Analysis of Bus Transit's Operating Labor Efficiency Using Section 15 Data

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ABSTRACT

Operator labor costs are the biggest operating expense category for motor bus transit systems; these costs account for approximately 42 percent of total operating expenses. Thus, if operating labor becomes more cost-efficient, significant overall cost reductions are possible. Operator labor cost per platform-hour or vehicle-operating hour was used as a macro measure of cost efficiency, and this measure was built up gradually from elementary and composite factors. The effect that environmental factors have on operator costs is examined by regressing them on each of the elementary and composite cost-efficiency measures. Using the results of these analyses, transit managers will be able to diagnose and possibly remedy the causes of their labor inefficiency.

Escalating costs, declining productivity, and increasing dependence on public subsidies have been the trend in the transit industry for the past two decades (1). Furthermore, transit has been given the assignment of accomplishing an array of social objectives, ranging from energy conservation to providing mobility for the poor and the handicapped. All this has led to an increased interest in the performance evaluation of the nation's transit systems. There is no general agreement on how to define and measure the performance of a transit system because the goals to be accomplished are often vague and conflicting. However, most researchers agree that transit performance is a multidimensional concept that includes some or all of the following elements (2,3):

- Efficiency,
- Effectiveness,
- Quality of service, and
- Societal impacts.

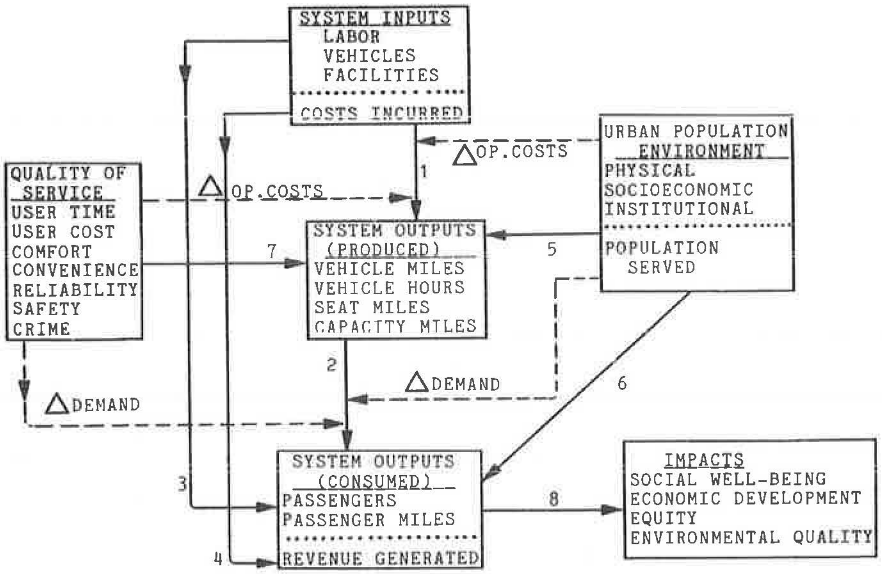
All of these elements of performance are not dealt with here; the focus here is only on the cost-efficiency concept (Link 1 in Figure 1) as it relates to the efficient use of operators in providing a vehicle-hour of service. For the purposes of this paper the term "operator" means only vehicle operators (i.e., drivers). The transit agency or firm that is responsible for the provision of service will be called system operator. Operator labor costs are the biggest system operating expense category and account for approximately 42 percent of total operating expenses (4). Thus, if operating labor becomes more cost-efficient, significant overall cost reductions are possible. Direct comparisons of systems and cross-sectional analyses are not generally useful because the major causes of operator cost variations are factors that are determined by the environment in which the system operates and are mostly outside the system operator's control. These environmental factors and their effect on operator labor costs are examined.

TRANSIT LABOR PRODUCTIVITY

Operators are paid at different hourly rates not only for the hours that they drive their buses (platform time) but for additional time as well, as the various Section 15 reporting categories given in Table 1 indicate. The definitions of all Table 1 items can be found in Volume II of the Uniform System of Accounts and Records (5). Table 2 gives abbreviated definitions of some key items as well as information on how these items are treated in labor contracts. Some of the categories in Table 1 are affected greatly by the combination of the system's service profile and its labor contract provisions (e.g., overtime and spread premiums, pull-in and pull-out times), and others are the result of contract clauses (e.g., run selection time, student training time). Because different categories are paid at different rates, the crucial question is not how many hours operators were paid in excess of their platform time but how much more they received in excess of the amount due to straight platform time service.

