PEAK-BASE COST ALLOCATION MODELS

Walter Cherwony and Subhash R. Mundle, Simpson & Curtin, Philadelphia

During the past several years, most transit agencies have been faced with the problem of rising deficits and limited tax resources to meet operating subsidies. For this reason, renewed emphasis has been placed on examination of the system's financial performance on a route-by-route basis. While route revenues can be determined by surveys and field counts, operating costs are more difficult to ascertain by route. Typically, the cost analysis has been conducted utilizing multivariable cost allocation models in which each expense account in a system is attributed to a particular resource (e.g., vehicle kilometers). This paper presents the cost analysis performed for the Metropolitan Transit Commission (Minneapolis-St. Paul) as part of the monitoring and evaluation program of the I-35W Urban Corridor Demonstration Project which tested the feasibility of express bus service on a metered freeway. The paper calls for the development of cost formulae that are sensitive to peak and base conditions rather than a single systemwide model. Also described in the paper is the development of labor productivity and service indices which can be used to compute both peak and base unit cost factors. The theoretical derivation of the relationship between the unit cost factors with systemwide costs and the indices, as well as the application of this theoretical concept, are presented.

With transit agencies beset by rising deficits and increased citizen opposition to higher taxes to support public transportation services, transit operators are more carefully examining their system's financial performance. Usually, this analysis involves an examination of each route or service type as an individual operating entity or "cost center." Route revenue, cost and margin are computed to determine the "profitability" of each transit line(1) and the extent of accommodation of service. Route revenues are relatively simple to determine by a variety of survey techniques - - passenger counts, origin-destination surveys or farebox checks. Route-by-route costs are more difficult to ascertain. The widely used method in the transit industry is the development of multivariable cost allocation models in which each system expense account can be attributed to one or more resources such as vehicle kilometers or vehicle hours. The cost allocation model is then applied to the resources required to provide service on each route to determine individual route cost. For the most part, cost formulae developed for transit properties throughout the nation represent systemwide averages which do not completely differentiate between cost associated with peak and off-peak transit services. This paper presents the development of a traditional cost allocation model, as well as the theoretical framework and computation of peak-base cost formulae.(2)

Traditional Cost Model

The first step in the development of peak-base cost formulae is the computation of a traditional cost allocation model.(3, 4) In this case, a "three-variable" model was computed rather than a more complex formula including numerous other variables such as passenger revenue.

Allocation of Expense Accounts

The Metropolitan Transit Commission's (MTC) monthly operating expense accounts were allocated to one of the three variables - - vehicle hours, vehicle kilometers or peak vehicles.

Vehicle Hours. Certain transit operating costs such as drivers' wages, which account for nearly half of the total operating costs, transportation supervision, etc., are directly related to number of vehicle hours. Therefore, these and some other expense categories which vary with the amount of service hours are appropriately allocated to vehicle hours. The use of vehicle hours which is a surrogate for payhours is preferred in cost allocation analysis since it is much easier to compute vehicle hours by line than payhours.

Vehicle Kilometers. Many operating costs are directly related to the vehicle kilometers of service provided. Expenses such as fuel, oil, tires and tubes, repairs to revenue equipment and servicing of revenue equipment are directly allocated to vehicle kilometers because they vary with kilometers of service operated.

Peak Vehicles. Many individual expense items do not vary as functions of either of the foregoing parameters - - vehicle hours or vehicle kilometers. For example, expenses for vehicle storage facilities are a function of the system's peak vehicle requirements rather than the number of kilometers or hours of service provided. Such peak vehicle-related expenses include supervision of shop and garage, maintenance of buildings, fixtures, grounds, service car equipment and other miscellaneous shop expenses. A number of broad overhead expenses also vary with the system's peak vehicle requirements including depreciation of revenue equipment, structures, service cars, and shop and garage equipment.

The Allocation Formula

The results of a traditional three-variable cost allocation model for a typical month (September 1974) are shown in Table 1. The three-variable formula resules in the apportionment of 59.3 percent of aggregate monthly cost on the basis of vehicle hours, 23.4 percent on a vehicle kilometer basis, and the remaining 17.3 percent as a function of the system's peak vehicle requirements. The costs attributable to vehicle hours result in a unit cost of $9.90 per hour and the costs attributable to vehicle kilometers of operation yield a unit cost of $0.19 per vehicle kilometer, while the costs allocated to peak vehicles produced a unit cost of $612.75 per peak vehicle per month.

Table 1. Development of three-variable cost allocation model, September 1974, Metropolitan Transit Commission.

