small subset of performance measures that represents each concept reduces the cost of data collection and focuses attention on a manageable number of performance indicators.

The comprehensive coverage of Section 15 data belies the many missing or erroneous values reported in the inaugural report (2). Only 155 of 311 bus systems could be used in this analysis. Data reporting could be simplified by selecting a conceptual framework of performance and requesting only two or three different performance measures to represent each performance dimension. Sufficient data would then be available to monitor trends in the transit industry as well as to provide data that management could use to improve the performance on each property.

ACKNOWLEDGMENT

Research for this paper has been supported by UMTA, U.S. Department of Transportation.

REFERENCES

1. S.C. Anderson and G.J. Fielding. Comparative Analysis of Transit Performance, Final Report. UMTA, Rept. UMTA-CA-11-0020-1, 1982.
2. National Urban Mass Transportation Statistics: First Annual Report, Section 15 Reporting System. UMTA, U.S. Department of Transportation, Rept. UMTA-MA-06-0107-81-1, 1981.
3. National Committee on Urban Transportation. Measuring Transit Service. Public Administration Service, Chicago, Procedure Manual 8, 1958.
4. G.J. Fielding, R.E. Glauthier, and C.A. Lave. Performance Indicators for Transit Management. Transportation, Vol. 7, No. 4, 1978, pp. 365-379.
5. J.H. Miller. The Use of Performance-Based Methodologies for the Allocation of Transit Operating Funds. Traffic Quarterly, Vol. 34, No. 4, 1980, pp. 555-585.
6. A.L. Comrey. A First Course in Factor Analysis. Academic Press, New York, 1973.
7. S.C. Anderson. The Michigan Transit Performance Evaluation Process: Application to a U.S. Sample. In Transportation Research Forum, Proceedings of the 21st Annual Meeting, Richard B. Cross, Oxford, Ind., 1980, pp. 94-103.
8. G.J. Fielding, S.R. Mundle, and J. Misner. Performance-Based Funding-Allocation Guidelines for Transit Operators in Los Angeles County. TRB, Transportation Research Record 857, 1982, pp. 14-18.
9. J.H. Holec, Jr., D.S. Schwager, and A. Fandalian. Use of Federal Section 15 Data in Transit Performance Evaluation: Michigan Program. TRB, Transportation Research Record 746, 1980, pp. 36-38.

Publication of this paper sponsored by Committee on Transit Management and Performance.

Method for Estimating the Costs of Drivers' Wages for Bus Services

ANNE HERZENBERG

To plan changes in bus transit service it is often necessary to estimate the costs of individual routes. Unfortunately, it is difficult to isolate the cost of one route from the costs of an entire network. A model for estimating only the marginal costs of drivers' wages for individual bus services is presented. The model shows that union work rules and an uneven demand for service influence labor costs, and that the marginal cost of drivers' wages is higher during peak hours than during off-peak hours. The model, developed for the Massachusetts Bay Transportation Authority (MBTA), is used to estimate how much the MBTA would save if any of 12 currently operating routes were dropped. This application reveals that the model is simple to use and can be applied by any agency considering increasing or decreasing bus transit service. The results demonstrate that the model is extremely accurate for routes for which the ratio of peak service to base service is similar to the ratio for the entire system. For peak-period-only bus service, or routes offering concentrated service during peak hours, a technique is presented for establishing a range in the cost of drivers' wages.

To plan changes in bus transit service it is often necessary to estimate the costs of individual services. For example, a transit agency might want to know how much it costs to run route x, or how much would it cost to add a bus to route y during the evening peak period. Such questions are difficult to answer because they force the agency to decide which, if any, administrative or overhead costs to allocate to individual routes. Furthermore, for agencies that assign individual drivers and buses to multiple routes, it is difficult to allocate the costs of wages, benefits, fuel, and maintenance to isolated services.

A model for estimating the marginal costs of drivers' wages for bus services is presented in this paper. The model deals only with drivers' wages for two reasons. First, drivers' wages are usually the largest single expense associated with bus services; therefore, an operator cannot estimate the total cost of a service accurately unless the drivers' wages are estimated accurately. Second, because the factors controlling drivers' wages (such as union work rules) are different from the factors controlling expenses such as fuel, maintenance, and administration, a separate model is necessary for drivers' wages.

The paper is divided into five sections. In the first section the difficulty of estimating the drivers' wages associated with individual services is explained. In the second section techniques used elsewhere for estimating wages are briefly reviewed. In the third section the model is presented and calibrated for the Massachusetts Bay Transportation Authority (MBTA). The results of applying the model to 12 MBTA routes are discussed, and in the fourth section the techniques are given for estimating drivers' wage costs in cases where the first model appears likely to be inaccurate.