Before Section 15 became available, the best method for examining operating labor productivity was to look at vehicle-hours per operator. Some researchers used the ratio of revenue vehicle-hours per operator, which does not reflect only labor productivity but is also dependent on the route and network structure of the system, which is a major factor in the accumulation of deadheading time. Besides, as pointed out by Fielding et al. (6), both of these ratios have an inherent major flaw: they make transit systems that use part-time operators seem unproductive, whereas the reverse is actually true.

The concept of employee equivalents was introduced later, with one operator being equivalent to 2,000 or 2,080 hours of work, but problems persist with this measure because it does not make the distinction between hours of work and hours paid for. An operator may "work" 8 hr during a day but he may get paid for 8, 9, or 10 hr depending on when and under what circumstances those hours were clocked. Employee equivalents, therefore, tend to hide the effect of work rules that require system operators to pay premium wages for certain types or hours of work occurring outside some predetermined norms. To make matters worse, system operators (or at least those who fill out the Section 15 forms) do not appear to grasp the employee equivalent concept. The hard copy Section 15 annual reports present figures



Link interaction definitions:

1	Efficiency (cost, labor, resources)	EX: Rev.Veh.Hrs./Op.Costs
2	Service Effectiveness	EX: Passengers/Veh.Hr.
3	Cost Effectiveness	EX: Passengers/Op.Costs
4	Revenue Effectiveness	EX: Op.Costs/Fare Revenue
5	Service Coverage/Intensity	EX: Veh.Hrs/Population
6	System Effectiveness	EX: Passengers/Population
7	Service Quality	EX: Accidents/Mill. Veh. Miles
8	System Impacts	EX: Retail Sales

FIGURE 1 Transit system performance evaluation model.

TABLE 1 Operators' Wages Subsidiary Schedule Data Elements

Form No. 321

	TIME CLASSIFICATION	DOLLARS	HOURS
1.	OPERATING TIME		
1.01	Report time (Pull out)		
1.02	Turn-in time (Pull in)		
1.03	Travel time		
1.04	Platform time-line service		
1.05	Platform time-charter & special service		
1.06	Intervening time		
1.07	Paid breaks & meal allowance		
1.08	Min. guarantee for call out		
1.09	Minimum guarante-daily		
1.10	Minimum guarantee-weekly		
1.11	Overtime premium-scheduled		
1.12	Overtime premium-unscheduled		
1.13	Spread time premium		
1.14	Shift premium		
1.15	Other operating premium		
1.00	TOTAL OPERATING TIME		
2.	NONOPERATING PAID WORK TIME		
2.01	Instructor premium for operator training		
2.02	Student training time		
2.03	Accident reporting time		
2.04	Witness time		
2.05	Stand-by time		
2.06	Time spent on uniform functions		
2.07	Run selection time		
2.08	Other time spent in transportation administration		
2.09	Time spent in revenue vehicle movement control		
2.10	Time spent in ticketing and fare collection		
2.11	Time spent in customer service		
2.12	Time spent in other nonoperating functions		
2.00	TOTAL NONOPERATING PAID WORK TIME		
3.00	TOTAL OPERATING AND NONOPERATING TIME		

