1,091	-1,034	-1,050	-944	-898
13	-431	-750	-613	-629	-551	-519
14	1,610	1,477	1,595	1,648	1,585	1,626
15	-325	-343	-323	-331	-330	-332
16	-689	-636	-716	-749	-761	-852
17	1,092	1,012	925	974	997	1,014
18	954	1,034	957	987	872	828
19	-609	-501	-549	-554	-507	-486
20	1,115	1,057	1,133	1,164	1,045	1,001

Figure B-24. Estimated weekly incremental costs for LANTA.

CASE (see Figure B-20)	"TRUE" COST CHANGE	ONE VARIABLE	TWO VARIABLE	PAY-TO-PLATFORM RATIO	SCHEDULE-BASED	WORKSHEET
1	823	833	978	1,042	1,042	1,089
2	-844	-830	-889	-952	-952	-966
3	-675	-704	-720	-770	-762	-727
4	-9,406	-8,869	-8,910	-9,567	-9,525	-9,551
5	630	465	509	541	541	542
6	-4,960	-5,333	-4,775	-5,124	-5,126	-5,128
7	660	476	500	532	528	505
8	-605	-610	-630	-672	-672	-673
9	386	333	306	326	326	326
10	1,824	1,498	1,425	1,534	1,524	1,475
11	1,034	865	883	949	949	926
12	-2,653	-3,038	-2,635	-2,852	-2,816	-2,668
13	(satisfactory results were not obtained for test case 13 for VIA)					
14	2,083	2,388	1,839	2,015	2,000	2,001
15	-160	-223	-216	-232	-231	-232
16	-1,007	-950	-1,086	-1,158	-1,159	-1,165
17	1,196	906	956	1,023	1,025	1,033
18	854	630	654	699	691	661
19	-2,692	-2,656	-2,636	-2,815	-2,794	-2,665
20	835	578	626	667	660	632

Figure B-25. Estimated weekly incremental costs for VIA.

CASE (see Figure B-20)	"TRUE" COST CHANGE	ONE VARIABLE	TWO VARIABLE	PAY-TO-PLATFORM RATIO	SCHEDULE-BASED	WORKSHEET
1	1,682	1,266	1,447	1,465	1,521	2,360
2	-1,470	-1,555	-1,571	-1,592	-1,615	-1,497
3	-682	-827	-741	-742	-723	-539
4	-7,469	-6,226	-6,636	-6,705	-6,685	-7,255
5	709	726	730	726	728	736
6	-1,838	-1,711	-1,734	-1,727	-1,730	-1,741
7	1,769	1,479	1,532	1,520	1,499	1,171
8	-807	-928	-874	-868	-853	-647
9	571	602	594	593	594	594
10	2,277	2,280	2,391	2,412	2,387	2,445
11	1,053	998	1,038	1,054	1,066	1,405
12	-2,590	-2,499	-2,294	-2,307	-2,238	-1,684
13	-736	-1,017	-794	-796	-772	-546
14	9,810	10,409	10,433	10,524	10,449	10,641
15	-35	-37	-38	-38	-38	-38
16	-9,251	-7,005	-8,613	-8,707	-8,809	-10,569
17	2,371	1,837	2,288	2,306	2,339	2,756
18	2,444	1,960	1,931	1,937	1,887	1,452
19	-804	-811	-862	-853	-844	-664
20	6,288	5,836	6,755	6,202	6,156	6,258

Figure B-26. Estimated weekly incremental costs for OCTD.

APPENDIX C

ASSESSMENT OF MORE COMPLEX MODELS

The point of departure for the review of existing models is an UMTA-sponsored research project which provides a relatively recent and comprehensive inventory of available cost estimating models. This appendix relies extensively on this research and builds on this data base in the current analysis. For this reason, those models that have been previously documented and summarized are only briefly described here and the reader is referred to the UMTA reports. Two models are documented in the same level of detail as the UMTA research because they have been developed only recently. The first is a modified version of the Adelaide model, revised to reflect American transit driver assignment and labor provisions, as opposed to those prevalent in British Commonwealth countries. The second is a new proposed method resulting from the UMTA research effort. This appendix provides a comprehensive reference without duplicating prior work.

In addition to the cost estimating procedures inventory, an assessment of existing models is presented in this appendix. This includes the selection of relevant evaluation criteria and their importance from the perspective of the intended users of cost estimating models. Similar to the inventory, this study augments and integrates the results presented in the UMTA research effort. This includes not only technical issues related to accuracy and sensitivity, but also the ease of use in terms of calibration and application. A key distinguishing feature of the current study in comparison with the earlier UMTA effort is the importance placed on ease of use and the resulting likelihood of model use.

The concluding element of this appendix is the findings based on the evaluation of existing methods. This includes their strengths and weaknesses, and tradeoffs associated with often conflicting evaluation criteria. Using the results of the assessment, the research team provides recommendations regarding desirable features of models. This includes a range of factors that affect the suitability of a particular model or technique as well as the probability of attaining wide use in the transit industry.

EXISTING MODELS

As noted above, the UMTA effort provided extensive documentation of available techniques at the outset of that research effort. This work is documented in *Bus Route Costing Procedures: A Review* prepared by Booz, Allen and Hamilton for the Urban Mass Transportation Administration in May 1981. Throughout this section, frequent reference is made to that report. In addition, two other models that emerged from the research effort are also described. The documentation for both of these more recent models is presented in the final report of the Bus Route Costing Procedures project.

Generic Types

A cataloging system previously established in the UMTA report can be used to group incremental cost estimating models into four generic types, as briefly described in the following:

- *Causal Factors*—This approach is very similar to a detailed budgeting exercise. Various quantities including personnel, resources, and materials are estimated individually. In turn, these quantities are multiplied by the appropriate units costs (e.g., drivers' wages and price of a gallon of fuel) to determine the estimated cost of each line item of expense. These results are summed to arrive at the total cost of any proposed service changes. A key component of this approach is a runcut to estimate driver costs, which is the single most important cost item. Because of its detailed, comprehensive, and time consuming nature, including a simulation of driver assignments, it should not be viewed as an acceptable costing procedure for planning purposes, in which a large number of proposed service changes may have to be evaluated. Instead, it represents a baseline approach to assess the accuracy of simplified procedures.
- *Cost Allocation Model*—This technique appears frequently in the literature and has the widest acceptance in the transit industry. While typically employed as a means to estimate individual route costs, it is often applied to forecast the incremental costs of service changes. Depending on the application, either all costs are included or fixed and variable expenses are disaggregated. With this method, each line item of expense is assigned to a particular operating statistic (e.g., vehicle-hours, vehicle-miles, and peak-vehicles). These allocated costs are summed and then divided by the appropriate operating statistic to arrive at unit costs. Although the literature typically presents models based on two to four operating statistics, many transit operators use a single variable formula (e.g., cost per hour or cost per mile). Cost per vehicle-hour is most commonly used because of the importance of drivers' wages and benefits.
- *Regression*—This generic model type involves the use of statistical techniques to determine costs and those factors that influence them. Frequently, this approach is used to analyze cost relationships among transit agencies. It relies on cross-sectional data (i.e., several agencies at one point in time) to develop and calibrate relationships. Because of the difficulty in generating the necessary data base, its use is limited. It should be noted that the UMTA Section 15 Reports provide a wealth of information that would allow this approach. Because of its reliance on data from several agencies, however, it does not lend itself to application at a single system to estimate the cost impacts of service changes. Another use of the regression approach is to quantify cost relationships based on time-series data at a single transit agency. This approach is not commonly employed because of the necessary data base and relatively complex statistical techniques required.
- *Temporal Variation*—This generic type attempts to model the inherent cost differences associated with providing service at different times of the day and days of the week. This approach relies on the cost allocation model to estimate nondriver costs. Driver compensation is examined intensively and comprises the main feature of this model type. In some cases, researchers have relied on an adjustment approach to modify traditional cost allocation models to be more sensitive to the span of service associated with the service change. The Peak-Base model falls in this category of temporal variation procedures. An alternate approach is to use statistical methods to perform the adjustment process as typified by the Arthur Andersen and London Transport models. A third method, termed resource approach, relies on modifying driver resource quantities by time of day and day of the week. The Adelaide model and proposed method from the UMTA research effort are representative of this approach.

Model Evolution

Research in cost estimation techniques has involved a continuing evolution. Each investigator has typically relied on available approaches and made enhancements designed to improve model accuracy and sensitivity. These objectives have sometimes been sought at the expense of simplicity and ease of use. For the most part, the evolutionary research process has been confined to the cost allocation and temporal variation generic types.

Inasmuch as any proposed methodology is likely to build on existing models, it is helpful to understand this evolutionary process and the rationale for subsequent cost estimation techniques. Presented below is a brief description of the evolution in cost estimating methodology.

• *Single Variable*—This relatively simple approach represents a special case of the cost allocation model, in which all transit agency operating expenses are allocated to a single variable. As noted previously, a commonly used variable is vehicle-hours. The advantage of this approach is the ease of model calibration and application. Unfortunately, this is accomplished with poor accuracy. First, the inclusion of fixed expenditures is inappropriate in determining the incremental costs of service changes. Second, by relying on a single variable, this approach does not reflect the underlying relationships that influence different line items of expense. For example, maintenance and fuel costs are more closely associated with vehicle-miles, while driver costs are more closely associated with vehicle-hours. A third defect of this approach is that it relies on a simple systemwide average. Differences in cost associated with operating speed and time of day are not reflected, which taken together diminish the single variable model accuracy. In order for the model to be a reliable cost estimation procedure, the characteristics of the service change must be the same as those found in the present system. To the extent that the disparity between the service change and system increases, the model will be less accurate. Depending on the differences, the model will either underestimate or overestimate incremental costs. For some systems, however, where fixed costs are relatively minor and where the typical service changes replicate systemwide averages (e.g., a pulse scheduled system where speeds and spans of service are comparable) the single-variable approach may achieve acceptable accuracy.

• *Multivariable Cost Allocation*—This approach is similar to the previous technique in that it is easy to calibrate and apply. It enhances the accuracy of cost estimates because it includes more than one operating statistic. Each expenditure item can be related to the variable that most directly influences that cost. The deficiency of this approach is that it is based on all costs, which implies that all expenditures are variable. Similar to the single variable technique, its accuracy is dependent on the similarity between the characteristics of systemwide averages and the service changes. A discussion of this approach has been presented as part of the UMTA-sponsored research effort (see Ref. 4, pp 15–22 at the end of the main text).

• *Fixed-Variable*—With the exception of categorizing expense items by type, this approach is identical to the previous model. By disaggregating costs into either fixed or variable expenses, it is more accurate for estimating incremental costs of service changes. The introduction of cost type has no material effect on the ease of use for this method relative to the multivariable approach. The model calibration and application is simple and straightforward. The same disadvantages of using systemwide averages is exhibited by this cost estimation technique. A discussion of this approach is presented in the previously cited report (see Ref. 4, pp. 22–28).

• *Temporal Adjustment*—This model type typically relies on traditional cost allocation models that use more than a single variable and stratify fixed and variable costs. The unique feature of this approach is that it focuses on drivers' compensation and the costs associated with providing service during different time periods and days of the week. Because of collective bargaining provisions, drivers' compensation is influenced by restrictions on driver utilization and methods of computing pay-hours. The objective is to more accurately estimate the single largest transit cost component.