COST-ESTIMATION PROBLEM

The difficulty in calculating precisely how much a transit agency spends on drivers' wages for a bus route is that wage rates vary within agencies. If there were a single wage rate, a transit agency could calculate the cost of wages for a route simply by multiplying the flat rate by the number of bus hours associated with the route. However, union work rules and the peaked nature of the demand for transit service create such significant variations in wage rates that this simplistic approach would be unrealistic.

Spread penalties and the 8-hr guarantee create most of the variation in wages, and they appear in the union contracts of most transit agencies. (Note that a spread penalty is equivalent to a split-shift premium.) A spread penalty is a bonus paid to any driver whose daily assignment, or run, keeps him on duty more than a specified number of hours after he begins in the morning. For example, an MBTA driver receives 1.5 times the basic wage rate for the time he works in the eleventh hour after his run begins, and he earns double pay for work in the twelfth and thirteenth hours. (Note that this paper includes several examples involving the MBTA. These examples are out of date because the MBTA now hires part-time drivers and thereby avoids much of the expense associated with the work rules discussed. Nevertheless, the examples illustrate problems still facing the majority of public transit agencies.)

Accordingly, an MBTA driver's daily pay can be anywhere from $88.38 to $116.00. A driver earns $88.38 if he is on duty for 8 continuous hours because the hourly wage is $11.0475. If, however, the driver is on duty for 8 hr during a 13-hr spread, he can earn $116.00, as follows:

Item	Cost ($)
5 hr at $11.0475	55.24
2 hr at $22.095	44.19
1 hr at $16.571	16.57
Total	116.00

Although spread penalties lead to variation in daily pay, the 8-hr guarantee leads to even greater variation in the amount that drivers earn for each platform hour. [Note that a platform hour is an hour in which a driver is responsible for a bus. It can involve driving time (on, to, or between routes) or scheduled layover time between trips. A nonplatform hour is an hour for which a driver is paid, although he is not responsible for a bus.] An 8-hr guarantee forces a transit agency to pay each driver for 8 hr of work even though the total daily demand for service is too low to provide 8 hr of driving for every driver needed during the peak periods. As a result, many drivers are productively employed for fewer than 8 hr a day, and their runs include slack time or nonplatform hours.

To calculate how much a driver earns for a particular platform hour, the driver's daily pay is divided by the number of hours he drives a bus. For example, a driver who earns $88.38 per day and drives for 7 hr and 50 min costs the MBTA $11.28 per bus hour, but a driver who earns $116.00 and drives for 7 hr (3 hr during the morning peak period and 4 hr during the afternoon peak period) costs the MBTA $16.57 per bus hour. What then is the wage cost of the vehicle hour?

Many transit agencies answer this question by calculating an average cost per platform hour. They divide the total amount they spend on drivers' wages by the number of hours of service they provide. Then, to calculate the cost of wages for an isolated service, they multiply the average cost per platform hour by the number of platform hours associated with the service. In doing so they implicitly assume that drivers earning spread penalties or driving fewer than 8 hr per day are evenly distributed throughout the day. As Figure 1 shows, drivers earning high wages for each platform hour are heavily concentrated in the peak periods.

Figure 1 shows the number of buses in service from one MBTA garage during each 0.25 hr of a weekday. It also shows the number of drivers working on each of four different driver shifts. The horizontal axis gives the time of day, and the vertical axis gives the number of buses or drivers in service. The figure shows that there are more than twice as many buses in service during the morning and afternoon peak periods as there are during the rest of the day. It also shows that a high percentage of the drivers working during the peak periods have expensive shifts (with spreads between 12 and 13 hr), although none of the drivers working in the middle of the day has such expensive shifts. As shown in Figure 1, schedulers assign drivers to inexpensive shifts whenever possible, but in order to operate peak-period service, it is impossible to avoid spread penalties and slack time. It is a fine art to fill the driver requirement at minimum cost to a transit agency, and some agencies use computers with automated run-cutting programs such as RUCUS to aid this process.