TABLE 2 Definitions of Selected Terms

Term	Item No.	Definition
Report time	1.01	Covers payments for the time allowed an operator to report to the dispatcher and receive instructions at the beginning and end of a piece of work.
Turn-in time	1.02	
Travel time	1.03	Covers payment for the time allowed an operator to travel between the operation station and the point where he relieves or is relieved by another operator.
Platform time-line plus charter and special service	1.04 1.05	Covers payments for time during which an operator operates the revenue vehicle in line or charter and special service, respectively. Deadheading and layover time is included.
Intervening time	1.06	Covers payment for the time between any two pieces of a run that is made up of more than two pieces.
Paid breaks and meal allowances	1.07	Covers payment for break time, other than layover time and intervening time, and allowances for company-paid meals.
Minimum guarantee for call-out	1.08	Covers payment for the time beyond that associated with the performance of a work piece, in order to bring the total amount paid up to the guaranteed minimum for the call-out.
Spread time premium	1.13	Is the bonus above straight-time pay for hours worked after a specified number of hours from the start of the operator's day. An operator who works two shifts, say from 7 to 11 a.m. and from 3 to 7 p.m., actually works 8 hr but "spreads" them over a 12-hr period in two "split" shifts, each one consisting of 4 hr of continuous working time. The contract may provide that operators are entitled to spread premiums after the tenth hour of work in a spread. Thus, this operator will get paid the spread premium for the last 2 hr of work. In addition, work assignments may be prohibited beyond a specified maximum spread time (e.g., 12 or 13 hr). Some contracts may also provide for an upper limit on the runs that could be spread (e.g., it may be stipulated that straight runs should be at least 60 percent of the total runs). Furthermore, a minimum work piece in a split shift may also be stipulated. This usually requires that each piece of a split shift be at least 2 or 2.5 hr long. Thus, an operator may not work just 1 hr in the morning and 7 hr in the afternoon and evening.
Shift premiums	1.14	Cover bonuses for working during times of the day that are subject to special time differentials (e.g., night or weekend service).

on vehicle-hours per operator and revenue vehicle-hours per operator. It might be thought impossible that these ratios exceed 2,000; however, the Year 4 annual report has 97 cases in which vehicle-hours per operator exceed 2,000 and some go higher than 5,000.

The results of recent research efforts in the area of transit labor productivity illustrate the problems encountered when trying to explain the labor efficiency of transit systems. Most of the studies were done using a relatively small and regionally segregated number of systems (7), and the data were not generated by a uniform reporting system. This is the reason for the conflicting results that were produced on some occasions. For example, in Giuliano's work (8) the positive sign of the variable average wage rate indicates that higher wages induce a more efficient use of labor, but Barnum's equation (9) shows the opposite because the variable enters with a positive sign also, but it explains what is effectively the inverse of Giuliano's variable. Some attempted to explain their efficiency measures by including a number of subsidy variables (9,10) that failed to increase significantly the explanatory power of the regressions. Using mostly contract provision variables in his equation, Wilson was somewhat successful in predicting pay-hours per bus-hour (11).

The operator efficiency analysis presented in this paper differs from all previous studies in most, if not all, of the following respects:

- Data are used for the first time that were produced from uniform, consistent, and precise reporting procedures and classifications;
- The transit systems in the sample represent all geographic regions of the country;
- The analysis is carried to the most detailed level possible, thus pinpointing the causes of inefficiency; and
- Greater emphasis is placed on the service characteristics of the systems.

OPERATOR LABOR COSTS

The indicator that best describes the total costs associated with operators is operator labor cost per platform-hour or vehicle-operating hour. However, this ratio is a macro measure, and it is possible to dissect it and build it up from elementary or composite factors as follows:

- Element A: Unproductivity factor (\$ paid for total salaries/\$ paid at the base rate for platform service),
- Element B: Average base wage rate (\$ paid at the base rate for platform service/platform-hours),
- Element C: Total salaries per platform-hour (product of A • B),
- Element D: Fringe benefits per platform-hour, and
- Element E: Operator labor cost per platform-hour [C + D or A•(B + D)].

If transit system managers want to evaluate their performance, analyses have to be performed not only on the macro measure but on all of its component elements as well. A transit system, for example, may appear to be doing well in terms of the macro ratio, but a closer examination may reveal that its unproductivity ratio is well above average and that it is paying rather low wages. Obviously, the corrective action suggested in this case would be entirely different from that for a situation in which the reverse is true (i.e., low unproductivity ratio and higher wages). The approach taken in this paper is to build up the macro measure from its component parts analyzing each one of them along the way.

DATA SOURCES

Data on operator labor costs, characteristics of service supplied and consumed, and generated revenues were obtained from the fourth year (FY ending

June 82) of Section 15 data (4). Data relating to socioeconomic and physical variables were obtained from the 1983 City and County Data Book (12), and additional information on wages for city employees was extracted from Bureau of the Census statistics (13).