An early research effort led to the development of the Peak-Base model (see Ref. 4, pp. 40–45). The model distinguishes only between the weekday peak periods and all other times. Using an "audit month," vehicle-hours and pay-hours are divided into two categories—peak and base. Various indices are computed which permit adjustment factors to be applied to the traditional cost allocation vehicle-hour unit cost. While the model calibration requires more time and effort than the standard cost allocation model, its application is also easy. Related approaches which rely on statistical techniques to reflect different costs by time of day are exemplified by the Arthur Andersen (see Ref. 4, pp. 50–54) and London Transport (see Ref. 4, pp. 54–58) approaches.

• *Temporal Resources*—The latest generation of cost estimating techniques falls into this category. Similar to the previous approaches, the focus of the models is on the drivers' compensation. Enhancements include sensitivity to costs not only by time of day, but also day of the week. Representative models include the Adelaide and Booz, Allen and Hamilton (BAH) models. The latter was developed as part of the UMTA-sponsored research effort. As might be expected, both models are complex and involve a great many variables. For these reasons, the models are difficult and time-consuming to calibrate and apply. Because these models represent the latest research, they are more fully described in this section.

Most recent models have focused on driver costs with reliance on cost allocation models for other expenses. Little research effort has been directed at the analysis of cost relationships for nondriver expenses.

The above evolution of cost estimating techniques over the past two decades is the point of departure for the current research effort.

Modified Adelaide Model

The original Adelaide model was developed by R. Travers Morgan as part of a bus costing study conducted in Australia. It incorporates several enhancements of earlier work performed by this firm for the Bradford bus system in the United Kingdom. A unique feature of the approach is a driver scheduling algorithm which converts the number of buses deployed by time of day into driver assignments that are subsequently converted into driver costs. A summary of the methodology is presented in the previously referenced UMTA report (Ref. 4, pp. 75–80). As part of the testing process for the UMTA study, the model was applied to service changes for the bus system in the Minneapolis-St. Paul metropolitan area. Although the extent of testing of the model in the Twin Cities was quite limited in terms of the number of test scenarios used, the testing did clearly demonstrate the extent of changes needed to apply the model in a typical U.S. transit system. Modifications to the original procedure were required to improve accuracy as well as adapt the procedure to U.S. transit industry conventions. These changes are briefly presented below:

• *Cost Accounts*—The Adelaide model relies on a fixed-variable cost allocation model to estimate nondriver costs. The allocation process was revised to reflect the UMTA Section 15 chart of expense accounts. This adjustment was relatively minor.

• *Vehicle Requirements*—An initial step in the model application is to determine the number of buses by time of day. These calculations are performed by dividing round trip times by headways. In the Twin Cities test case, headways were irregular, which reflected the introduction of trippers during peak periods. Also, because of route variations and short turns, round trip times did not follow a uniform pattern. Use of average values had a substantial adverse impact on model accuracy. For this reason, headway sheets were necessary to attain reasonable model reliability. However, this information is not available during the planning process. To apply this model, a part of the scheduling process must be performed, which greatly adds to the complexity and time required to apply the method. Another necessary adjustment was to compute decimal values for bus requirements. The original Adelaide model used only integer values. Use of integer values resulted in the Adelaide model being the worst performer in terms of accuracy of all models tested in the UMTA-sponsored study.

• *Driver Assignments*—Using the simplified scheduling algorithm, the number of drivers and assignment (run) types were determined. This process is repeated twice to reflect conditions before and after the service change. Modifications were made to reflect U.S. practice of trippers and part-time drivers. The original Adelaide model used only straight or split assignments. Based on dispatcher data, split runs from the original model were allocated to split, tripper combination, part-time and overtime assignments in the modified version. Similar to vehicle requirements, the number of driver assignments are determined in decimal rather than integer values. The concluding step is the net change ("after" less "before") in driver assignments. The use of decimal values was found to be extremely important to maintaining accuracy when relatively small service changes are involved.

• *Worked and Penalty Hours*—Averaged worked and penalty hours are determined from the model calibration step. These values are then multiplied by the net change in driver assignments to determine total worked and penalty hours associated with the service change. To reflect U.S. transit industry practice, trippers were included in the modified version. Also, hours were aggregated separately for full- and part-time drivers.

• *Incremental Costs*—For nondriver costs, vehicle-mile and platform-hours were multiplied by the appropriate unit cost values. In a similar manner, driver-hours (full-time, part-time and penalty) were multiplied by the appropriate units costs. The driver unit costs include allowances for fringe benefits and absences. These unit costs were established as part of the calibration phase. All costs were summed and then annualized to arrive at the incremental cost.

Necessary modifications of the Adelaide model for application in the Twin Cities leads to several key findings. First, incorporating features to reflect trippers and part-time drivers adds to the calculation steps. This is of particular concern in the driver scheduling algorithm inasmuch as the user must exercise some discretion in applying the Adelaide model. Second, the use of decimal values is not unreasonable, but does detract from the logic of the method because buses and driver assignments should be integers. Finally, the use of headways and round-trip times to establish bus requirements in the Twin Cities mandated performing part of the scheduling process (headway sheets) to obtain reasonable accuracy. This greatly increases the time required to apply the model.

A computer program has been written for the Adelaide model by R. Travers Morgan, who has applied the model in both England and Australia. However, like the original model, this program does not allow for trippers and part-time drivers, and therefore would have to be modified for application in most U. S. cities.

Booz, Allen and Hamilton (BAH) Model

The BAH model is a temporal variation model that provides for detailed analysis of driver costs by time of day and day of the week. Nondriver costs are handled using a conventional two variable cost allocation procedure. The BAH model is described below under the same headings that are used in the review of existing procedures in the UMTA-sponsored study.

• *Input*—Since the BAH model relies on a conventional fixed-variable cost allocation model for nondriver costs, a necessary input is the UMTA Section 15 Report, which presents expenditures by account. Because, a two-variable approach is used, vehicle-hours and vehicle-miles must be obtained. Most of the data requirements are associated with estimating drivers' compensation (wages and fringe benefits). The method relies on numerous detailed indices describing driver utilization and the scheduling process, rather than systemwide aggregate measures. As shown in Figure C-1, the resulting data needs are quite extensive. For the most part, the data items relate to the number and type of assignments, driver assignment lengths, and premium hours. Additional information must also be collected to define wage and benefit rates as well as absence rates.

• *Algorithm*—As noted previously, the cost estimating model proceeds in two separate ways reflecting the stratification of expenditures into driver and nondriver costs. The nondriver costs are estimated in a relatively simple and straightforward process. The change in vehicle-hours and miles is multiplied by the appropriate unit cost values and summed.

The driver cost estimating procedure is more complicated and requires a substantial number of calculations. Only two expense accounts (wages and fringe benefits) are used in this phase of the analysis. Driver compensation is computed for conditions after the service change (existing plus net change). This value is then compared with present expenditures to determine incremental driver costs. This is in contrast to the estimation of nondriver costs, which relies on only the net service change.

The initial step in the process is to estimate the platform-hours in each time period by adding proposed changes to present hours. Next, these hours are allocated to different types of assignments—straights, splits, and trippers. The basis for the allocation process is the present distribution of hours determined during the calibration phase. As shown in Figure C-2, current platform-hours are tabulated in a two dimensional matrix (time of day and assignment type). Data on average assignment length are then used to determine the number of assignments by type. Calibration results from this step are presented in Figure C-3. As part of this process, special treatment of trippers is required because this work can be assigned to part-time drivers, overtime, and combinations (extraboard). The necessary indices to explicitly treat trippers are presented in Figure C-4. Similar to the previous steps, it is assumed that the scheduling of the revised system (after service change) will be similar to that before the change.

Because premium-hours paid drivers vary by type of assignment, these rates are multiplied by the previously calculated

Calibration

- Percent of Platform Hours Assigned to Straight Runs
  - -- Early A.M.
  - -- A.M. Peak
  - -- Midday
  - -- P.M. Peak
  - -- Evening
- Percent of Platform Hours Assigned to A.M. Trippers
  - -- Early A.M.
  - -- A.M. Peak
  - -- Midday
- Average Assignment Length
  - -- Straight Run
  - -- Split Run
  - -- A.M. Tripper Piece
  - -- P.M. Tripper Piece
- Percent 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
- Percent of Platform Hours Assigned to Split Runs
  - -- Early A.M.
  - -- A.M. Peak
  - -- Midday
  - -- P.M. Peak
  - -- Evening
- Percent of Platform Hours Assigned to P.M. Trippers
  - -- Midday
  - -- P.M. Peak
  - -- Evening
- Average Spread Premium Hours by Schedule Type
  - -- Split Runs
  - -- 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

Application

- 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

Source: Bus Route Costing Procedures: Final Report; prepared for the Urban Mass Transportation Administration; by Booz, Allen and Hamilton; April 1984; Exhibits 4-15 and 4-16.

Figure C-1. BAH model data requirements.

number of assignments to estimate premium wages paid after the service change is implemented. Selected rates from the calibration phase are also presented in Figure C-3.

An unusual feature of the BAH model is its sequence of calculations to reflect the rostering process. In essence, the number of daily assignments (five weekdays, one Saturday, and one Sunday) must be operated by drivers who work only 5 days during the week. In addition, allowances must be made for absences, since all drivers do not report to work. This allowance is reflected in computed ratios of drivers to work which varies by day of the week (Figure C-5).

The concluding steps are to convert the previously calculated values (driver and platform-hours) to wages and benefits paid both full- and part-time drivers. Similar to the previous steps, analysis of existing conditions from the calibration stage is used during the application phase to measure the cost impacts. Driver wage and benefit parameters are presented in Figure C-6. By multiplying these parameters by the appropriate statistics computed previously, drivers' compensation is estimated. This value is then compared to present drivers' compensation to arrive at the net impact of the service changes.

The BAH model deals specifically with the number and type of assignments and drivers. Using the various indices determined during model calibration, the approach attempts to follow the scheduling process. In this way, the approach can be applied at different steps in the process depending on the information available on the service change. In certain respects, the model may be viewed as modular because all steps need not be utilized. One apparent disadvantage of the approach is the number of indices that are computed during the calibration and subsequently applied. This results in a large number of variables and sequential calculations.

• *Output*—The BAH model provides a considerable amount of information on the anticipated driver and assignment changes expected with a service change. The calibration tables presented previously indicate the number of variables estimated. These intermediate values are then used to compute incremental cost. Further, wage and benefit components comprising drivers' compensation are estimated separately. All previous models do not provide such detailed estimates.

• *Application*—This model has been applied in the Twin Cities as part of the testing process of the UMTA-sponsored research effort. Driver scheduling and cost data were accumulated for only a single division (i.e., garage).

Type of Assignment	Number	Platform Hours: Early A. M.	A. M. Peak	Midday	P. M. Peak	Evening	Total	Spread Premium Hours	Overtime Hours
		WEEKDAY							
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	48.06	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
	WEEKDAY				
Straight Runs	64.70	24.13	48.92	28.75	63.48
Split Runs	21.03	41.19	41.22	45.42	27.42
A.M. Tripper	14.27	33.68	3.56	0.0	0.0
P.M. Tripper	0.00	0.00	6.30	25.83	9.12
All Assignments	100.0	100.0	100.0	100.0	100.0

Type of Assignment	Number	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

Source: Bus Route Costing Procedures: Final Report; prepared for the Urban Mass Transportation Administration; by Booz, Allen and Hamilton; April 1984; Exhibits 3-1 and 3-2.

