Abridgment

Operating Cost Model for Transit Based on Direct System Characteristics

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Most procedures for estimating the operating costs of proposed mass transit systems are called unit cost models. Unit cost models are of the form

$$\text{Operating cost} = \sum_{i=1}^{n} A(i)\cdot[\text{Level of causal factor (i)}] \qquad (1)$$

where the causal factor is a physical characteristic of the system (such as total vehicle kilometers, total vehicle hours, or number of passengers) and A(i) is the cost per unit of causal factor i (1, 2, 3). Some cost models divide the operating cost into categories and calculate the total operating cost by adding the costs in each category. Nonlinear cost models have also been considered (1), but linear models have been shown to be at least as accurate as nonlinear models for predictive purposes.

If a model is to be useful in general settings, the independent variables used should reflect, as much as possible, the true nature of the system under consideration. Previous models of operating costs for transit systems may give accurate cost estimates in a particular situation, but they do not consider all of the characteristics that can influence cost; their usefulness in general settings should be carefully determined. These cost models (except for the supervisory cost for the Washington Metropolitan Area Transit Authority study) never use, for example, the number of operators in their cost computations, although the wages paid to operators make up a significant portion of the cost of any transportation system. This may lead to questions about the rationale for these models. Scheduling crews is a complicated and time-consuming operation when it is done manually; therefore, the planner is forced to use a surrogate factor (such as in-service hours) to estimate crew costs. However, the relationship between operators' wages and the surrogate factor is tenuous; therefore, the estimate of operators' wages may be inaccurate. Furthermore, the estimation of costs for maintenance, fuel, leases, and tires requires accurate estimates of both the distances traveled by vehicles in service and deadhead and the peak number of vehicles. However, due to layover times, deadheading, and other intricacies of scheduling, the levels of vehicle kilometers and peak numbers of vehicles in operation cannot be estimated accurately without vehicle schedules.

Our approach estimates operating costs based on accurate estimates of the underlying physical characteristics of the system. This approach can therefore be transferred among systems without loss of accuracy. Also, it is an extremely fast computational approach. In particular, this cost model produces estimates of worker requirements over the day and actual vehicle schedules for the proposed systems. Because costs are sensitive to numbers of workers, numbers of vehicles, and the distances traveled by vehicles, knowledge of the temporal allocation of crews and vehicles is extremely important to the derivation of accurate cost estimates. The model described in this paper separates operating costs of a proposed multimodal transportation system into 15 categories. Each category is either a financial accounting and reporting elements (FARE) category, an aggregation of FARE categories, or a part of a FARE category (4).

Although costs for many of the categories are based on unit costs, the costs for several cost categories are based on the temporal characteristics of the vehicle schedule and crew estimates. These cost categories constitute most of the operating costs for transit systems. Determining the costs for these cost categories by the procedures described below represents a major change from existing cost estimation procedures. The underlying characteristics and causal factors used in this cost model are listed below:

1. Number of crews by type of shift required by time of day;
2. Number of peak vehicles required;
3. Distance traveled deadhead;
4. Distance traveled in service, broken down by speed;
5. Number of right-of-way kilometers;
6. Number of crew hours required by urban transportation planning system (UTPS) time period; and
7. Number of passengers.

In this model, operators' salaries are based not only on the number of operators required but also on the length of operators' shifts and their times of reporting and leaving. Fuel costs and other costs are based on the distance vehicles travel deadhead and in service.

MANPOWER AND VEHICLE REQUIREMENTS

Cost estimates of the proposed transportation system are derived by first finding the system's characteristics, such as number of operators required by time of day, number of vehicles in service and deadheading by time of day, and the distance traveled deadhead and in service during the day. To determine these estimates of system characteristics, fast algorithmic procedures for estimating staffing requirements and for constructing vehicle schedules were developed. A timetable for the systems was necessary to form the vehicle schedules. Since UTPS does not require a timetable as input, we developed a procedure for forming a timetable for the proposed transit system from the data input to UTPS.