Section 15 Data Elements

The Operators Wage Subsidiary Schedule (Form 321 and machine readable file OWSS, required for systems operating more than 25 revenue vehicles and effectively duplicated in Table 1) was used to obtain values for the first two elementary factors that can be used for the calculation of the macro measure. If the average base wage rate is defined as

Dollars for platform (line + charter) service/Hours of platform (line + charter) service,

the Form 321 items needed to compute it are

Dollars (1.04 + 1.05)/Hours (1.04 + 1.05).

In computing the unproductivity factor, the question may legitimately be raised whether Items 2.08 through 2.11 (time spent on a temporary basis on nonoperating functions) should be counted as productive or unproductive time. Operators getting paid for these items may be unproductive because they are not performing their major function (i.e., driving a bus). On the other hand, it may be noted that they perform at least some service to the system's public and therefore they are productive. To resolve this problem, three major unproductivity ratios were computed in terms of the following Table 1 items:

Y1 = Item 3.00/Items (1.04 + 1.05),
Y2 = Item 3.00/Items (1.04 + 1.05 + 2.08 + 2.09 + 2.10 + 2.11), and
Y3 = Items [3.00 − (2.08 + 2.09 + 2.10 + 2.11)] ÷ Items (1.04 + 1.05).

The first of these unproductivity factors considers Items 2.08 through 2.11 as unproductive time, the second considers them as productive, and finally the third simply ignores them completely by not including them in the computation. The unproductivity factor is a dimensionless ratio and either hours or dollars can be used for its derivation. Dollar amounts were chosen as more representative because the objective is not to reduce operator hours per se but to reduce the cost associated with those hours. A transit system, for example, may pay 1.1 times the base wage rate for night shift service and twice the base rate for unscheduled overtime. Therefore, paying an operator for an hour of unscheduled overtime results in overpayments that are equal to 10 hr of night shift premiums.

A close examination of the items in Table 1 reveals that some of them are greatly dependent on a system's service characteristics (e.g., Items 1.06, 1.13, 1.14) and that others simply reflect system policy (e.g., Items 1.01, 1.02, 2.01). To perform a more detailed analysis of a system's unproductivity, dollar amounts from file OWSS were used to produce the following six partial ratios:

Y4 = Items (1.06 through 1.15 + 2.05)/Items (1.04 + 1.05);
Y5 = Items (1.03 + 1.06 through 1.15 + 2.05)/Items (1.04 + 1.05);
Y6 = Items (1.01 + 1.02 + 1.03 + 1.06 through 1.15 + 2.05)/Items (1.04 + 1.05); and

$$\left.\begin{array}{l}\text{Y7} =\\ \text{Y8} =\\ \text{Y9} =\end{array}\right\}\ \begin{array}{l}\text{Numerators as in Y4, Y5, and Y6, respect-}\\ \text{tively, and denominator = Items (1.04 + 1.05}\\ \text{+ 2.08 + 2.09 + 2.10 + 2.11).}\end{array}$$

The major unproductivity ratios (Y1 to Y3) are always greater than one, but the six partial ratios (Y4 to Y9) have values that are less than one and cannot be used in their presented raw form as a building block for the computation of total operator labor cost per platform-hour. Variables Y4 to Y9 are in effect ratios of unproductive to productive time, whereas Y1, Y2, and Y3 are ratios of total to productive time. Payments for the unquestionably productive times (platform time-line plus charter and special service) are the denominator of Y4, Y5, and Y6, and the questionable Items 2.08 to 2.11 are added to the denominators of Y7, Y8, and Y9. The numerators of Y4 and Y7 contain only items that are influenced mainly by a system's service characteristics. Travel time is added to the numerators of Y5 and Y8, and, finally, report and turn-in times are also included in the numerators of Y6 and Y9. The three major and six partial unproductivity ratios constitute a total set of nine unproductivity measures that were examined individually in order to determine whether they are affected differently by the various environmental and service characteristics factors.