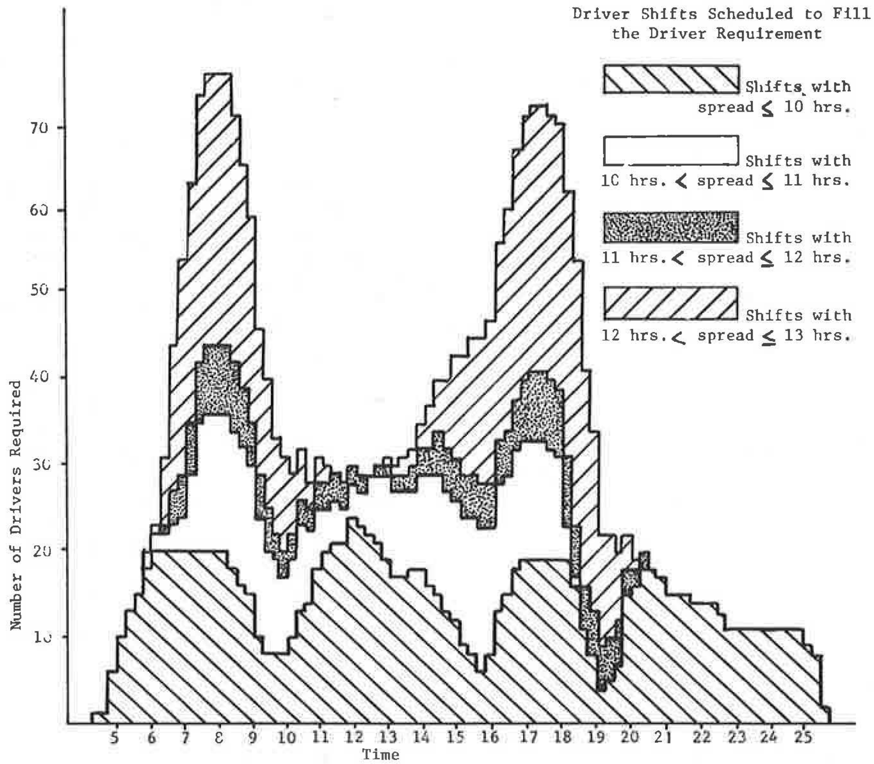
In summary, the cost-estimation problem is that drivers' wage costs vary throughout the day, and any accurate model must deal with this problem.

PREVIOUS WORK

Because drivers' wages depend on the scheduling process, the most accurate way to calculate the drivers' wages associated with a particular route is to compare the costs of two sets of drivers' runs, only one of which provides drivers for the route in question. For minor service changes, such as adding a route involving one bus and one driver, this may be a feasible technique, but for substantial changes that involve a number of drivers it can be prohibitively time consuming (except for agencies that cut runs by computer). Consequently, scheduling methods are rarely used to estimate costs. At the other extreme, the least-accurate method for estimating the cost of drivers' wages is average costing, which was described in the previous section.

To bridge the gap between these two extremes, transit agencies and researchers have developed a number of techniques for estimating driver costs without creating entirely new schedules. Cherwony, Gleichman, and Porter (1) reviewed some of these techniques and evaluated their applicability to service planning. As they explain, none of the available models is entirely satisfactory. The simpler models ignore the variation of labor costs throughout the day, and the models that reflect this variation (such as the Bradford model, the Northwestern model, and the Adelaide model) tend to be complex. These models express the cost of labor for a bus service as a function of the driver hours needed for the service. [Note that driver hours, which are also referred to as pay hours, worked hours, or man

Figure 1. Driver requirement for one MBTA garage.



Note that the figure shows the driver requirement for the Charlestown garage for the schedule period beginning June 22, 1981.

hours, include both actual driving time (platform hours) and slack time (nonplatform hours).] For example, the Bradford model expresses cost as a function of pay hours, and the Adelaide model involves worked hours, among other variables. Consequently, the application of these models involves three separate steps. First, the user must calibrate the model, i.e., the cost of 1 pay hour or 1 worked hour for the agency in question must be estimated. Second, the number of pay hours or worked hours required for a particular service must be estimated. Finally, the user substitutes the estimate of driver time into the calibrated model to estimate the wage cost of the service. The first two steps are complex because they force the user to consider the idiosyncratic work rules and scheduling practices of a particular agency.

Some simpler models that reflect the temporal variation of wages have been proposed, but few have been tested for accuracy. One such technique is the Arthur Andersen model, which assumes that a driver's pay for each platform hour is a weighted average of a fixed hourly pay for driving in the base period and a fixed hourly pay for driving in the peak period. This appears to be a reasonable approximation, but the model did not give reasonable results when calibrated for the MBTA (2).