Basis of Allocation	Total Allocated Cost	Percent of Total Cost	Total Operating Statistics	Unit Cost
Vehicle Hours(H)	1499400	59.3	151500	$ 9.90 per vehicle hour
Vehicle KM(K)	590800	23.4	3116000	$ 0.19 per vehicle km
Peak Vehicles (V)	437500	17.3	714	$612.75 per peak vehicle (per month)
Total(C)	2527700	100.0		

During the I-35W Urban Corridor Demonstration Project, a three-variable cost allocation model was prepared for each month from October 1972 to December 1974 - - the duration of the monitoring program.

Peak-Base Theoretical Framework

The traditional cost allocation model to some extent addresses the issue of different cost by time of day through the use of a peak vehicle unit cost factor. It does not account for the major cost differences between peak and base time periods in the labor-intensive transit industry in which drivers' wages represent the largest single expenditure. It is widely accepted that it costs more to operate a bus during the peak period than during off-peak hours because of the provisions in most labor agreements which require more payhours per vehicle hour for peak period service than base operations. Typical provisions which impact costs include:

1. Straight runs insure that at least some peak period drivers will have a continuous uninterrupted workday.
2. Combination time prescribes penalties for peak period only drivers to receive a full day's pay for less than eight hours of work.
3. Spread time provides premium pay for any work performed beyond a fixed daily time span (e.g., 10 hours).
4. Guarantee time sets minimum weekly pay regardless of hours worked (e.g., 40 hours pay per week).

While it is evident that these prohibitions and penalties associated with drivers' wages cause higher vehicle hour unit costs for peak period service, the quantification of these differences is yet another matter. The vehicle hour unit cost factor determined by the traditional cost allocation model represents a weighted average of both peak and base conditions. As noted previously, vehicle hours represent an easily quantified surrogate variable for payhours. Thus, it would be desirable to relate peak and base unit cost per vehicle hour factors to the systemwide unit cost (traditional model). Further, this relationship should include some measure of labor productivity (payhours/vehicle hours) and the service levels operated in each period (peak/base vehicle hours). These indices would be computed possibly one month a year and then used for model development in each of the 12 months of that year. The mathematical derivation of these desired relationships is presented below.

Consider the following definition of terms - -

VH_P = Peak period vehicle hours
VH_B = Base period vehicle hours
PH_P = Peak period payhours
PH_B = Base period payhours
TC = Total cost allocated to vehicle hours
UC_S = Vehicle hour unit cost (traditional cost model)
UC_P = Peak period vehicle hour unit cost
UC_B = Base period vehicle hour unit cost.

In a traditional model, UC_S is computed as shown in Equation 1.

$$UC_S = \frac{TC}{VH_B + VH_P} \quad (1)$$

Further, the relationship between payhours and vehicle hours can be established.

$$E_P = \frac{PH_P}{VH_P} = \text{Peak period labor productivity} \quad (2)$$

$$E_B = \frac{PH_B}{VH_B} = \text{Base period labor productivity} \quad (3)$$

The indices which should be related along with UC_S to peak and base unit cost factors are:

$$n = \frac{E_P}{E_B} = \text{Relative labor productivity} \quad (4)$$

$$s = \frac{VH_P}{VH_B} = \text{Service index} \quad (5)$$

It should be recognized that these values can be determined for each transit operator. Relative labor productivity (n) is a measure of the various features of the labor agreement while the service index (s) measures the relative amount of service offered in each time period. Mathematically, the desired relationship for peak and base vehicle hour unit costs are presented in Equations 6 and 7, respectively.

$$UC_P = f(UC_S, n, s) \quad (6)$$

$$UC_B = g(UC_S, n, s) \quad (7)$$

As noted previously, vehicle hours is an easily computed surrogate variable for payhours. Also, for derivation purposes, it is necessary to define payhour unit cost as follows:

$$UC_H = \frac{TC}{PH_B + PH_P} \quad (8)$$

By substituting Equations 2 and 3 in Equation 8, it can be shown:

$$TC = UC_H E_B VH_B + UC_H E_P VH_P \quad (9)$$

Since the sum of the unit costs multiplied by the appropriate quantities for each operating period must equal total cost, UC_P and UC_B can be defined as follows:

$$UC_P = UC_H E_P \quad (10)$$

$$UC_B = UC_H E_B \quad (11)$$

By various substitution of terms in Equation 10, it can be shown:

$$UC_P = \frac{n(1+s)}{1 + ns} UC_S \quad (12)$$

The term multiplied by UC_S can be thought of as an adjustment factor to compute UC_P. Similarly, by various substitution of terms in Equation 11, it can be shown:

$$UC_B = \frac{1 + s}{1 + ns} UC_S \quad (13)$$

The term multiplied by UC_S can be thought of as an adjustment factor to compute UC_B. Also, from Equations 12 and 13, it can be shown:

$$UC_P = n\, UC_B \quad (14)$$

Thus, it has been derived that the peak and base vehicle hour unit cost factors are a function of the systemwide unit cost, relative labor productivity, and service index. Because of space limitations, the complete derivations of Equations 12 and 13 are not presented in this paper. Traditional cost allocation model vehicle hour unit cost (systemwide) underestimates the cost of peak period service and overestimates the cost of base period service. The greater the values of either relative labor productivity (n) or service index (s), the greater the disparity in peak and base vehicle hour unit costs.

When the relative labor productivity equals one (no prohibitions or penalties in labor utilization), vehicle hour unit costs for the system base and peak periods are the same regardless of relative service levels (Figures 1 and 2). For any given value of service index, the peak adjustment factor is directly proportional to the relative labor productivity index which implies a widening disparity between system and peak period vehicle hour unit cost factors. Care should be exercised in interpreting the relationship portrayed in Figure 1. When relative labor productivity is greater than one (the typical situation), a greater value for the service index produces a lower value for the peak adjustment factor. For example, when the relative labor productivity equals two, the peak adjustment factor is larger when $s = 1(VH_B = VH_P)$ than when $s = 2$ $(VH_B = \frac{1}{2}VH_P)$. At first glance, this may seem illogical; except, it should be noted that the systemwide vehicle hour unit cost factor is not fixed. As the service index increases, UC_S will also increase. Thus, with increasing values of service index, the systemwide unit cost factor becomes more similar to the peak unit cost factor with the peak adjustment factor approaching one. The overall result of greater value of service index is that both systemwide and peak unit cost factors would be greater.

As shown in Figure 2, the base adjustment factor also represents a family of curves which all intersect when the relative labor productivity equals one. For a given value of relative labor productivity, the base adjustment factor is inversely proportional to the service index. Thus, as the cost structure of the system more closely resembles the peak unit cost factor, the disparity between base and systemwide costs becomes greater.

The derived relationships between unit cost factors with relative labor productivity and service index are presented in Figures 3 and 4. As shown in Figure 3, for all values of relative labor productivity, the peak adjustment factors converge on the value of one with increasing values of service index. Conversely, the base adjustment factor diverges from one with increasing values of service index (Figure 4).

Model Application

The first step in applying the derived formulae is to select a month to compute the two indices -- relative labor productivity and service index. Since the tabulation of vehicle hours and payhours for both peak and base periods requires considerable data collection and manipulation, this effort was performed for only a single month. The indices computed from this data tabulation were then applied to subsequent months. It should be recognized that the indices would have to be recomputed when the labor contract changed affecting relative labor productivity (n) or when service levels were changed thereby affecting the service index (s). The results of this data tabulation for the "audit" month are presented in Table 2. Not surprising, the peak period requires 31 percent more payhours than vehicle hours, while the base period has only 14 percent more payhours than vehicle hours, which produced a relative labor productivity of 1.15. These results clearly indicate that provisions in labor contracts which restrict driver utilization and provide for penalty payments can affect costs as significantly as the drivers' hourly wage rates.

To compute the peak-base unit cost factors, the first step was the development of the traditional cost model as described previously. The next step was to apply the index values in Equation 12 and Equation 13 to determine the peak and base vehicle hour unit cost factors, respectively, for the month being

Figure 1. Peak adjustment factor vs. relative labor productivity.