Fringe benefit data were obtained from the Transit System Employee Count Schedule (Form 404 and file EMPSCH) and Expenses Classified by Function (Form 301 and file XTFO). File XTFO contains aggregate data by function (Vehicle Operations, Vehicle Maintenance, Nonvehicle Maintenance, and General Administration), and it is not possible to isolate operators' benefits. File EMPSCH contains employee equivalents for the following classes in the vehicle operations function:

11. Transportation executive, professional, and supervisory personnel;
12. Transportation support personnel; and
13. Revenue-vehicle operators.

In terms of these classes, the fraction of vehicle operating personnel that actually operates vehicles is 13/(11 + 12 + 13). Therefore, by taking the product of this fraction times total fringe benefits for the vehicle operations function, an approximate figure for operators' benefits can be obtained.

The Transit System Service Supplied, Service Consumed and Service Personnel Schedule (Form 406 and file NRSTDY) provides data by time period for vehicles in operation, vehicle-hours, vehicle-miles, and full-time plus part-time operators. Service period durations were obtained from the Transit System Service Period Schedule (Form 401 and file WDSPSC), and system revenue information was extracted from the Revenue Summary Schedule (Form 201 and file REVSCH). Systems were considered to be privately owned if they reported in their balance sheets (Form 101 and file CAPSCH) capital for private corporation or noncorporate ownership. Finally, the population of the urbanized area in which the system operates was obtained from file UAREA.

Only single-mode motor bus transit systems were analyzed in order to avoid problems with joint expenses. Because the use of file OWSS was necessary, only systems with more than 25 vehicles were included. There are 108 such systems, but 20 of them had to be eliminated because they either did not file Form 321 or had zero entries in file WDSPSC. Two additional systems were excluded due to missing data on other variables. Thus 86 systems with valid data were available for the analyses. These systems represent 29 states and range in size from 26 to 2,960 revenue vehicles.

Census and Other Data Sources

The 1983 edition of the County and City Data Book (12) was used to extract information on

- Percentage of persons using public transportation for the work trip for both the county and city area,
- Percentage of the civilian labor force unemployed in the county and city,
- Percentage of area (county) that is urbanized,
- Mean temperature in January and July, and
- Heating and cooling degree-days in a year.

Data on average monthly earnings of city employees were derived from Government Statistics Reports on City Employment (13). These reports provide data for the month of October of each year. Reports for 1980, 1981, and 1982 were used to extrapolate data and make them coincidental with the sixth month of each system's fiscal year. The Directory of Regularly Scheduled, Fixed Route, Local Public Transportation Service (14) was used to identify the systems that are managed by private contract management firms.

OPERATOR LABOR COST ELEMENT ANALYSIS

Unproductivity Factor (Element A)

Factors Hypothesized to Influence this Variable

The service profile of a transit system influences greatly the payment amounts for some of the categories given in Table 1. The variables derived from the service profile and expected to be proportional with the unproductivity factor are as follows:

- Vehicles high peak to vehicles midday,
- Shoulder-to-shoulder time (start of a.m. peak to end of p.m. peak),
- Midday duration (end of a.m. peak to start of p.m. peak), and
- Vehicles high peak to vehicles low peak.

In addition, the unproductivity factor should be influenced by the following:

1. Size of the transit system. Union strength and bargaining power should be greater in larger systems, but, on the other hand, larger systems may have better scheduling techniques that may result in the reduction of the unproductivity factor. The variables used to represent system size were
    - Number of employees,
    - Number of revenue vehicles (total and during each service period),
    - Weekday hours of operation,
    - Annual hours of operation,
    - Annual vehicle-miles, and
    - Annual vehicle-hours.
2. The relative wealth of the system's area of operation represented by
    - County income per capita and
    - Average monthly earnings of city employees.
3. The system's ability to generate revenue represented by the variable passenger revenues per platform-hour.
4. The system's organizational or management structure or whether it is
    - Public or private,
    - Managed under contract by a private firm,

    or
    - A transit authority or transit district.
5. The fraction of operators that work full time. The use of part-time operators enables a system to alleviate some of the problems arising from its peaking characteristics, and it would be expected that unproductivity would increase as this fraction approaches 1.0.