Figure C-2. BAH model calibration—allocation of platform-hours.

ASSESSMENT OF EXISTING MODELS

The foregoing discussion has provided an overview of existing cost estimation models and a more detailed description of two relatively recent models—BAH and Modified Adelaide. The next step is to compare the performance of models relative to criteria that gauge their advantages and disadvantages. The selection and application of the various criteria are from the perspective of the user. The evaluation is pragmatic rather than an abstract review based on theoretical considerations. Because certain features of the previous models should be retained while others will require modification or deletion, special attention is given to understanding how specific features of existing procedures affect their performance.

Evaluation Criteria

Twelve evaluation criteria have been specified for the current analysis. All measures are not of equal importance. Also, some of the criteria conflict with each other, so that tradeoffs are involved in trying to satisfy the competing criteria. For example, a decision to use a modular approach where different cost components are determined separately would add to the model complexity and detract from its simplicity. Many of the criteria pairings involve tradeoffs that have to be examined in specifying a proposed technique. Presented below is a brief description of the 12 criteria utilized:

- *Accuracy*—Disparities between actual and estimated costs should be sufficiently small to not cause planning decision errors.

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.

Source: Bus Route Costing Procedures: Final Report; prepared for the Urban Mass Transportation Administration; by Booz, Allen and Hamilton, and Abrams-Cherwony & Associates; April 1984; Exhibit 3-4.

Figure C-3. BAH model calibration—average platform lengths and times.

• *Ease of Use*—A technique should be easy to implement at a transit agency and apply on a continuing basis without a significant commitment of staff resources.

• *Sensitivity*—A technique should properly respond to cost changes for a variety of service modifications.

• *Temporal Stability*—A cost estimating technique should continue to be an effective tool over a reasonably long forecast period.

• *Modularity*—Various cost components of the estimating technique should be separable and permit different approaches based on available information and resources.

• *Logic*—A cost method should reflect valid relationships that are intuitively logical and conform with observed cost impacts.

• *Simplicity and Understandability*—The formulation of a cost estimating procedure and its application should not be complex or difficult to understand and use.

• *Economy*—Resources (personnel and facilities) required for use should be within levels typically available to users.

• *Turnaround*—To avoid impeding an examination of service options, cost estimates should be obtainable in a relatively short period of time.

• *Application*—A cost estimating procedure should be sufficiently flexible to reflect unique provisions at each transit agency to encourage wide use.

• *Data*—Input data needs should not be excessive. Models should rely primarily on data normally gathered by transit agencies.

• *Software*—Procedures should be adaptable to electronic data processing (EDP) equipment as well as to manual techniques.

The foregoing items do not represent all possible evaluation criteria. Nonetheless, they provide a comprehensive basis for

	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

Source: Bus Route Costing Procedures: Final Report; prepared for the Urban Mass Transportation Administration; by Booz, Allen and Hamilton, and Abrams-Cherwony & Associates; April 1984; Exhibit 3-3.

Figure C-4. BAH model calibration—allocation of trippers.

	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		

Source: Bus Route Costing Procedures: Final Report; prepared for the Urban Mass Transportation Administration; by Booz, Allen and Hamilton, and Abrams-Cherwony & Associates; April 1984; Exhibit 3-5.

Figure C-5. BAH model calibration—driver utilization ratios.

Maximum Percentage 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	0.078
Fixed Benefit Award:	
• Full Time	$1,167/Year
• Part Time	$300/Year

Source: Bus Route Costing Procedures: Final Report; prepared for the Urban Mass Transportation Administration; by Booz, Allen and Hamilton, and Abrams-Cherwony & Associates; April 1984; Exhibit 3-6.

Figure C-6. BAH model calibration—wage and benefit parameters.

assessing existing models and evaluating features of suggested methods.

Evaluation Results

Four cost estimating approaches were selected for evaluation: BAH, Modified Adelaide, Peak-Base, and Cost Allocation. These techniques were selected for three primary reasons. First, they represent either the latest work in cost analysis or commonly employed procedures. Second, they comprise a full range of procedures from relatively simple to complex. Finally, the UMTA research project provided quantitative information on the accuracy and ease of use for each of the four models.

A summary of evaluation results is presented in Figure C-7 and the rationale for the ratings is presented in the following:

• *Accuracy*—As part of the testing program in the Twin Cities, each model was applied to 12 service change scenarios (see Ref. 1, Ch. 5). While this is not sufficient to draw statistically sound conclusions, it does provide a controlled basis to gain insights as to the performance of each model for this important criterion. The "true" costs for drivers' compensation were based on runcuts with the service changes implemented.

Although a number of statistical tests were performed to gauge model accuracy, only the ranked performances are presented here. With this approach, the models were ranked from 1 (most accurate) to 4 (least accurate) for each of the 12 scenarios. The rankings were summed for various strata and a combined rank was determined. As shown in Figure C-8, model accuracy varied widely depending on the time span of the service change. For weekday peak only service changes, the Peak-Base model exhibited the greatest accuracy, with the BAH method attaining second place. Somewhat surprisingly, the Modified Adelaide was least accurate for these types of service changes. For midday service changes, the more complex models, BAH and Modified Adelaide were the most accurate with the latter attaining first place in all test cases. In terms of weekday all day changes, the BAH model was most accurate with the Modified Adelaide in last place. The simpler techniques (Peak-Base and Cost Allocation) attain an intermediate position. Shifts in rankings are also observed for weekend service changes. The complex methods are more accurate than the other two approaches.

The four models were also compared in terms of the size of the service change. Each service modification was expressed as a percent change, relative to present service levels at the division. The overwhelming majority of changes were reductions in service. For the large scale changes, the complex methods were judged more accurate than the relatively simple models.

The Peak-Base model was most accurate for the small changes followed by BAH and Cost Allocation. The least accurate was the Modified Adelaide.

The aggregate ranking for all 12 test scenarios suggests two primary conclusions. The more complex methods exhibit higher overall accuracy, which is to be expected. Somewhat surprisingly, the reduced accuracy achieved by the simple procedures is not substantial. This reflects the different rankings obtained by the four models for the 12 test scenarios. No single method is ranked consistently best for all service changes.

These results are graphically displayed in Figure C-9. The Modified Adelaide approach typically ranked best or worst with few intermediate rankings. The other complex model (BAH) attains a first or second place ranking for most scenarios. The two simple procedures also exhibit a relatively more uniform distribution, with most rankings being third or fourth places.

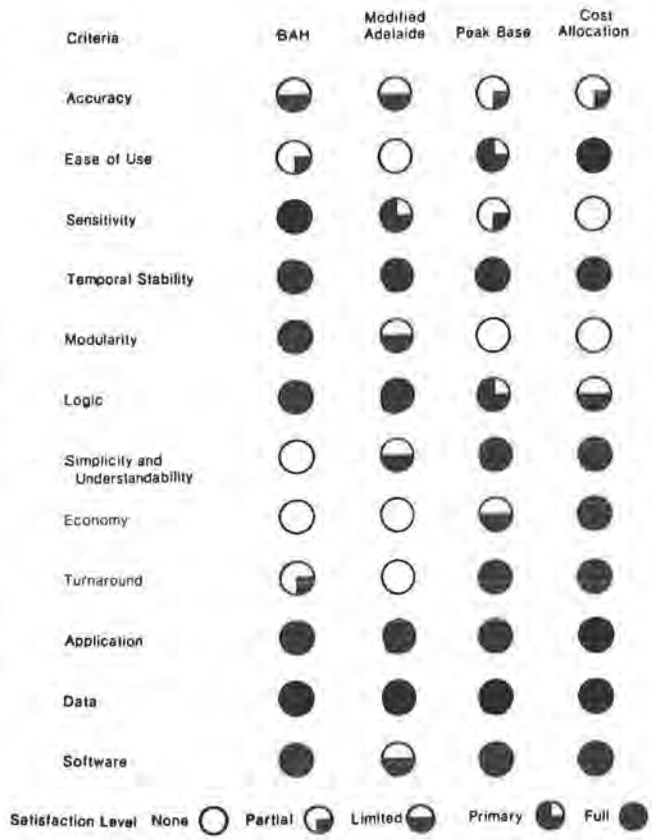


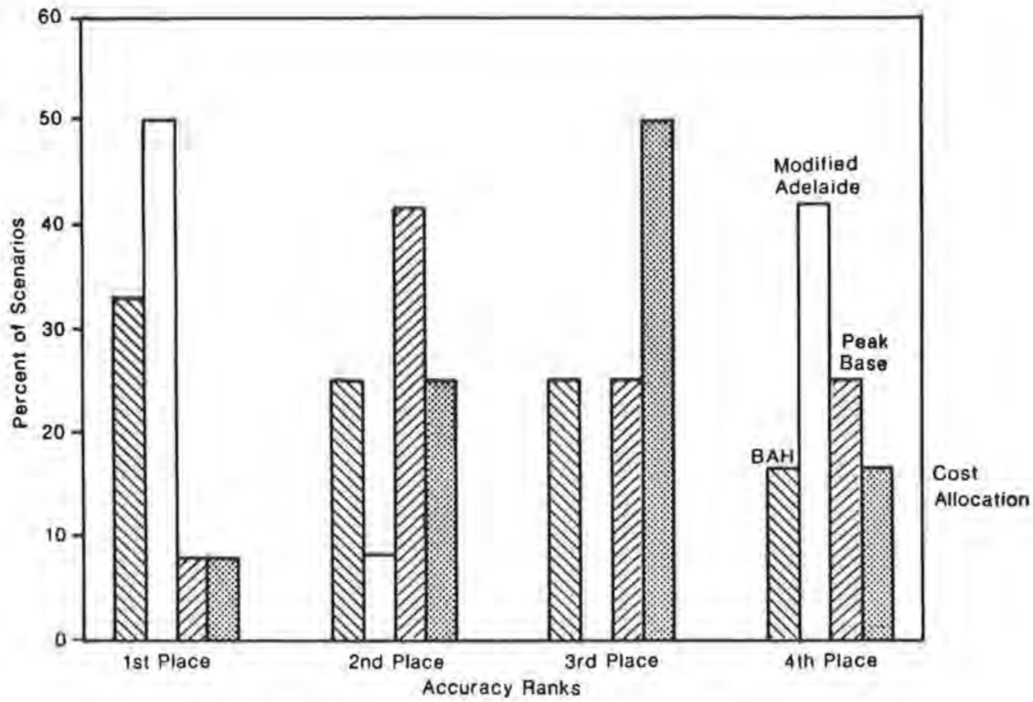
Figure C-7. Evaluation results.

CATEGORY	BAH	Modified Adelaide	Peak-Base	Cost Allocation
Time of Day				
Weekday Peak Only	2.25	3.25	1.75	2.75
Weekday Midday Only	2.50	1.00	3.50	3.00
Weekday All day	2.00	3.00	2.67	2.33
Weekend	2.33	1.33	3.33	3.00
Size of Change				
Large (Greater than 1.0%)	2.25	1.75	3.00	3.00
Medium (0.2% to 1.0%)	2.25	2.00	3.25	2.50
Small (Less than 0.2%)	2.25	3.25	1.75	2.75
All Conditions	2.22	2.33	2.67	2.75

Rankings range from 1 (most accurate) to 4 (least accurate)

Source: Sydec and Abrams-Cherwony, based on data in BAH reports.