After reviewing the available models, Cherwony and Porter (3) developed a model that, like the Bradford, Northwestern, and Adelaide models, reflected the variation in labor costs throughout the day and considered the scheduling practices of the agency in question. The Cherwony and Porter model shared several common shortcomings with these models:

1. Although the model reflects the temporal variation of labor costs, it assumes that the unit cost of driver time is constant during large segments of the day. (It divides the day into five segments: early morning, morning peak, midday, evening peak, and evening.)
2. The model expresses cost as a function of driver hours rather than vehicle hours. As a result, the user must consider the scheduling practices of the agency in question twice: once to calibrate the model (i.e., to estimate the cost of 1 driver hour), and again to estimate the driver time necessary for a particular service. The model would be easier to use if it expressed cost in terms of vehicle hours so that the user would only have to consider the scheduling practices of a particular agency once: to calibrate the model.
3. The model assumes that the cost of one unit of driver time during a specific part of the day is equal for all services operating during that part of the day. Unfortunately, this is not so. For example, both peak-period-only and all-day services operate during the evening peak period, but the unit costs of these services are not equal. An agency might be able to eliminate one split-shift driver by eliminating only 6 or 7 hr of peak-period-only service, whereas it would have to eliminate 8 hr of an all-day service in order to eliminate one straight shift.

MODEL FOR ESTIMATING DRIVERS' WAGES FOR A BUS SERVICE

The model presented in this section reflects some of the principles of the models mentioned previously but avoids some of the shortcomings. It uses a sample set of drivers' runs for the agency in question to calculate a separate unit cost of drivers' wages for each 0.5 hr of the day. It takes into account that

1. The mixture of shift types used to operate a schedule varies throughout the day, and

2. Slack time (nonplatform hours) and spread penalties are unevenly distributed among runs.

Other important features of the model are as follows.

1. Simplicity: The model expresses the cost of drivers' wages for a bus service as a function of platform hours. Because platform hours are equivalent in number to vehicle hours, a planner can use the model without estimating the total number of platform and nonplatform hours associated with a particular service.
2. General applicability: Any transit agency could calibrate the model to reflect its own union work rules and use it to estimate the drivers' wages associated with its own services.

Calibration

To calibrate the model for a particular transit agency, a sample of drivers' runs is used and a separate wage per platform hour for each 0.5 hr of the day is estimated. For example, to estimate the cost of a platform hour between 6:00 and 6:30 a.m., the steps are as follows.

1. Identify all runs (i) with at least one-quarter of a platform hour between 6:00 and 6:30 a.m.
2. For each run (i), divide the total daily wage (W_i) by the number of platform hours in the run (PH_i). This gives w_i, the average wage per platform hour for run i.
3. Find the average value of w_i over all i. This average is an estimate of the wage per platform hour between 6:00 and 6:30 a.m.

This can be stated as follows:

$$\bar{w}_{6:00\text{ to }6:30\text{ a.m.}} = \sum_{i=1}^{n} [(W_i/PH_i)/n] \quad (1)$$

where

$\bar{w}_{6:00-6:30\text{ a.m.}}$ = wage per platform hour between 6:00 and 6:30 a.m.,
W_i = total daily wage for run i,
PH_i = number of platform hours in run i, and
n = number of runs (i) with at least one-quarter of a platform hour between 6:00 and 6:30 a.m.

Figure 2 helps clarify this procedure. The figure represents all of the drivers' runs for one MBTA garage for a weekday. The horizontal axis gives the time of day, and each two-part horizontal bar represents one driver's run identified by the driver's number. For example, driver 1031 leaves the bus garage shortly after 7:00 a.m. and remains on duty until 11:00 a.m., when his first half ends. His second half begins at 2:00 p.m. and ends at 6:00 p.m. The figure shows only the platform hours in each run. Runs with fewer than 8 platform hours and with various spread penalties are also indicated.

The vertical column helps with the first step in calibrating the model by isolating all of the runs with platform hours between 6:00 and 6:30 a.m. From these runs, the planner can identify those with at least one-quarter of a platform hour inside the column, and then complete step 2 by calculating the wage per platform hour for each run. (Some of these costs are given in the figure as multiples of the basic hourly wage rate.) The final step is to average these wages per platform hour.

To calibrate the model completely, the planner must repeat the three steps for each 0.5 hr of the day.

Figure 3 is a plot of the wage per platform hour for each 0.5 hr of the MBTA day. The curve through the points is hand fit. The shape of the curve is not surprising, considering the mix of shifts used to fill the driver requirement at each time of the day (see Figures 1 and 2). In the early morning, midday, and evening hours most of the active drivers are on straight shifts (shifts with spreads less than 10 hr). In the peak periods, however, most of the active drivers are on swing shifts with high spread penalties. Figure 3 shows that the highest values of the wage per platform hour occur in the outer peak-period hours. As Figures 1 and 2 show, the MBTA schedules a group of runs with spreads of about 11 hr and low spread penalties between 7:00 a.m. and 6:00 p.m. Because these runs do not reach the outer peak-period hours, the MBTA has to use shifts involving higher spread penalties to fill the driver requirement in the outer peak-period hours.