The following components were developed and implemented by means of the UCOST program, which is described in more detail elsewhere (5).

1. The line-scheduling component converts the network description of the transit system and a specification of headways into a timetable. The objective used in forming the timetable is to synchronize the lines to reduce the total passenger transfer time.
2. The vehicle-scheduling component calculates the

size of the fleet and vehicle schedules for the proposed transit system. The technique used to form the vehicle schedule is the Dilworth chain decomposition algorithm (5).

3. The staffing estimation component calculates an estimate of the work force requirements for the proposed system. This is based on the algorithm presented by Segal (6).

These components give the planner knowledge of the fundamental causal factors that determine costs for transit systems. We know of no other cost model that provides this information.

OPERATING COST MODEL

The operating cost model implemented by means of the UCOST program is divided into 15 cost categories. Because UTPS allows the consideration of transportation systems with up to five different modes (such as local bus, express bus, and rapid rail), the operating cost for each category is further broken down by mode. If the planner, for example, allows the vehicles and staff to serve only one mode, this cost model treats each mode separately. If the planner allows staff or vehicles to serve more than one mode, UCOST is used to compute the appropriate costs for the combination of modes and these costs are prorated to the individual modes. For cost categories that can be computed by line, this proration is not necessary. Since proration of costs to modes is somewhat arbitrary, any attempt to avoid this proration is desirable.

The precise cost model categories are given in Table 1, as are the corresponding FARE categories and the dependent variable. The major categories in FARE are considered individual dependent variables and the others are combined.

Implementation

The important aspects of the UCOST program include:

1. An analysis of the cost and operation of the transportation system by transit mode (up to five modes allowed),
2. The options of a user input timetable or user input constraints on the formation of the timetable, and
3. The flexibility in the planner's design of the final shape of the cost model.

To run the UCOST program during a normal execution of UTPS, the planner must specify cost parameters of the system (for the cost categories he or she decides to use) and other characteristics of the transportation system that are used to form the line schedules, vehicle schedules, and estimates of crew size. All other characteristics are generated by other programs of UTPS, which are executed before the UCOST program is run.

The UCOST program gives the planner the option of modifying the cost model in several ways. The planner may decide to expand, combine, or delete some of the cost categories. Most changes of this type are easy to make in UCOST programs through the use of data cards.

The planner may wish to make major changes to the cost model but still use many characteristics of the proposed transportation system found in the first three components of the UCOST program. In this case, the UCOST program allows the planner, using a user-coded subroutine, to write his or her own cost model (or section of cost model). An incremental analysis can be integrated with the cost model to give the planner a myriad of options in costing a transportation system (5).

Cost Parameters and Examples

This cost model requires the use of certain cost parameters. Unit cost factors are necessary for many of the cost categories, but more detailed cost specifications are desired for a few categories. Default cost parameters were set within UCOST to allow the planner to run UCOST without having to determine his or her own parameter values. The default values are based on results reported elsewhere (5, 7, 8). These parameters are formulated so that costs are given on a daily basis. Many of the default cost parameters have been given zero values and aggregated into the general fraction category. The aggregation of many marginal costs into one category simplifies the list of default values.

In Table 1, the term "equivalent operator" was used. The number of equivalent operators is equal to the total number of operator minutes (determined from the staffing estimation component) divided by 480.

Default fuel costs and shift specifications were also developed for the UCOST program and used in the example that was tested. The fuel costs were interpolated from a table based both on the fuel-use figures presented in Characteristics of Urban Transportation Systems (7) and an assumed cost of diesel fuel of 30 cents/km/d (50 cents/mile/d).

Shift costs were based on a base wage rate of \$5.99/h plus premiums for split shifts (\$3.00 for two 4-h shifts) and overtime (50 percent of the excess time). These cost factors were used in several runs made

Table 1. Default cost categories.