Figure C-8. Average accuracy ranks for four models tested.



Source: Sydec and Abrams-Cherwony, based on data in BAH reports.

Figure C-9. Distribution of rankings.

• *Ease of Use*—As part of the UMTA research effort, the time required to calibrate and apply each model was also estimated as presented below:

Method	Calibration (Hours)	Application (Minutes)
BAH	24	43
Modified Adelaide	18	150
Peak-Base	10	5
Cost Allocation	1	5
Runcut (Base Line)	3	930

The approaches that rely on indices obtained from scheduling and dispatchers' data require more effort in the calibration phase. This includes the BAH, Modified Adelaide, and Peak-Base techniques. The resources required are directly proportional to the number of indices utilized by each method. The Cost Allocation model, which requires no data input from schedules, requires only an hour to calibrate. The runcut approach requires relatively modest calibration efforts involving the conversion of scheduling process output to costs.

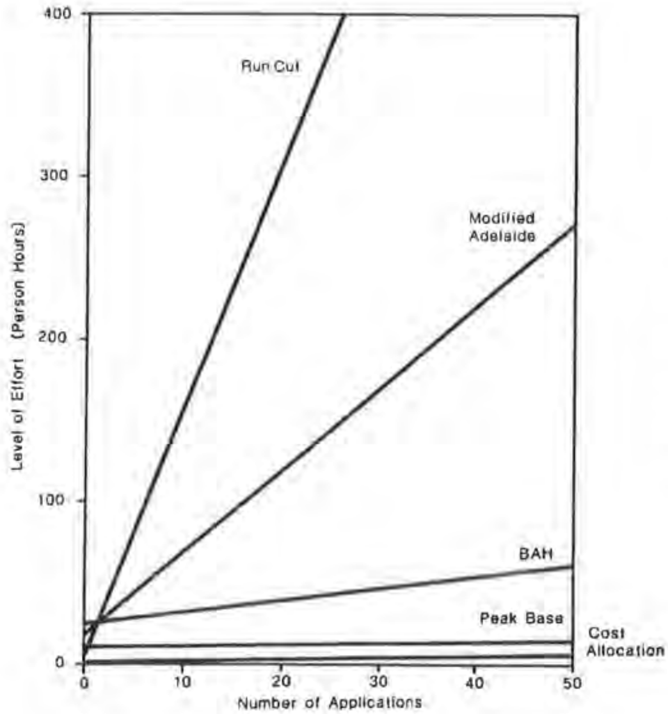
For all four cost estimation models, the time per application is less than the initial calibration. The base line method, which calls for the production of a runcut, has a more time-consuming application effort. Those cost estimating models that require more effort in calibration also require more effort in application, since the more scheduling indices used in the process, the greater the effort for both phases. Note that the Modified Adelaide technique requires headway tables, which greatly increase the time to apply this method. Without route variations and non-uniform headways, which occur in the Twin Cities, preparation of headway tables could be eliminated without diminishing accuracy.

As shown in Figure C-10, the aggregate time required to calibrate and apply the models for different numbers of applications varies widely among the methods. These results are also compared on a per application basis in Figure C-11.

Because accuracy and ease of use are very important criteria, the previously presented results were summarized in a single chart in Figure C-12. An inverse relationship exists between accuracy and ease of use. The more complex and time-consuming procedures generally yield improved accuracy. Conversely, techniques that are relatively easy to calibrate and apply attain lower accuracy ratings. As noted previously, the need for headway tables with the Modified Adelaide approach results in the relatively high person minutes without a corresponding increase in accuracy.

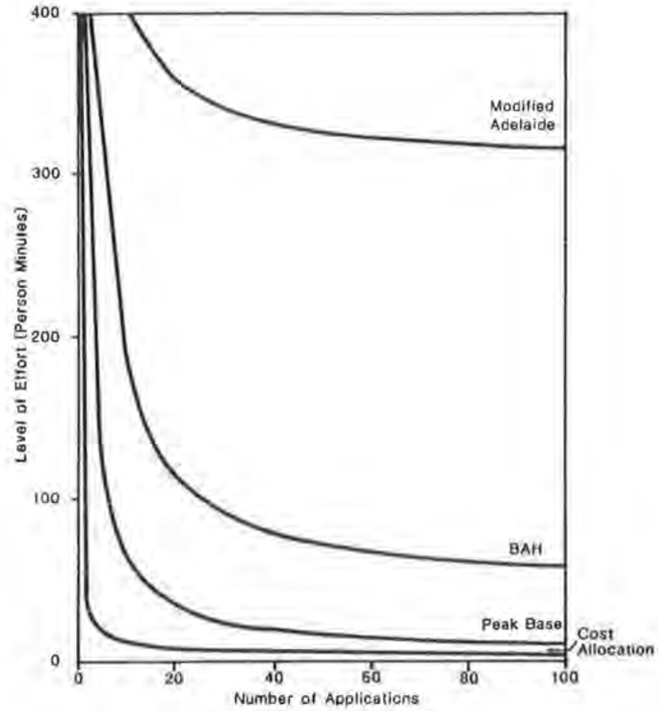
• *Sensitivity*—Because both the BAH and Modified Adelaide approaches utilize indices from the scheduling process, they are rated high for this criterion. The BAH model attains a somewhat higher rating because it incorporates provisions for rostering and different categories of fringe benefits. The Peak-Base approach should not be sensitive to all types of service changes because vehicle-hours and pay-hours are stratified into only two categories—weekday peak and all other times. The Cost Allocation technique relies on systemwide characteristics for all operations and is rated relatively low.

• *Temporal Stability*—All four models are rated superior for this evaluation criterion. This reflects the need to perform a calibration phase prior to applying the method to a service change. The stability over time would not differ appreciably



Source: Sydec and Abrams-Cherwony, based on data in BAH reports.

Figure C-10. Aggregate resource requirements (including calibration).



Source: Sydec and Abrams-Cherwony, based on data in BAH reports.

Figure C-11. Resource requirements per application (including calibration).

among the four models. The frequency of calibration could vary depending on changes that would influence operating costs.

• *Modularity*—The Peak-Base and Cost Allocation techniques attain a lower rating for this criterion. Both models attempt to measure only the cost impacts of service changes. No intermediate calculations are made during application which would provide additional information. Further, the simple methods cannot incorporate cost impacts if scheduling data on the service change are available. The Modified Adelaide attains a satisfactory rating since it focuses on drivers' compensation. One deficiency is the scheduling algorithm which is somewhat a disadvantage with this evaluation criterion. Also, fringe benefits are not analyzed separately, but are included in the hourly driver rate. The BAH is rated superior because it provides information on types of drivers, assignments, extraboard, and fringe benefits. However, this is accomplished at the expense of simplicity. Because of its specific intermediate calculation steps, it can compute costs given different input data from the scheduling process. If no data are available, the method relies entirely on calibrated indices.

• *Logic*—All four models being evaluated satisfy this criterion, but to different degrees. Because the Cost Allocation model relies on systemwise characteristics for all service periods, its rating in terms of logic is relatively low in comparison to the other techniques. This applies only to drivers' compensation since all models rely on an allocation approach for other expenses.

The Peak-Base model improves the logic of the standard allocation model because labor productivity by two different time periods is incorporated into the methodology. Following similar reasoning, the more complex models are rated high. Both include measures of driver utilization and collective bargaining pay provisions that have different cost impacts by time of day and day of the week.

• *Simplicity and Understandability*—Both the Cost Allocation and Peak-Base models are relatively simple and readily understood. This results in high ratings for both methods. While the Peak-Base technique incorporates an adjustment factor, the limited number of indices does not increase complexity. The Modified Adelaide approach is more complicated than the simple techniques. However, the use of a scheduling algorithm, even with provisions for trippers and part-time drivers, is relatively straightforward. This accounts for the intermediate performance for this model. The BAH model is rated as poor for this criterion because of the number of indices used and the extent of calculations. For these reasons, it is difficult to gain an understanding of the procedure.

• *Economy*—Both the BAH and Modified Adelaide models exhibit poor performance for this evaluation criterion. The necessary staff resources to perform the data analysis and calculations for calibration and application are typically not available at most transit agencies. The Peak-Base technique attains an intermediate rating since some agencies could implement this approach. The simplicity and limited resources required for the Cost Allocation procedure suggest that this technique is compatible with the resources that are typically available to the planning function.

• *Turnaround*—The Peak-Base and Cost Allocation models require limited and relatively simple calculations to estimate the incremental cost of a service change. For this reason, the time required to use either procedure would not impede the planning process. Transit analysts would not be faced with a situation where a full range of service options could not be investigated because of the time required to estimate cost impacts. In contrast, the BAH method with application times of nearly one hour is not rated highly for this criterion. In a similar manner, the Modified Adelaide approach attains the lowest rating. The headway and travel time calculations, as exhibited by the Twin Cities test scenarios, indicate a relatively lengthy turnaround time. Computerization of the BAH and Modified Adelaide models would eliminate the lengthy turnaround time, however.

• *Application*—All models are rated superior for this evaluation criterion. The four techniques require a calibration phase which measures the labor and cost required at a transit agency. This does not imply that all situations can be accurately accommodated by the different techniques.

• *Data*—While data requirements vary widely for each of the four models, all information should be readily available. Financial, scheduling, and dispatcher data are maintained at transit agencies. No additional data collection would be required, although data manipulation and analysis would differ substantially among the four models.

• *Software*—With the exception of the Modified Adelaide model, all techniques are readily adaptable to automated calculations and reporting. Because of the need to prepare headway tables for the Modified Adelaide approach as well as the need for some discretion in applying the scheduling algorithm, it is rated fair for this evaluation criterion. The need for computer application differs among the models. For example, the BAH model with its numerous variables and calculation steps would suggest computer applications. This could reduce not only the turnaround time, but also the likelihood of computational errors. On the other hand, the Peak-Base and Cost Allocation approaches are so simple that EDP techniques are not necessary. Computer programs would be cost effective only during the calibration phase.

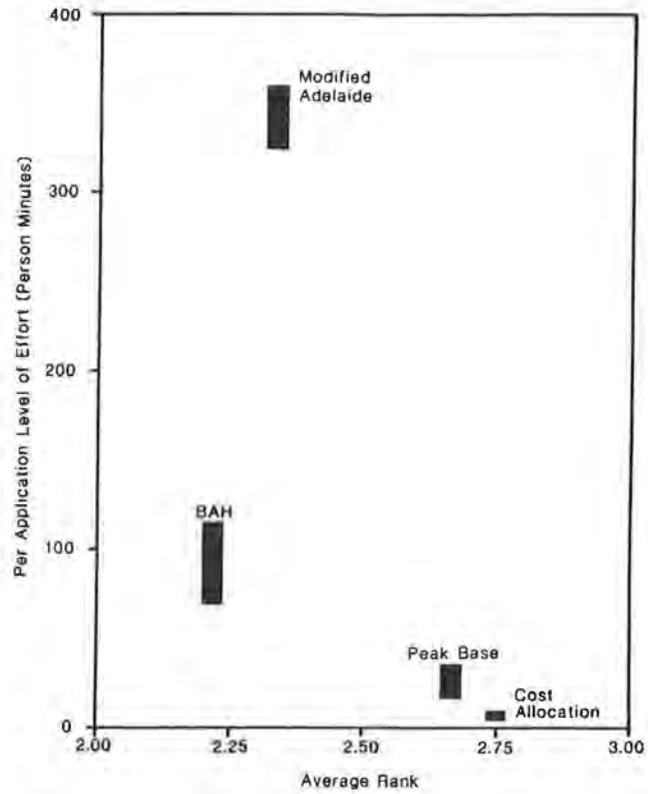
The foregoing discussion indicates the ratings of each model for the 12 selected criteria. These evaluation results provided insights into remedial and new steps in developing proposed cost estimating procedures.