Because the total driver requirement is much higher in the peak period than in the off-peak period, many of the runs with platform hours in the peak period include nonplatform hours, and the wage per platform hour for these runs is usually one-sixth to one-seventh of the total daily pay for the run. (The wage per platform hour for a straight run is about one-eighth of the total daily pay for the run.) This is one of the reasons that the wage per platform hour is higher in the peak period than in the off-peak period.

Application

Once the model has been calibrated for a particular transit agency, the cost of drivers' wages for an isolated service can be calculated as follows:

$$C_r = \sum_{\text{all } x} P_{rx} w_x \quad (2)$$

where

C_r = cost of drivers' wages for route r,
P_{rx} = number of platform hours required for route r in period x, and
w_x = wage per platform hour for period x.

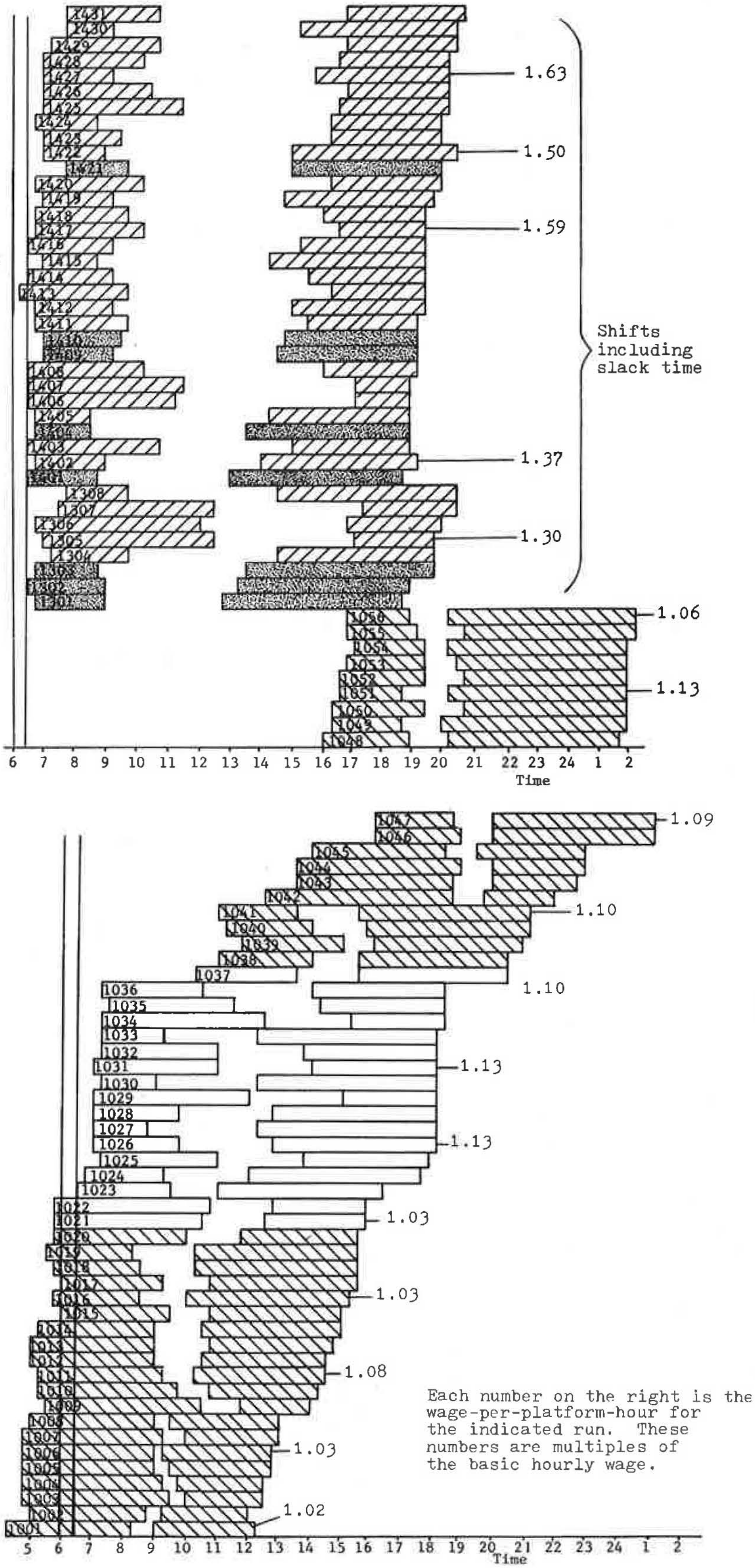
Figure 4 shows how the model is used to calculate the cost of drivers' wages for a single route. On the left of the figure a route profile shows the number of buses and drivers needed to operate the MBTA's route 60 during each 0.25 hr of the day. The first column gives the number of platform hours needed for each 0.5 hr of the day, and the second column gives the wage per platform hour for each 0.5 hr (expressed as a multiple of the basic wage rate). The third column gives the cost of wages for all drivers working on route 60 in each 0.5 hr (again as a multiple of the basic wage rate). Each entry in the third column is the product of the corresponding entries in the first and second columns. The total cost of drivers' wages for route 60 is the basic wage rate multiplied by the sum of the entries in the third column. In this case the total cost is $827.