Category Name	Equivalent Fare Categories	Dependent Variable	Default Coefficient per Day
Operator's salaries	501-01-030	Operator's hours	See text
Fringe benefits and other salaries per revenue vehicle operators	501-02-030, 502-15-020	Number of equivalent operators	\$17.10
Fuel lubricants and power including fuel taxes per revenue vehicles	503-08-030, 504-01-030, 510-05-030	Vehicle miles	See text
Tires and tubes per revenue vehicle operator	510-02-030	Vehicle miles	\$0.014
Lease and licensing of revenue vehicles	506-04-030, 510-04-030	Number of vehicles	0
Transportation operations	010	Number of equivalent operators	\$2.53
Servicing revenue equipment	050	Number of vehicles	\$4.00
Inspection and maintenance of revenue equipment	060	Vehicle miles	\$0.10
Repairs of vandalized revenue vehicles	070	Number of passengers	0
Fuel, service, inspection, and maintenance of service vehicles	080, 090	Vehicle miles	0
Ticketing and fare collection, including maintenance	110, 150	Number of passengers	0
Operation and maintenance of power facilities	140	Right-of-way miles	0
Other maintenance and maintenance administration	100, 120, 130	Number of vehicles	\$4.00
Scheduling and general administration	020, 160	Number of passengers	0
General function	180	Vehicle miles	\$0.401

Note: Calculations for this paper were made in U.S. customary units.

through the UCOST program. These test runs were based on an existing transit system that has approximately 25 lines, 675 runs, 51 buses, and 69 drivers. The vehicle and staffing routines were first tested by executing these routines on the existing timetable for this transit system; 49 vehicles and 68 drivers were obtained as the requirement for this system. The system was then modified by implementing constant headways for each time period, by splitting the system into two companies, and by extending all service for the duration of the 19-h day. The complete version of the UCOST program was then run. At this point in the process of implementation, certain routines (such as generation of deadhead times and transfer demands) had not been completed. The solution was 53 vehicles (31 for company A and 29 for company B, less a 10 percent surplus for spares) and 88 full-time drivers and 36 part-time drivers. The increase in workers was due to the increased service in the off-peak hours caused by the modifications.

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**Mr. Roark was with Schimpeler-Corradino Associates when this research was performed.*

Abridgment

Nonevent Planning

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The traditional urban planning process is the sequential development of (a) goals, (b) inventory, (c) forecasts, (d) plan development, (e) system simulation, (f) evaluation, (g) adoption, and (h) implementation (and appropriate feedback loops). One of the major accomplishments of the process has always been the formal adoption of the project-specific plan by the appropriate elected body. The introduction of the continuous planning effort has created some conflict between the adoption of a specific plan and the implementation of the continuous process. After a plan has been adopted, most political bodies are unwilling to modify the plan on a short-term, periodic basis (2 to 5 years). This has created the existence of plans that are no longer realistic or appropriate and has also led to unnecessary conflicts between planning and programming functions.

The nonevent planning concept suggests that political bodies should adopt transportation goals and criteria rather than a project-specific plan. This would precipitate public discussion and involvement in goal adoption rather than in the individual aspects of specific projects. The process also suggests the existence of two types of goals: (a) those that have a high probability of remaining important and (b) goals (some of which may be unidentifiable at this time) that may change in their importance as time passes. The assumption is that, although goals may vary with time, they represent a more stable set of parameters than does a set of individual projects.

The concept also emphasizes the use of probability theory to identify realistic ranges for forecasting primary variables. These ranges should be used throughout the process to identify probable ranges of demand (by mode, if that is desired). Alternatives would be developed, as is traditionally the case, and measured against the probable ranges and the adopted goals. Since some projects are probably justifiable throughout the realistic range of future demand, the process would then identify those components. Alternative themes would be developed for components that are justifiable only under some conditions of or assumptions about future demand. The continuing planning process would then operate on this second set of projects.

The nonevent planning concept is based on the need to identify and analyze goals and to make these activities the primary political activities in the planning process. Decisions about individual projects would then become short-range planning (programming) functions, performed on a continuous basis. The political difficulty of officially updating project-specific plans has left many