FINDINGS AND RECOMMENDATIONS

The description of the cost estimation models and discussion of the evaluation results indicated the strengths and weaknesses of each model. More importantly, it provided an analytical framework and guidance in developing improved procedures. Presented in the following discussion are a number of findings and recommendations based on this assessment of more complex models.

Accuracy vs. Ease

An inverse relationship exists between the accuracy and ease of use of present methodologies. Cost models with numerous



Source: Sydec and Abrams-Cherwony, based on data in BAH reports.

Figure C-12. Comparison of accuracy and level of effort (20 to 50 applications).

indices and variables as well as extensive calculation steps result in enhanced accuracy to some extent. Conversely, simpler models have somewhat reduced accuracy. However, increased complexity does not produce a corresponding gain in model accuracy, as was shown in Figure C-12. No single model was most accurate for all test scenarios (i.e., span of service and size).

A related issue is the likelihood that a cost estimation technique will be used given the ease of use. The situation can be expressed as a probability function as shown in Figure C-13. Based on the survey of prevailing practice, the likelihood of using a procedure declines rapidly with increasing difficulty. By combining the two relationships (accuracy and probability of use), the expected accuracy for cost estimation models can be approximated. This derived formula yields a maximum value when the ease of use is between the easy and difficult classification. In essence, an easy technique with wide acceptance in the transit industry has relatively low reliability which results in limited expected accuracy. At the other end of the ease of use spectrum (difficult), the expected accuracy is also low. The combined effect of more accurate results with little or no use produces relatively low expected accuracy. For this reason, the proposed methodology should attempt to balance accuracy with ease of use. This will result in the maximum value for expected accuracy.

The relationships described above are illustrative; however, they indicated an important dimension in developing the pro-

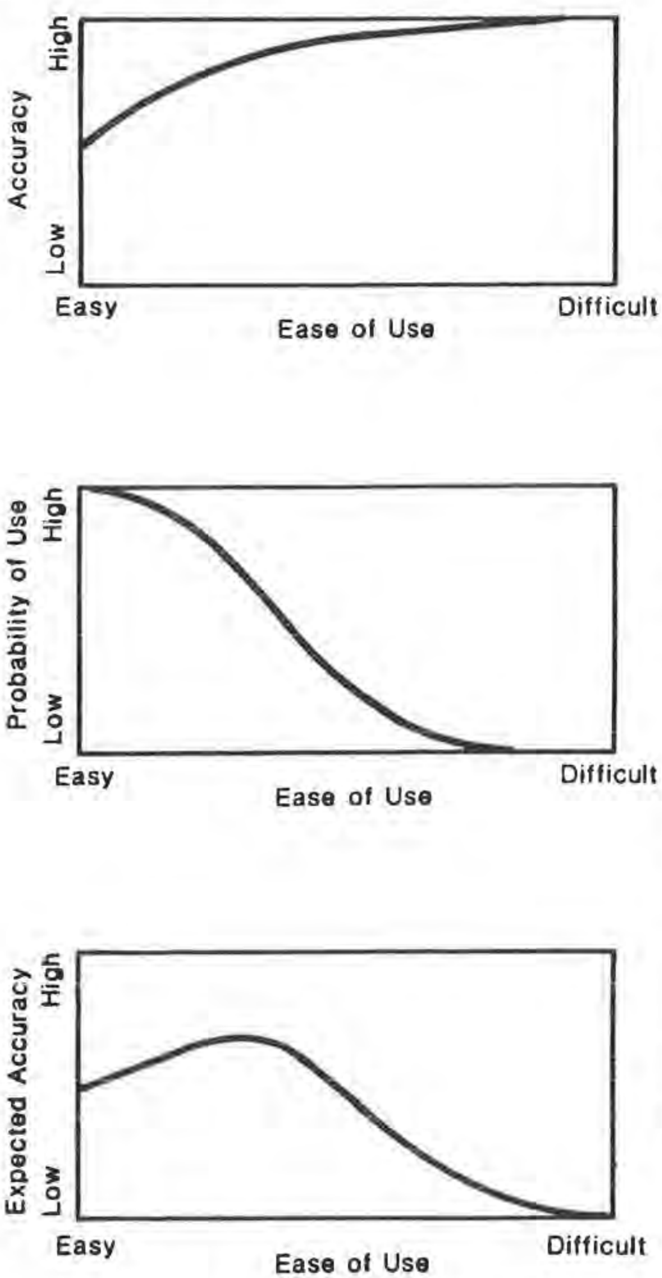


Figure C-13. Consequences of accuracy and ease of use.

posed methodology. The issue is not how accurate a model can be made but rather the level of accuracy that can be attained while gaining wide use in the transit industry. Experience from the survey reported in Appendix A demonstrates that preference should be given to ease of use in considering tradeoffs with accuracy.

Necessary Accuracy

Cost estimates are only one component in the financial evaluation of service changes. Forecasts of patronage and revenue are also necessary to determine the anticipated deficit of service options. In most cases, the latter amount is the critical financial criterion. For this reason, the appropriate level of accuracy should be viewed in terms of the reliability of revenue estimates and resulting deficit. To address this, the percent error in deficit was related to the allowable error in revenue and cost as well as farebox recovery.

Consider the following terms:

C,R,D = true estimates of cost, revenue, and deficit, respectively

c,r,d = error in cost, revenue, and deficit, respectively

$\frac{c}{C}, \frac{r}{R}, \frac{d}{D}$ = percent error in cost, revenue, and deficit respectively

For simplicity, it is assumed that the percent error in cost and revenue is the same ($a = c/C = r/R$). The reliability of patronage and revenue estimates is relatively limited for small scale service changes. This provided some guidance in appropriate accuracy for cost estimates.

The largest error in deficit occurs when either cost is overstated and revenue understated (Eq. 1) or when cost is understated and revenue overstated (Eq. 2).

$$d = (1 + a)C - (1 - a)R - (C - R) \qquad (1)$$

$$d = (1 - a)C - (1 + a)R - (C - R) \qquad (2)$$

Under both conditions, the absolute error in deficit would be the same. By defining farebox recovery as f, the following equation can be devised for a percent error in deficit.

$$\frac{d}{D} = \frac{a(1 + f)}{1 - f} \qquad (3)$$

The error would be either positive or negative depending on whether Eq. 1 or Eq. 2 was used in the derivation.

The foregoing formula indicates that percent error in deficit is a function of the error in cost and revenue as well as the farebox recovery. Not suprisingly, the greater the percent error in revenue or cost the greater the disparity between estimated and actual deficit. This linear relationship is graphically displayed in the top part of Figure C-14. Of particular interest is the impact of farebox recovery on percent error in deficit. The lower part of the figure derives this relationship from the top half. For a given percent error in revenue and cost, the error for deficit increases with higher farebox recovery. Moreover, the percent error increases at an increasing rate. The closer revenue matches costs, the smaller the deficit and therefore the wider is the variation in deficits on a percent error basis. Conversely, the lower the farebox recovery, the less inaccurate the expected deficit value on a percentage basis. These relationships should also be considered in defining acceptable accuracy levels for cost estimation procedures.

As noted previously, the derivation above assumes the same allowable percent error in cost and revenue; however, the relationships would still be valid with different revenue and cost reliabilities.

Model Documentation

Completeness and specificity of model documentation is of great importance in determining whether a model will be widely and properly used. Gaps in model documentation, which require complex decisions on the part of individuals calibrating or applying the model, should be avoided.

Intermediate Outputs

One feature of the BAH model is its modular framework that permits the quantification of various items (e.g., driver type and assignments) that are used in preparing cost estimates. This capability also adds to the complexity of the method and possibly the diminished accuracy for small service changes. For this reason, it is suggested that intermediate outputs be kept to a minimum. Instead, the procedure should be oriented to producing cost estimates in as simple a manner as possible.

Incremental vs. "Before" and "After"

Another distinguishing feature of previous cost models is whether the estimation procedure is applied to only the service change or conditions after the change. For example, the BAH and most other models rely on a cost allocation approach for nondriver costs. The dimensions of the service change are multiplied by the appropriate unit costs. The resulting cost estimate is only for the change in the nondriver expense items associated with the proposed service change. In contrast, the BAH model relies on a "before" and "after" computation for drivers' compensation. Wages and fringe benefits are estimated for the entire system or division for the "after" condition. The difference between this computed value and the present cost from financial records is the incremental cost for drivers compensation.

An incremental rather than "before" and "after" approach is preferable for three reasons. First, the incremental approach is relatively simple and straightforward. Second, with the incremental approach there is no need to develop a data base on conditions "before" the service change other than the calibration steps. Finally, the use of smaller values and a smaller number of quantities to estimate reduces the likelihood of computational errors.

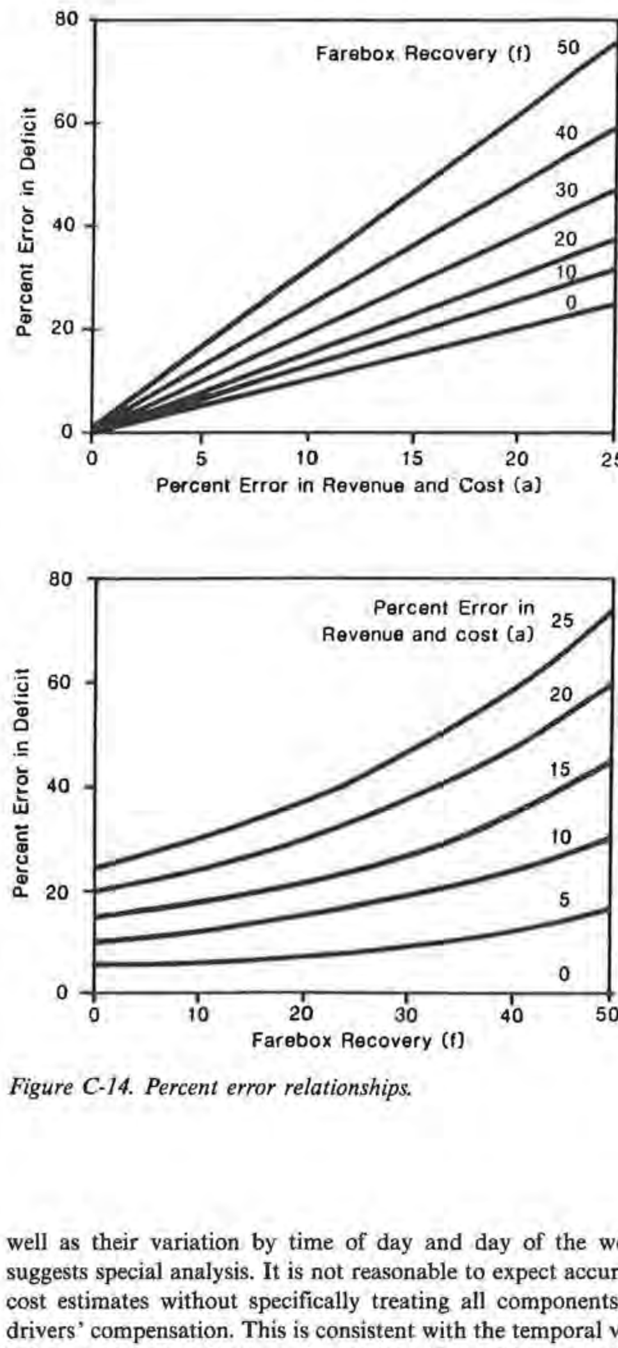


Figure C-14. Percent error relationships.