In the example, each wage per platform hour is read from the hand-fit curve in Figure 3. (In using values read from the curve rather than the exact values calculated from a sample of runs, it is assumed that there would be a smooth, continuous relationship between the wage per platform hour and time if enough runs and sufficiently small time intervals were used in calibrating the model.)

EVALUATION

How accurate is the model? Ideally, this question would be answered by applying the model to actual

Figure 2. Driver runs for one MBTA garage.



Notes: The figure shows the driver runs for the Charlestown garage for the schedule period beginning June 22, 1981. See Figure 1 for a key to shift types.

Figure 3. Wage per platform hour for MBTA drivers.

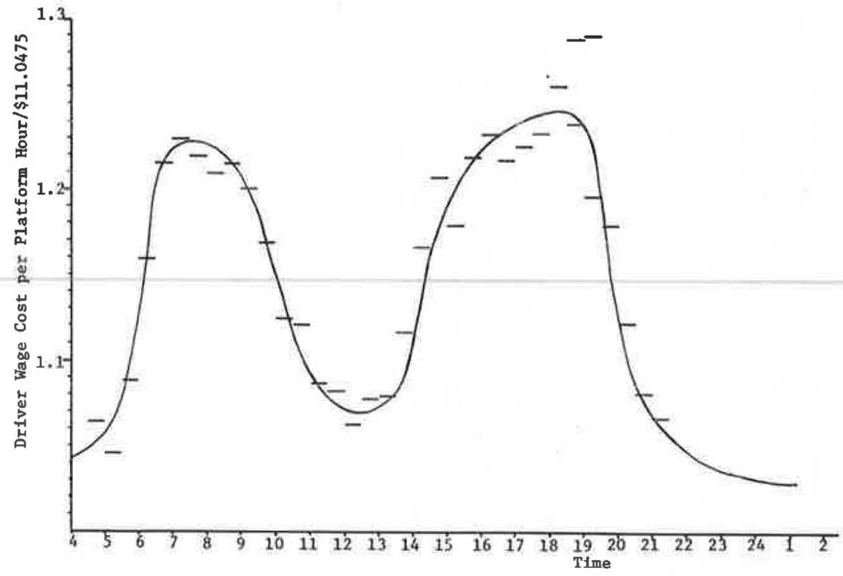
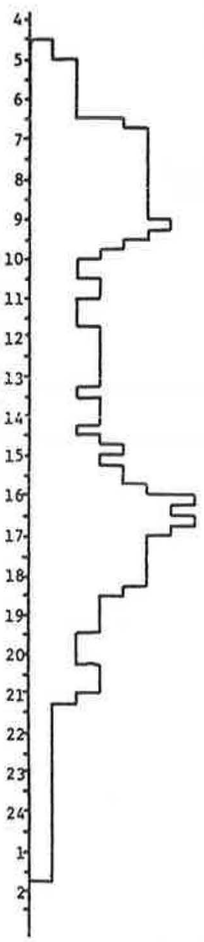


Figure 4. Application of model to estimate the cost of drivers' wages for MBTA route 60.



Platform Hours	Wage Cost per Platform Hour/$11.0475*	Wage Cost/$11.0475*
0.5	1.05	0.52
1.0	1.05	1.05
1.0	1.10	1.10
1.0	1.16	1.16
2.25	1.22	2.75
2.5	1.23	3.08
2.5	1.23	3.08
2.5	1.22	3.05
2.5	1.21	3.02
2.75	1.2	3.30
1.75	1.17	2.05
1.0	1.13	1.13
1.5	1.11	1.67
1.0	1.09	1.09
1.25	1.08	1.35
1.5	1.07	1.60
1.5	1.07	1.60
1.25	1.08	1.69
1.5	1.09	1.63
1.25	1.13	1.41
1.75	1.18	2.07
1.75	1.20	2.10
2.25	1.22	2.74
3.25	1.23	4.00
3.25	1.24	4.03
2.50	1.24	3.10
2.50	1.25	3.12
2.25	1.25	2.81
1.5	1.24	1.86
1.5	1.22	1.83
1.0	1.15	1.15
1.25	1.10	1.38
1.5	1.08	1.62
1.25	1.06	1.32
0.5	1.05	0.52
0.5	1.04	0.52
0.5	1.04	0.52
0.5	1.04	0.52
0.5	1.03	0.51
0.5	1.03	0.51
0.5	1.03	0.51
0.5	1.03	0.51
0.25	1.03	0.26
		74.83