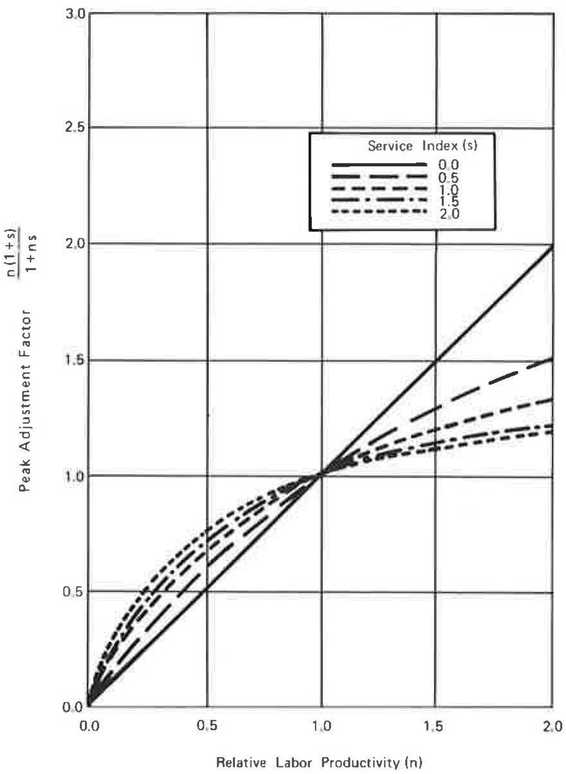


Figure 2. Base adjustment factor vs. relative labor productivity.

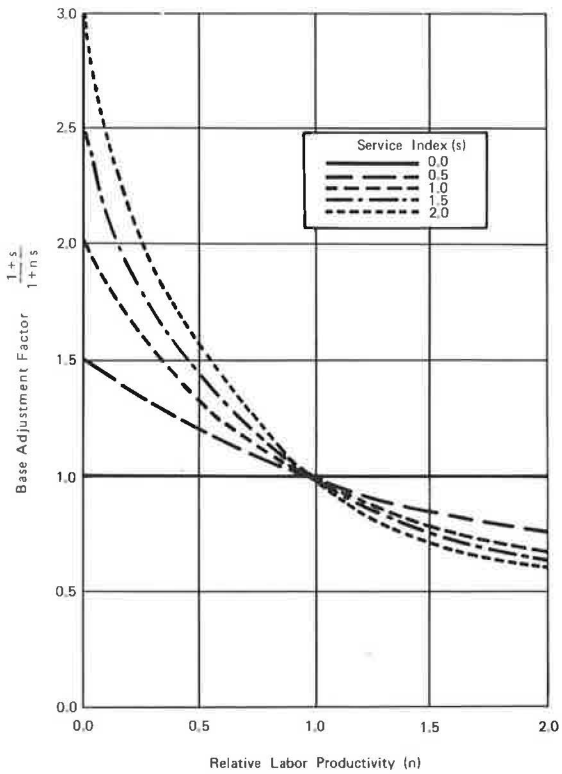


Figure 3. Peak adjustment factor vs. service index.

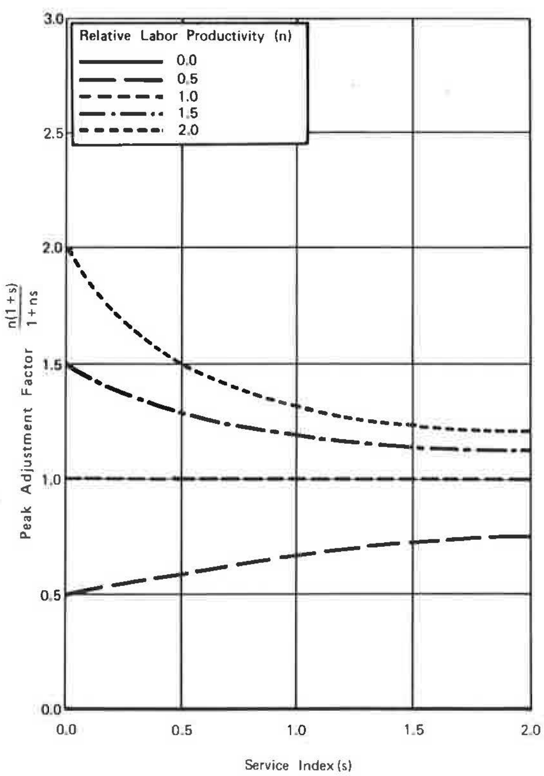
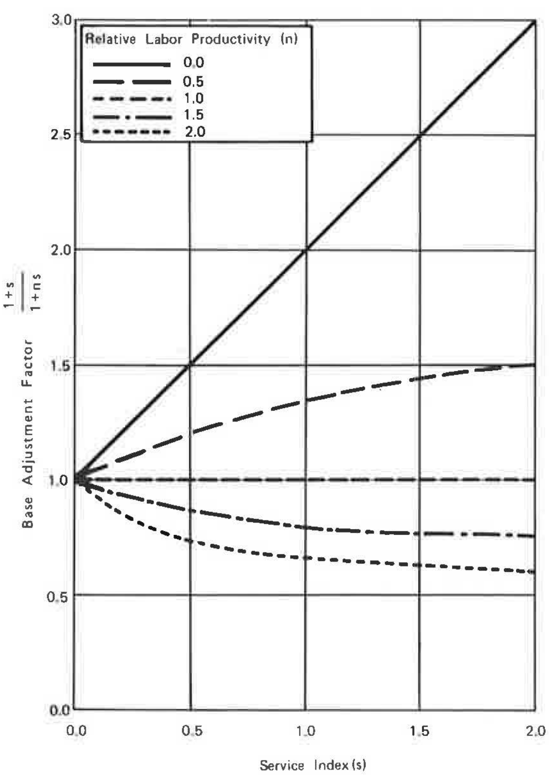