Fixed vs. Variable

Incremental cost estimating requires the segregation of fixed and variable costs since, by definition, it is only the latter that are likely to be affected by small service changes. The calibration of an incremental cost model requires judgments about whether individual cost items should be classified as fixed (and dropped from further consideration) or classified as variable (and included in the calibration). For most important cost items, these judgments are relatively easy to make. Items that are difficult to classify as either fixed or variable account for a very small share of total operating expenses at most transit agencies. This problem may be considerably more difficult in analyzing large service changes because many cost items that are classified as fixed (and dropped from further consideration) in analyzing small service changes may become variable, and therefore may be important to consider in analyzing larger service changes.

Driver Costs

The importance of wages and fringe benefits of operators as well as their variation by time of day and day of the week suggests special analysis. It is not reasonable to expect accurate cost estimates without specifically treating all components of drivers' compensation. This is consistent with the temporal variation models described previously. In view of the evaluation results for the four models, a new method to estimate this cost component appeared to be warranted.

Nondriver Costs

For most nondriver expenditures, a traditional cost allocation model is appropriate. Vehicle-miles and vehicle-hours are reasonable variables to use. This should satisfy requirements for accuracy, ease of use, and simplicity for these expenditures.

Vehicle Type

Certain nondriver costs may warrant special analysis similar to drivers' compensation. None of the available models address the cost consequences of different vehicle types. Many transit agencies are opting for mixed fleets where vehicle capacity is oriented to ridership levels. Articulated vehicles have different costs for numerous expense items (e.g., fuel, maintenance, and tires). Use of a single unit cost for all vehicle types, such as fuel expense per vehicle-mile, may introduce error in the cost estimates. To provide greater accuracy and sensitivity to vehicle type, procedures for special treatment of nondriver costs should be developed.

Simple Manual Techniques

The primary emphasis in improved procedures should be on simple techniques with a limited number of variables and calculation steps, such that they can be calibrated and applied manually. Automation of the procedures might be considered as an enhancement after their practicality and usefulness have been demonstrated.

The foregoing items provided guidance in development of the proposed methods based on the review and evaluation of available cost estimating procedures.

APPENDIX D

GUIDELINES FOR APPLICATION OF THE METHODS

Appendix B provided a detailed, step-by-step description of the calibration process and an overview of the application of each tested procedure. In this appendix, a more detailed description of the application process is presented, relying on a single test case. The example selected is for implementation of a weekday peak period express service between Allentown and Bethlehem for the LANTA system. The proposed route would operate at a 30-min headway between 6:15 AM and 8:00 AM in the morning and from 2:45 PM to 5:45 PM in the afternoon.

The first step in the cost estimation process, regardless of method used, is the computation of key operating statistics (i.e., vehicle-hours and vehicle-miles). A review of the proposed route indicates a one-way route distance of 5.4 miles, which can be traversed in 15 min with sufficient allowance for layover and recovery. This results in an operating speed of 21.6 miles per hour, which is reasonable in view of existing traffic conditions and the nonstop nature of the proposed service. Based on a round-trip cycle time of 30 min and the proposal for a 30-min headway, one bus would be assigned to this route. As shown below, a preliminary headway table for the route would appear as follows:

Pull-out/ Pull-in	Allentown	Bethlehem
6:10 AM	6:15 AM	6:30 AM
	6:45 AM	7:00 AM
	7:15 AM	7:30 AM
	7:45 AM	8:00 AM
8:20 AM	8:15 AM	—
2:40 PM	2:45 PM	3:00 PM
	3:15 PM	3:30 PM
	3:45 PM	4:00 PM
	4:15 PM	4:30 PM
	4:45 PM	5:00 PM
	5:15 PM	5:30 PM
5:50 PM	5:45 PM	—

A total of 20 one-way trips would be completed along with four pull-outs/pull-ins. The daily vehicle-miles would be computed as follows:

	One-Way		Vehicle-Miles	
	Distance	Trips	Daily	Weekly
Revenue	5.4	20	108.0	540.0
Deadhead	0.8	4	3.2	16.0
Total				556.0

Based on the proposed operating plan, the vehicle-hours would be computed as follows:

			Vehicle-Hours	
	Pull-Out	Pull-In	Daily	Weekly
Morning	6:10 AM	8:20 AM	2.17	10.83
Afternoon	2:40 PM	5:50 PM	3.17	15.83
Total				26.67

The calculations for vehicle-miles and vehicle-hours are based on an assumed operating plan. In some cases, this information would not be available to the planner. Instead, the planner would know only the revenue service to be provided. After the route proposal was scheduled, the deadhead mileage and hours would be determined. Without an operating plan, daily statistics could be computed as follows:

	Span	Duration (Min)	Cycle Time (Min)
Morning	6:15 AM–8:15 AM	120	30
Afternoon	2:45 PM–5:45 PM	180	30
Total		300	

	Number of Round Trips	Round-Trip Distance	Daily Vehicle-Miles
Morning	4	10.8	43.2
Afternoon	6	10.8	64.8
Total			108.0

In turn, these results would be converted to weekly statistics and an allowance made for deadhead movements, as follows:

	Revenue			
	Daily	Weekly	Deadhead	Total
Vehicle-hours	5.00	25.00	0.75	25.75
Vehicle-miles	108.00	540.00	16.20	556.20

In the calculations above, the planner has assumed a 3 percent allowance for deadhead based on past experience, taking into account the fact that the route terminal in the Allentown CBD is in close proximity to the garage. The first set of calculations are used as inputs to the applications of the methods as presented below.

ONE VARIABLE

With this simple approach the weekly vehicle-hours (26.67) are multiplied by the one variable vehicle-hour unit cost ($27.28, as developed in Appendix B, Figure B-3) to determine the weekly incremental cost of the service change—$727.56.

TWO VARIABLE

As shown below, this method requires only that the two unit costs (as developed in Appendix B, Figure B-3) be multiplied by the appropriate operating statistics:

	Unit Cost	Operating Statistics	Weekly Cost
Vehicle-hours	$18.08	22.67	$482.19
Vehicle-miles	$0.70	556.0	$389.20
Total			$871.39

Like the one-variable approach, this is a relatively simple and easy technique to apply.

NONDRIVER COST

The other remaining procedures utilize special techniques to estimate incremental costs associated with drivers' compensation (wages and fringe benefits). All methods rely on a simple two variable model to estimate nondriver costs as shown below (using the unit cost factors developed in Appendix B, Figure B-3):

	Unit Cost	Operating Statistics	Weekly Cost
Vehicle-hours	$0.91	26.67	$24.27
Vehicle-miles	$0.70	556.0	$389.20
Total			$413.47

This nondriver estimate of $413.47 will be used in all the temporal variation models.

PPR METHOD

Based on the cycle time and headway, a single bus will be used during the peak period span of service. For this reason, each full hour of service has one vehicle-hour. In those cases where only a fraction of an hour is operated, the appropriate vehicle-hours are computed. The daily vehicle or platform-hours are multiplied by the PPR values (from the first column of Figure B-18 in Appendix B) as shown below:

Hour Beginning	Minutes	Hours	PPR Value	Estimated Payhours
6 AM	50	0.83	1.157	0.964
7 AM	60	1.00	1.153	1.153
8 AM	20	0.33	1.135	0.378
2 PM	20	0.33	1.131	0.379
3 PM	60	1.00	1.148	1.148
4 PM	60	1.00	1.145	1.145
5 PM	50	0.83	1.150	0.958
Total	320			6.125

Next, the daily pay-hours are converted to a weekly statistic based on five service days per week. The vacancy rate is applied along with the average wage rate to establish drivers' wages for the service change, which, in turn, is expanded by the fringe benefit multipilier. These three factors were developed for the PPR method in Appendix B, Figure B-6. This result is then added to nondriver cost to estimate the incremental cost of the service change. This simple sequence of calculations is presented as follows:

Daily pay-hours	6.125
Service days	5
Weekly pay-hours	30.625
Vacancy rate	1.043
Total pay-hours	31.942
Average wage rate	$11.07
Total drivers' wages	$353.60
Fringe benefit multiplier	1.403
Total driver compensation	$496.28
Nondriver cost	$413.47
Incremental cost	$909.75

The intermediate calculations to determine drivers' compensation could be eliminated by use of a single factor—$16.20 per pay-hour, which is merely the product of the three multipliers (1.043 × $11.07 × 1.403).

SCHEDULE-BASED METHOD

This method uses identical values as the PPR method for the vacancy rate, average wage rate, and fringe benefit multiplier. Three unit cost values, expressed on a per platform-hour basis, were estimated in Appendix B, Figure B-8, for peak periods, off-peak periods, and Saturdays. However, in this particular example only a peak period weekday service increase is planned. The incremental cost increase estimated for drivers' cost is therefore simply the product of the platform-hours and the peak period unit cost factor, C_{pp}): (26.67)($19.11) = $509.66. The total weekly incremental cost estimate for the Schedule-Based method then is:

Total drivers' compensation	\$509.66
Nondriver cost	413.47
Incremental cost	\$923.13

WORKSHEET METHOD

This method requires only the use of the two unit cost factors—cost per vehicle-hour and cost per peak-vehicle. As shown below, the calculations are relatively simple.

	Unit Cost	Operating Statistics	Driver Cost
Vehicle-hours	\$13.77	26.67	367.25
Vehicle-miles	\$21.54	10	215.40
Total			\$582.65
		Nondriver Cost	\$413.47
		Incremental Cost	\$996.16

Note that the peak vehicle unit cost is based on total AM and PM peak-vehicles during the week (i.e., 1 AM + 1 PM = 2 per day, at 5 days per week = 10).