Note: Cost of drivers' wages for route 60 = 74.83 x $11.0476 = $827/day.

*$11.0475 was the basic hourly wage for MBTA drivers in June 1981.

routes and comparing the resulting estimates with estimates developed through rescheduling, but this approach is beyond the scope of this paper.

A quicker alternative would be to compare the model's estimates for a sample of currently operating routes with the wages paid to the drivers actually assigned to these routes. But even this approach is complex because the drivers in many transit agencies each work on several routes during a single day. Nevertheless, the actual cost of drivers' wages can be estimated for the individual routes in a network by allocating each driver's wages to his multiple routes in proportion to the time spent on each route.

The data in Table 1 compare estimates that result from the model with the actual costs of drivers' wages for 12 currently operating MBTA routes. (The data also explain precisely how the actual cost of each route was calculated.) The results prompt some significant conclusions about the model.

The model yields extremely accurate cost estimates for routes on which the driver-requirement profile is approximately the same shape as the driver-requirement profile for the whole MBTA network. These routes include routes 60, 96, 220, 222, 300, and 700. (The driver-requirement profile for route 60 is shown in Figure 4.)

Table 1. Costs of drivers' wages for MBTA routes.

Route No.	Actual Cost[a] ($)	Model Estimate ($)	Upper Bound[b] ($)
60	824	818	NA
96	1,024	1,023	NA
220	849	838	NA
222	568	570	NA
300	766	737	860
302	298	268	328
304	860	914	1,148
305	562	511	607
325	285	289	332
326	296	294	347
700	651	639	NA
701	805	751	901

Note: NA = not available.

[a]Actual costs are calculated as follows:

$$C_r = \sum_{i \in I_r} (PH_{ri}/PH_i) \cdot W_i$$

where

C_r = daily cost of drivers' wages for route r,
PH_{ri} = platform hours that driver i spends on route r,
PH_i = number of platform hours in driver i's run,
W_i = driver i's daily pay, and
I_r = set of all drivers working on route r.

Thus, in order to calculate the actual cost of route r,

1. Identify all drivers working on route r,
2. Determine the fraction of each driver's platform hours spent on route r,
3. Multiply each driver's daily pay by the fraction found for him in 2, and
4. Sum the products found in 3 over all drivers identified in 1.

[b]The derivation of the upper bound is discussed in the section on Refinements.

Nevertheless, the model yields low estimates for routes on which most or all of the service is offered during the peak periods. Such routes include routes 300, 302, 304, 305, and 701. This result is not surprising because the estimates are based on the average wage per platform hour for all drivers with platform hours at a given time of the day. Strictly speaking, the cost of drivers' wages for a service is the marginal cost of wages, i.e., the amount the operator would save by eliminating the route. For peak-period-only services, or mostly peak-period services, the marginal cost of drivers' wages is considerably higher than the average cost because these services are responsible for spread penalties and slack time. If an operator eliminated a peak-period-only service, then the shifts that cost far more than the average could be eliminated.

Similarly, if an operator were to delete an all-day service with a steady driver requirement throughout the day, then only the shifts that cost less than the average could be eliminated. The cut would not allow for the elimination of spread penalties or slack time from the schedule. If the model were used, the savings from the cut would be overestimated because the model attributes the costs of spread penalties and slack time to all routes operating while any drivers with expensive shifts are on the road.

For the same reason, Cherwony and Porter drew this conclusion about their model (3):

> Adjustments should be made . . . when the service-change profile significantly differs from existing service levels by time period. For example, a service change calling for an additional express trip in the morning and evening peak periods would not result in driver assignments and types similar to the entire system.