Results Obtained

For these as well as all other variables, the Statistical Package for the Social Sciences (SPSS) was used to test regression equations of various linear and nonlinear functional forms. Variables were checked for multicollinearity problems and they were included in the equations only if they entered at a 0.05 level of significance or better. The number f cases (N) is 86 for all regressions, and the standardized regression coefficient along with the F-value of each independent variable are presented in brackets and parentheses, respectively. The equations that predict best the nine unproductivity indices are the following:

$$Y1 = 0.342 + \underset{(33.7)}{\underset{\{0.53\}}{0.705 \cdot 10^{-2} \cdot X1}} + \underset{(5.4)}{\underset{\{0.21\}}{0.119 \cdot 10^{-4} \cdot X3}} + \underset{(16.2)}{\underset{\{0.30\}}{0.609 \cdot X4}}$$

$$R^2 = 0.561 \text{ (adjusted} = 0.545) \tag{1}$$

$$Y2 = 0.386 + \underset{(36.8)}{\underset{\{0.53\}}{0.653 \cdot 10^{-2} \cdot X1}} + \underset{(7.5)}{\underset{\{0.24\}}{0.125 \cdot 10^{-4} \cdot X3}} + \underset{(17.1)}{\underset{\{0.30\}}{0.556 \cdot X4}}$$

$$R^2 = 0.593 \text{ (adjusted} = 0.578) \tag{2}$$

$$Y3 = 0.369 + \underset{(37.6)}{\underset{\{0.54\}}{0.669 \cdot 10^{-2} \cdot X1}} + \underset{(7.4)}{\underset{\{0.24\}}{0.124 \cdot 10^{-4} \cdot X3}} + \underset{(17.4)}{\underset{\{0.30\}}{0.574 \cdot X4}}$$

$$R^2 = 0.596 \text{ (adjusted} = 0.581) \tag{3}$$

$$Y4 = -0.423 + \underset{(23.2)}{\underset{\{0.39\}}{0.367 \cdot 10^{-2} \cdot X1}} + \underset{(20.7)}{\underset{\{0.36\}}{0.694 \cdot 10^{-2} \cdot X2}}$$

$$+ \underset{(10.3)}{\underset{\{0.25\}}{0.353 \cdot X4}} + \underset{(4.1)}{\underset{\{0.16\}}{0.394 \cdot 10^{-4} \cdot X5}}$$

$$R^2 = 0.587 \text{ (adjusted} = 0.567) \tag{4}$$

$$Y5 = -0.394 + \underset{(42.9)}{\underset{\{0.55\}}{0.641 \cdot 10^{-2} \cdot X1}} + \underset{(5.6)}{\underset{\{0.18\}}{0.417 \cdot 10^{-2} \cdot X2}}$$

$$+ \underset{(5.8)}{\underset{\{0.20\}}{0.982 \cdot 10^{-5} \cdot X3}} + \underset{(5.1)}{\underset{\{0.17\}}{0.292 \cdot X4}}$$

$$R^2 = 0.640 \text{ (adjusted} = 0.622) \tag{5}$$

$$Y6 = -0.374 + \underset{(40.7)}{\underset{\{0.55\}}{0.645 \cdot 10^{-2} \cdot X1}} + \underset{(6.5)}{\underset{\{0.20\}}{0.463 \cdot 10^{-2} \cdot X2}}$$

$$+ \underset{(4.1)}{\underset{\{0.17\}}{0.854 \cdot 10^{-5} \cdot X3}} + \underset{(5.4)}{\underset{\{0.17\}}{0.310 \cdot X4}}$$

$$R^2 = 0.625 \text{ (adjusted} = 0.607) \tag{6}$$

$$Y7 = -0.410 + \underset{(23.4)}{\underset{\{0.40\}}{0.360 \cdot 10^{-2} \cdot X1}} + \underset{(19.2)}{\underset{\{0.35\}}{0.654 \cdot 10^{-2} \cdot X2}}$$

$$+ \underset{(10.4)}{\underset{\{0.25\}}{0.346 \cdot X4}} + \underset{(4.0)}{\underset{\{0.16\}}{0.378 \cdot 10^{-4} \cdot X5}}$$