TRUE COST

The concluding method applied is an estimate of the true cost of the service change based on a runcut. In the LANTA example, the schedule-maker would add two trippers to implement the express service. This appears reasonable in view of LANTA's collective bargaining agreement and present scheduling practice. This is not to say this represents the optimum solution (i.e., minimum pay-hours). Nonetheless, the scheduling of two trippers reflects true costs since this is how the schedule-maker would implement the service change. Based on the runcut prepared by the schedule-maker, the following changes in platform (vehicle) hours and pay-hours are determined:

	Weekly Change
Vehicle-hours	26.67
Pay-hours	32.08

These statistics are based on the runcut in existence (i.e., before the change) and the one proposed to implement the proposed service change. Based on the change in pay-hours, the incremental cost is estimated utilizing the various factors from the PPR Method as shown below:

Weekly pay-hours	32.08
Vacancy rate	1.043
Total pay-hours	33.459
Average wage rate	\$11.07
Total drivers' wages	\$370.40
Fringe benefit multiplier	1.403
Total drivers' compensation	\$519.78
Nondriver cost	\$413.47
Incremental cost	\$933.25

The resulting value of incremental cost is used as the true cost and benchmark for assessing the accuracy of the alternative cost estimating procedures. Note that the expected pay-hours from the runcut can be compared with the estimate from the PPR method because it is the only cost estimation technique that generates pay-hours as an intermediate calculation. Also note that the Schedule-Based method produces an estimated cost that is closest to the "true" cost in this particular example.

APPENDIX E

COMPUTER PROGRAM FOR CALIBRATIN(MODEL

A computer program for calibrating a simple driver cost model was developed in this study. The outputs of this program are unit costs for the following model:

$$D = C_{PV} * PV + C_{WD} * VH_{WD} + C_{SAT} * VH_{SAT} + C_{SUN} * VH_{SUN}$$

where: D is the predicted change in driver cost for the service change under consideration; VH_{WD}, VH_{SAT}, and VH_{SUN} are the changes in vehicle-hours for weekdays, Saturdays, and Sundays respectively; PV is the change in the number of vehicles operated during weekday AM and PM peak periods; and C_{WD}, C_{SAT}, C_{SUN}, and C_{PV} are the four unit costs produced by the computer program for weekdays, Saturdays, Sundays, and peak-vehicles.

This model can be applied together with a cost allocation model for nondriver costs to predict total costs for service changes.

The form of the model is the same as that developed using the Worksheet method. The four unit costs may differ appreciably between the two approaches, however, because the computer approach is based on a more in-depth view of scheduling practices and constraints.

The model is sensitive to possible peak vs. off-peak differences in driver costs, since the effect on driver costs (including all premiums and fringe benefits) of the number of vehicles operated during peak periods is explicitly included in the model. The model is also sensitive to weekday vs. weekend differences, since separate unit costs are developed for weekday, Saturday, and Sunday service.

SAMPLE APPLICATIONS

The computer program is currently implemented as a Multiplan spreadsheet template on an Apple Macintosh personal computer.

Figure E-1 is a sample copy of the input-output page from the spreadsheet template. The spreadsheet shows inputs for a hypothetical transit agency, together with the four unit costs calculated from these inputs. Because the program is implemented as a spreadsheet template, it is very easy to perform sensitivity analyses. Changes to program inputs are typed into the spreadsheet, and changes in program outputs are calculated almost instantaneously.

The four unit costs produced by the calibration computer program can be applied (by hand) to predict the change in driver costs associated with different service changes. Also, these unit costs can be combined with nondriver unit costs (such as nondriver cost per vehicle-mile and per vehicle-hour from a cost allocation model) to predict the change in total cost for a given service change.

Figure E-2 shows the application of the unit costs from Figure E-1 in four sample cases.

In Case 1, the model is used to estimate the change in driver cost associated with an increase in weekday off-peak service. Since the service change does not affect the maximum number of vehicles operated in the AM and PM peak periods or the number of vehicle-hours operated on weekends, only the unit cost for the weekday vehicle-hours is needed to calculate the effect of this change.

In Case II, the model is used to estimate the driver cost effect of a service decrease which is concentrated primarily in the peak periods. Unit costs for both peak-vehicles and vehicle-hours are used in this calculation. Note that changes in the maximum number of vehicles operated in each peak period are counted separately in applying the unit cost for peak-vehicles.

Case III is an increase in weekend service. Only the unit cost for weekend vehicle-hours is needed for this calculation.

In Case IV, the model is used to estimate the cost of adding a new route, involving changes in the number of vehicle-hours on both weekdays and weekends, as well as changes in the maximum number of vehicles operated in both the AM and PM peak periods.

DATA REQUIREMENTS

The inputs to the computer program include cost data and operating statistics for an "audit" period of 4 weeks to one year in length. Figure E-1 lists all of the data required to run the program. Each of these items should be readily available from accounting records or other documents that are already prepared by transit agencies on a regular basis. The following paragraphs discuss these data items and possible sources.

Audit Period. If wage rates, policies, and schedules have not changed much during the past year, the specification of the audit period is somewhat arbitrary and can be done to conform to periods for which data are most easily available.

To avoid having to split costs in a pay period, it is desirable that the audit period be defined to cover a given number of whole pay periods (e.g., if the pay period for drivers is weekly, the audit period might be defined as four recent pay periods).

If rates, policies, or schedules have changed appreciably, the audit period should, if practical, be specified to avoid including data from before the changes.

Wages and Premiums. Drivers' wages and premiums during the audit period are divided into two categories: (1) wages and premiums for runs operated; and (2) wages and premiums for standby and other nonoperating time. Wages and premiums for runs operated are divided further into those for runs operated on weekdays, Saturdays, and Sundays. If this split by day of the week is not available directly from accounting records, it can be developed from drivers' pay and assignment sheets for a typical week during the audit period.

Wages and premiums for standby and other nonoperating time include pay for activities such as supervisor, instructor, answer market phone, jury duty, union business, etc. This category should not include pay for holidays, vacation, and sick days, because such pay is reflected in the fringe benefit multipliers (discussed next).

Fringe Benefits. Fringe benefit multipliers are applied to driver wages and premiums, so that the resulting cost estimates include costs to the agency for fringe benefits. The program provides for three different fringe benefit multipliers, since different categories of wages and premiums may incur different costs for fringe benefits. Fringe benefits such as FICA are directly related to the amount of total pay (including premiums) earned by full-time and part-time drivers. Other fringe benefits such as vacations and paid holidays, however, are not provided to part-time drivers and generally are not affected by the amount of spread, overtime, and other premiums.

Peak-Vehicle and Vehicle-Hours Per Day. Data on weekday, Saturday, and Sunday vehicle-hours and weekday AM and PM peak-vehicles can be obtained from schedules, terminal sheets, or run guides in effect during the audit period. To reduce the effort in assembling data on vehicle-hours, it is important to avoid selecting an audit period during which there were significant schedule changes.

Wage Rates and Guarantee Hours. The average base wage rate for full-time and part-time drivers in effect during the audit period may be obtained as the ratio of total wages to total pay-hours for each type of driver. Alternatively, the wage rates can be estimated by counting the number of full-time drivers in each wage class (wage classes are usually based on seniority) and then calculating a weighted average of the base wage rate for each class.

Minimum guarantee hours of pay for straight runs, split runs, and trippers on overtime can usually be obtained from the current labor agreement. At most agencies, the minimum guarantee for straight runs and split runs is 8 hours.

Many labor agreements include a minimum guarantee number of hours for trippers on overtime. In some cases, this minimum is stated as a minimum number of pay-hours. If so, pay-hours should be divided by 1.5, to convert to vehicle-hours at time-and-a half. If the labor agreement does not specify a minimum for trippers on overtime, this minimum should be estimated based on practical considerations such as the time required to make at least one trip in revenue service.

CALIBRATION OF A SIMPLE DRIVER COST MODEL

INPUTS

Number of Days in Audit Period:

20	<< Weekdays
4	<< Saturdays
4	<< Sundays and Holidays

Driver Wages and Premiums During the Audit Period for:

$200,000	<< Weekday Runs Operated
$20,000	<< Saturday Runs Operated
$16,000	<< Sunday Runs Operated
$5,000	<< Non-Operating Time

Vehicle Hours Per Day During Audit Period for:

750	<< Weekdays
400	<< Saturdays
310	<< Sundays

150	<< AM + PM Peak buses Per Weekday During Audit Period

Average Hourly Wage for:

$11.00	<< Full-Time Drivers
$10.00	<< Part-Time Drivers

$6.00	<< Average Spread Premium Per Split Run
15	<< Average Report, Turn-In, and Travel Time Per Piece Worked in Minutes

Minimum Guarantee Time in Hours Per Run for:

8	<< Straight Runs
8	<< Split Runs
2	<< Trippers on Overtime

50.00%	<< Minimum Straight Runs as Percent of Total Straight and Split Runs
10.00%	<< Maximum Part-Time Drivers as Percent of All Drivers
3	<< Hours Per Piece Worked by Part-Time Drivers

Fringe Benefit Multipliers for:

1.4	<< Full-Time Driver Wages
1.1	<< Part-Time Driver Wages
1.1	<< Overtime, Spread, and Other Operating Premiums

OUTPUTS

$11.69	<< Unit Cost Per AM and PM Peak Vehicle
$16.46	<< Unit Cost Per Weekday Vehicle Hour
$17.87	<< Unit Cost Per Saturday Vehicle Hour
$18.45	<< Unit Cost Per Sunday Vehicle Hour

Figure E-1. Input-output page from calibration program—calibration of a simple driver cost model.

CASE I: Increase midday service by adding 4 buses from 10:00 AM to 4:00 PM on weekdays.

Changes in Service Measures			Unit Cost	Driver Cost Per Day		Days	Driver Cost Per Year
Weekday Vehicle Hours:	+24	x	$16.46/hr	= $395	x	253	= $99,945

CASE II: Reduce peak service by eliminating 3 buses from 7:00 AM to 9:30 AM and 4 buses from 4:00 PM to 6:30 PM.

Changes in Service Measures			Unit Cost	Driver Cost Per Day		Days	Driver Cost Per Year
Weekday Vehicle Hours:	-17.5	x	$16.46/hr	= -$288			
Peak Vehicles:	-7	x	$11.69/veh	= -$82			
				-$370	x	253	=-$93,580

CASE III: Increase weekend service by adding 20 vehicle hours to Saturday service and 15 vehicle hours to Sunday and Holiday service.

Changes in Service Measures			Unit Cost	Driver Cost Per Day		Days	Driver Cost Per Year
Saturday Vehicle Hours:	+20	x	$17.87/hr	= $357	x	53	= $18,942
Sun. & Hol. Vehicle Hours:	+15	x	$18.45/hr	= $277	x	59	= $16,382
							$35,270

CASE IV: Add a new route, with the following service measures:

- 150 vehicle hours per day on weekdays
- 15 vehicles (maximum) during the AM peak
- 17 vehicles (maximum) during the PM peak
- 80 vehicle hours per day on Saturdays
- 40 vehicle hours per day on Sundays and Holidays

Changes in Service Measures			Unit Cost	Driver Cost Per Day		Days	Driver Cost Per Year
Weekday Vehicle Hours:	+150	x	$16.46/hr	= $2,469			
Peak Vehicles:	+32	x	$11.69/veh	= $374			
Subtotal for Weekday Service				$2,843	x	253	= $719,299
Saturday Vehicle Hours:	+80	x	$17.87/hr	= $1,430	x	53	= $75,769
Sun. & Hol. Vehicle Hours:	+40	x	$18.45/hr	= $738	x	59	= $43,542
							$838,610

Figure E-2. Sample application of simple driver cost model.