Figure 4. Base adjustment factor vs. service index.



analyzed. The resulting cost formulae for September 1974 are presented below:

$$\text{Peak:} \quad C = 10.57H + 0.19K + 612.75V \qquad (14)$$

$$\text{Base:} \quad C = 9.20H + 0.19K \qquad (15)$$

Table 2. Computation of indices, "Audit" month — March 1974.

	Peak	Base
Vehicle Hours	74967 (VH_P)	72947 (VH_B)
Payhours	98130 (PH_P)	83086 (PH_B)
Labor Productivity	1.31 (E_P)	1.14 (E_B)
Relative Labor Productivity	1.15(n)	
Service Index	1.03(s)	

The difference in cost estimates between the peak and base models can be illustrated by determining the cost of bus service in the I-35W Corridor by both formulae. For September 1974, the peak cost model would yield monthly operating costs of about $302,000, while the base cost model would estimate bus costs of $193,000 - - a difference of 56 percent. These results are not surprising since the base cost model has a lower vehicle hour unit cost and does not include a third variable to reflect peak vehicle requirements. The disparity between cost by the two models would confirm the need to develop separate cost formulae by time period.

By developing models requiring route statistics on vehicle hours rather than payhours, the cost model can be readily applied to individual line data to compute route-by-route cost.

Conclusions

The foregoing analysis permits the following conclusions to be drawn:

1. The use of traditional cost allocation formulae only partially explains the different cost structure of peak and base services. This traditional approach, by use of a peak vehicle unit cost, only accounts for the higher cost of providing service attributable to those cost items such as administrative and physical plant costs which are a function of the maximum number of vehicles in service at any one time.

2. In view of the labor-intensive nature of transit operations, the systemwide vehicle hour unit cost factor represents an average of differing costs by time of day. Clearly, there is a need to define peak and base vehicle hour unit cost factors. Also, the determination of these factors should reflect the consequences of various prohibitions and penalties in the utilization of drivers.

3. Traditional cost allocation models underestimate the cost of peak period service and overestimate the cost of base period service.

4. The peak and base vehicle hour unit cost factors are a function of the systemwide cost structure, as well as the relative labor productivity and service index. Further, these relationships can be mathematically derived.

5. Restrictions on driver utilization and penalty payments can affect transit operating cost as significantly as the drivers' wage. For example, a change in spread time from 10 to 9 hours may produce the same increase in cost as a 10-cent increase in the drivers' wage rate.

6. Expansion of service in peak periods at a relatively greater rate than base periods will also adversely affect transit operating costs. This conclusion has particular relevance to many transit properties that have embarked on ambitious programs to serve journey-to-work travel through express bus service and park-ride facilities - - peak period operations.

7. Although vehicle hours is really a surrogate for payhours, the ease of computing vehicle hours by route as opposed to computing payhours by route suggests its use in cost formulae.

8. The proposed peak-base approach described in this paper only requires data collection at infrequent intervals to compute the necessary indices (relative labor productivity and service index). By utilizing these indices, detailed peak and base cost formulae can be readily determined and applied each month to accurately assess the financial performance of each route.

References

1. Water Cherwony. A Cost Center Approach to Transit Performance. Transit Journal, American Public Transit Association, Fall 1977.
2. Bather, Ringrose, Wolsfeld, Inc. and Simpson & Curtin. I-35W Urban Corridor Demonstration Project. Final Report for the Metropolitan Council of Minneapolis/St. Paul. Minneapolis, MN: Bather, Ringrose, Wolsfeld, Inc., August 1975.
3. Michael G. Ferreri. Development of a Transit Cost Allocation Formula. HRB, Highway Research Record 285, 1969.
4. Walter Cherwony and Brian E. McCollom. Development of Multi-Model Cost Allocation Models. Proceedings of Fourth Annual Intersociety Conference on Transportation, American Society of Mechanical Engineers, 1976.