Despite this problem, the estimates given in Table 1 for peak-period-only routes are approximately 5 to 10 percent off the actual costs. (Note that the estimates for routes 325 and 326 are almost identical to the actual costs given in Table 1 for these routes, even though these are peak-period-only services. This is merely a coincidence, which shows that the actual-cost calculation used in Table 1 is inappropriate for these routes. Although routes 325 and 326 offer service only during the peak periods, their drivers, whose wages are reflected in the actual costs in the table, have about 8 platform hours each in their runs. If either route 325 or 326 were eliminated, schedulers might succeed in eliminating slack time from the schedule by assigning the drivers from route 325 or 326 to other peak-period-only routes and eliminating drivers with slack time in their runs from these other routes. Therefore, it appears likely that the actual costs given in the table for routes 325 and 326 are lower than the true marginal costs of these routes.)

REFINEMENTS

Because the model tends to underestimate the marginal costs of drivers' wages for peak-period-only services, two methods for obtaining more reliable estimates for such services are suggested in this section.

Some operators could recalibrate the model specifically for routes with high peak-to-base ratios. This would require a set of drivers' runs specially designed (or cut) to supply drivers for mostly peak-period services. Some agencies have this data. For example, the MBTA cuts independent sets of runs for each of its garages, and the peak-to-base ratio of the services operating from some garages is higher than the peak-to-base ratio of the system as a whole.

Even if an agency did not have the necessary runs on hand, it could cut them. This would be time consuming, but much less so than rescheduling runs to estimate the costs of wages for individual services (which would be done to obtain the exact cost of wages for a route). Inevitably, a planner would have to judge how much time to trade for accuracy. An agency willing to recut runs could recalibrate the model any number of times, and each version could be used to estimate the costs of runs with peak-to-base ratios within a narrow range.

Without recalibrating the model for services with high peak-to-base ratios, a transit agency could use the model to determine a range for the drivers' wages associated with such service, assuming that the model gives the lowest possible cost of drivers' wages for routes with high peak-to-base ratios. An upper bound can be calculated by assuming that the upper bound for the wage per platform hour in a given period of the day is the wage per platform hour of the most expensive driver on duty at that time.

By using a complete set of drivers' runs for one agency, the steps for calculating the upper bound for the cost of drivers' wages for route r are as follows.

1. Identify all runs (i) with at least one-quarter of a platform hour during period x (see Figure 2).
2. For each run (i), divide the total daily wage (W_i) by the number of platform hours in the run (PH_i). This gives w_i, the average wage per platform hour for run i.
3. Rank the runs in descending order of wage per platform hour to determine u_{x1}, the wage per platform hour of the most expensive run in period x; u_{x2}, the wage per platform hour of the second most expensive run in period x; and so on.
4. Determine the number of platform hours needed for route r during period x (see Figure 4).
5. Calculate the cost of route r during period x by assuming that the first platform hour costs u_1, the second costs u_2, and so on.
6. Repeat steps 1 through 5 for each period of the day and sum the results. The sum is an upper bound for the daily cost of drivers' wages for route r.

The data in Table 1 give upper bounds for the costs of seven MBTA routes with high peak-to-base ratios.

SUMMARY AND CONCLUSIONS

The model presented in this paper can help any transit agency estimate the cost of adding or cutting service in an existing bus network. It simply and reasonably accurately predicts changes in drivers' wages caused by small or moderate changes in service.

The application demonstrated in the previous section of the paper indicates that the model is extremely accurate for service changes for which the required vehicle hours are distributed throughout the day in the same manner as the vehicle hours required for the entire system. The model is less accurate for service changes with unusually high peak-to-base ratios. Nevertheless, the model provides a lower bound for the costs of wages for peak-period-only services. Furthermore, the model can be recalibrated specially for service changes with atypical temporal distributions, although this procedure could involve considerably more effort than calibrating the basic model.

The model does not replace scheduling as a means of determining the exact cost of a service change. Nevertheless, it is a useful sketch-planning tool, and it is considerably simpler than the previously proposed models for estimating drivers' wages without scheduling. The essential simplifying step is to calculate the average wage per platform hour during each 0.5-hr period of a day, thereby capturing the impact of an agency's idiosyncratic work rules on the labor cost during each period.

REFERENCES

1. W. Cherwony, Gleichman, and B. Porter. Bus Route Costing Procedures--Part 1: A Review. UMTA, U.S. Department of Transportation, Rept. UMTA-IT-09-9014-81-1, 1981.
2. A. Herzenberg. Who Should Run Boston's Buses. Massachusetts Institute of Technology, Cambridge, Mass., Master's thesis, May 1982.
3. W. Cherwony and B. Porter. Bus Route Costing Procedures--Part 2: Proposed Method. UMTA, U.S. Department of Transportation, Rept. UMTA-IT-09-9014-81-1, 1981.

Publication of this paper sponsored by Committee on Transit Management and Performance.