1. Four types of driver assignments are considered

   - straight runs (NX)
   - split runs providing service in both peak periods (NY)
   - peak period trippers on overtime (NZ)
   - peak period trippers by part-time drivers (NP)

   NX, NY, NZ, and NP designate the number of runs in each case. The values of NX, NY, NZ, and NP are determined so that driver cost per weekday is minimized, subject to the constraints listed below.

2. There is a minimum number of straight runs (relative to the number of total straight and split runs):

   $KXY \leq NX / (NX + NY)$

   where KXY is a constant. If there is no lower limit on the number of straights, then KXY = 0.

3. There is a maximum number of runs by part-time drivers (relative to the total runs):

   $KP \geq NP / (NX + NY + NP)$

   where KP is a constant. If part-time drivers are not used, then KP=0.

4. Straight, splits, and trippers on overtime all have a minimum guarantee number of hours per run -- GX for straight runs, GY for split runs and GZ for trippers on overtime.

5. Trippers by part-time drivers have a maximum number of hours per run -- GP.

6. Vehicle hours per assignment is calculated by subtracting an allowance for report, turn-in, and travel time from the guarantee time for the run. The allowance per piece worked (LT) is the same for each of the four types of assignments.

7. Runs required to cover peak periods:

   $PB = NX + 2\ NY + NZ + NP$

   where PB is AM peak buses plus PM peak buses. The number of peak buses includes twice the number of split runs (2 NY) because each split run will cover both AN and PM peak periods.

8. Runs required to cover daily schedule:

   $VH = NX\ (GX - LT) + NY\ (GY - 2LT) + NZ\ (GZ - LT) + NP\ (GP - LT)$

   where VH is total weekday vehicle hours.

9. Driver cost per weekday is calculated as follows:

   COST = (NX) (GX) (AWF) (FMFT)
   + (NY) (GY) (AWF) (FMFT)
   + (NY) (ASP) (FMPREM)
   + (NZ) (GZ) (1.5) (AWF) (FMPREM)
   + NP (GP) (AWP) (FMPT)

where:

- AWF and AWP are the wage rates for full-time and part-time drivers.
- NX, NY, NZ, and NP are number of runs for each of the four types of runs.
- GX, GY, GZ, and GP are hours per run for each of the four types of runs.
- FMFT, FMPT, and FMPREM are fringe multipliers for full-time drivers wages, for part-time driver wages, and for overtime, spread, and other premiums.
- ASP is the average spread premium per split run.
- LT is the average allowance time in hours for report, turn-in, and travel time per piece worked.

Figure E-3. Computer-based calibration—assumptions.

Minimum Straight Runs. Many transit labor agreements specify lower limits on the number of straight runs. These limits are generally expressed as a minimum percentage of regular runs which must be straights. Also, some agencies have an informal policy of maintaining a given percentage of straight runs for full-time drivers, even if such limits are not mandated. If so, these limits are input to the calibration.

Part-Time Drivers. Agencies that use part-time drivers generally have either formal or informal limits on the percentage of runs that may be by part-time drivers and on hours per run by part-time drivers. For agencies that do not use part-time drivers, zero is input as the maximum percentage of runs by part-time drivers.

MODEL STRUCTURE

The computer-based procedure uses a set of assumptions about scheduling practices and constraints to develop a theoretical estimate of driver cost per weekday based on the maximum number of vehicles operated in the AM and PM periods and on vehicle-hours per weekday. These assumptions are listed in Figure E-3.

In Assumption 7 of Figure E-3, the number of pieces worked on a weekday is assumed to be determined by the number of AM plus PM peak-buses. If the transit agency operates owl runs that do not provide service in either peak period, the number of pieces worked will be greater than the number of AM plus PM peak-buses. In this case, the variable PB should be reinterpreted as "AM peak-buses plus PM peak-buses plus owl runs." This change in interpretation should also be reflected in the input to the calibration program.

Unit driver cost per weekday vehicle-hour and per peak-vehicle are then calculated. These unit costs represent the change in the theoretical minimum cost for a one unit change in vehicle-hours or peak-vehicles.

It is necessary to adjust the theoretical unit costs upward because they are based on a theoretical minimum cost solution that may not be achievable in practice. They also contain no provision for standby and other nonoperating time.

To address the first problem, the theoretical unit costs are multiplied by the vacancy rate, which is the ratio of actual wages and premiums for runs operated on weekdays during the audit period to wages and premiums for the theoretical minimum cost solution.

To address the second problem, a "nonoperating time multiplier" is used. This multiplier is defined as total wages and premiums during the audit period (including those for nonoperating time) divided by wages and premiums for runs operated during the audit period.

The unit cost per vehicle hour on Saturdays is calculated as:

$$(W * C * F) / (N * V)$$

where: W is wages and premiums for Saturday runs during the audit period; F is the fringe benefit multiplier for full-time drivers' wages; N is the number of Saturdays in the audit period; V is vehicle-hours per Saturday; and C is the multiplier for nonoperating time (discussed earlier). The same equation is used to calculate the unit cost per vehicle-hour on Sundays, with Sunday values for W, N, and V.

LANTA CALIBRATION

Figure E-4 shows inputs and outputs from applying the calibration computer program to data from the Lehigh and Northhampton Transportation Authority (LANTA), the same data

CALIBRATION OF A SIMPLE DRIVER COST MODEL

INPUTS

	Number of Days in Audit Period:
20	<< Weekdays
4	<< Saturdays
0	<< Sundays and Holidays
	Driver Wages and Premiums During the Audit Period for:
$92,764	<< Weekday Runs Operated
$11,565	<< Saturday Runs Operated
$0	<< Sunday Runs Operated
$1,884	<< Non-Operating Time
	Vehicle Hours Per Day During Audit Period for:
365.133	<< Weekdays
232.2	<< Saturdays
0	<< Sundays
74	<< AM + PM Peak buses Per Weekday During Audit Period
	Average Hourly Wage for:
$11.07	<< Full-Time Drivers
	<< Part-Time Drivers
$7.33	<< Average Spread Premium Per Split Run
15	<< Average Report, Turn-In, and Travel Time Per Piece Worked in Minutes
	Minimum Guarantee Time in Hours Per Run for:
8	<< Straight Runs
8	<< Split Runs
2	<< Trippers on Overtime
39.00%	<< Minimum Straight Runs as Percent of Total Straight and Split Runs
0.00%	<< Maximum Part-Time Drivers as Percent of All Drivers
	<< Hours Per Piece Worked by Part-Time Drivers
	Fringe Benefit Multipliers for:
1.4033	<< Full-Time Driver Wages
	<< Part-Time Driver Wages
1.0987	<< Overtime, Spread, and Other Operating Premiums

OUTPUTS

$11.10	<< Unit Cost Per AM and PM Peak Vehicle
$14.92	<< Unit Cost Per Weekday Vehicle Hour
$17.79	<< Unit Cost Per Saturday Vehicle Hour
NO SERVICE	<< Unit Cost Per Sunday Vehicle Hour

Figure E-4. Input-output page from LANTA calibration—calibration of a simple driver cost model.

as are used for the Worksheet method in Appendix B. This exhibit is in the same format as Figure E-1. Figure E-4 differs from Figure E-1 in that actual transit agency data are used rather than hypothetical data.

Because LANTA does not provide Sunday service, zero is input as number of Sundays in the audit period and drivers' wages and premiums for runs operated on Sunday. The program prints "NO SERVICE" instead of calculating a marginal cost per Sunday vehicle-hour.

LANTA does not use part-time drivers. Therefore, a zero is entered as the maximum percentage of part-time drivers, and entries for part-time drivers' average wage, fringe benefit multiplier, and hours per day are left blank.

The unit costs shown as outputs in Figure E-4 were combined with nondriver unit costs for LANTA and applied to the 20 service change test cases used in Appendix B to test the simple driver cost models. The results are shown in Figure E-5, together with the "true" costs for each service change test case.

Figures E-6 and E-7 show the root mean square error (RMSE) and percent RMSE for the unit costs produced by the computer program. RMSE and percent RMSE for the other driver cost models used in this study are shown for purposes of comparison.

In terms of overall accuracy, the application of unit costs from the computer program rank second to the Schedule-Based method. It ranked best or close to best for weekday off-peak periods and Saturdays, second best for service decreases and medium size service changes, and third or fourth in the five other categories shown in Figures E-6 and E-7. Like other methods tested in this study, it tends to overstate the cost savings from service decreases and to understate the added cost of service increases.

A significant reservation regarding the conclusiveness of this test is that LANTA, unlike many other transit systems, does not have Sunday service, does not use part-time drivers, and does not have some work rules and pay provisions that affect temporal variations in operating costs.

Case	True[1/]	Predicted[2/]
1	933	922
2	-517	-665
3	-640	-790
4	-2,107	-2,269
5	198	194
6	-376	-376
7	438	394
8	-208	-214
9	292	286
10	2,133	1,968
11	977	1,004
12	-891	-944
13	-431	-551
14	1,610	1,584
15	-325	-331
16	-689	-774
17	1,092	952
18	954	872
19	-609	-607
20	1,115	1,045

[1/] True costs are based on LANTA's best estimate of the driver costs for each service change together with a two variable cost allocation model for non-driver costs.

[2/] Predicted costs were developed using the unit costs produced by the calibration computer program (see Figure E-4) and on the same two variable model as above for non-driver costs. Thus, predicted vs. true costs differ only in the driver cost component.

Figure E-5. Predicted vs. true costs for LANTA test cases.

Types of Test Cases	Average Driver Cost	Pay-to-Platform Method	Schedule-Based Method	Worksheet Method	Computer-Based Method
OVERALL	102.24	101.49	86.47	119.36	91.55
SERVICE INCREASES	93.28	56.47	77.92	91.24	78.75
SERVICE DECREASES	110.48	131.96	94.26	142.01	102.77
LARGE SERVICE CHANGES	123.90	104.59	115.26	148.44	125.56
MEDIUM SERVICE CHANGES	111.17	118.18	91.37	142.79	95.13
SMALL SERVICE CHANGES	69.11	75.22	48.33	40.75	48.41
WEEKDAY PEAK PERIOD	103.29	85.25	82.02	158.55	99.77
WEEKDAY OFF-PEAK PERIOD	123.74	136.86	95.23	98.72	95.25
SATURDAY	7.49	7.36	4.86	5.01	4.87
MIXED	126.81	113.00	132.06	174.04	134.44

Figure E-6. Root mean square error for LANTA test cases.

Types of Test Cases	Average Driver Cost	Pay-to-Platform Method	Schedule-Based Method	Worksheet Method	Computer-Based Method
OVERALL	14.53%	15.68%	11.91%	15.50%	12.53%
SERVICE INCREASES	7.40	4.79	6.35	9.89	6.76
SERVICE DECREASES	19.17	21.65	15.60	19.57	16.38
LARGE SERVICE CHANGES	8.31	6.70	6.83	8.51	8.08
MEDIUM SERVICE CHANGES	16.02	17.84	14.64	21.83	15.49
SMALL SERVICE CHANGES	16.15	17.51	11.28	9.51	11.29
WEEKDAY PEAK PERIOD	11.99	12.50	13.08	24.38	15.16
WEEKDAY OFF-PEAK PERIOD	21.90	23.96	16.24	15.16	16.25
SATURDAY	2.79	2.34	1.96	2.00	1.96
MIXED	5.97	5.42	6.24	8.27	6.37

Figure E-7. Percent root mean square error for LANTA test cases.