$$R^2 = 0.581 \text{ (adjusted} = 0.567) \tag{7}$$

$$\begin{aligned} Y8 = -0.387 &+ \underset{\substack{\{0.55\}\\(42.3)}}{0.629\cdot 10^{-2}\cdot X1} + \underset{\substack{\{0.16\}\\(4.6)}}{0.376\cdot 10^{-2}\cdot X2} \\ &+ \underset{\substack{\{0.21\}\\(6.1)}}{1.00\cdot 10^{-4}\cdot X3} + \underset{\substack{\{0.17\}\\(5.1)}}{0.288\cdot X4} \\ &\qquad R^2 = 0.612\ (\text{adjusted} = 0.598) \end{aligned} \tag{8}$$

$$\begin{aligned} Y9 = -0.367 &+ \underset{\substack{\{0.55\}\\(39.8)}}{0.632\cdot 10^{-2}\cdot X1} + \underset{\substack{\{0.16\}\\(5.4)}}{0.419\cdot 10^{-2}\cdot X2} \\ &+ \underset{\substack{\{0.21\}\\(4.4)}}{0.877\cdot 10^{-5}\cdot X3} + \underset{\substack{\{0.17\}\\(5.3)}}{0.305\cdot X4} \\ &\qquad R^2 = 0.618\ (\text{adjusted} = 0.599) \end{aligned} \tag{9}$$

where

X1 = passenger fares/platform-hour,
X2 = duration midday x fraction of full-time operators x high peak-to-base ratio,
X3 = county income per capita (1981),
X4 = vehicles high peak/vehicles low peak, and
X5 = average monthly earnings for city employees (adjusted for system FYs).

The signs of the various regression coefficients indicate that the factors hypothesized to influence the unproductivity factor really do so, although not all of them managed to be included in the equations. The relatively low coefficients of determination (R^2) are somewhat disappointing. However, this is because the explanatory variables used here did not try to forecast costs using actual contract provisions but rather to investigate the influences that the system's operating environment has on the various measures of unproductivity. Entries for Table 1 Items 2.08 to 2.11 are supplied by few systems and in extremely small amounts. This is the reason for the practically identical fits and coefficients of the equations that predict the three major unproductivity indices, although Equation 3 has a slight edge over the previous two. Considering that any work done on Items 2.08 to 2.11 is by definition only on a temporary basis and only a minute fraction of the total labor hours, it appears that Y3 should be the most appropriate unproductivity factor.

The revenue-generating ability variable, passenger fares per platform-hour, which also reflects service use intensity, proved to be the variable with the highest explanatory power for all nine indices. The service characteristics factors, duration midday, fraction of operators working full time, and high peak-to-base ratio, were represented in a single variable (X2), which had a better explanatory power than the sum of its three individual components. This probably reflects the fact that service characteristics factors have a dynamic and multiplicative influence on each other. It is interesting to note that variable X2 explains the six partial unproductivity ratios (Y4 to Y9) that focus on payment categories that are greatly influenced by the system's service profile, but it does not enter the equations explaining the three major unproductivity factors. The only service profile variable that entered into all equations was the vehicles high peak-to-vehicles low peak ratio. The hypothesis that operating labor will obtain more generous contract provisions in wealthier areas is supported by the finding that county income per capita (X3) is an explanatory variable for all three major and most of the minor unproductivity factors. In the only two cases (Y4 and Y7), where X3 does not enter the equations, another measure of area wealth, the average monthly earnings of city employees (X5), takes its place. System size variables have some individual correlation with the unproductivity factors (r = 0.25 to 0.40) but they did not enter the equations at the required level of significance. Shoulder-to-shoulder time proved to be insignificant also, possibly because of definitional ambiguities and erroneous Section 15 reporting by system operators. Private ownership or contract management dummy variables were not well correlated with the unproductivity factors.

Average Base Wage Rate (Element B)

The average base wage rate represents hourly payments for regular, straight operating time and its exact derivation was presented previously.

Factors Hypothesized to Influence this Variable

A variety of system operating characteristics, policy, and environmental factors was considered to influence the wage rate as follows:

1. City employee wages in the system's area of operation.
2. Income per capita in the county of operation.
3. Transit system size.
4. Public transportation's predominance in the area as measured by the percentage of work trips made by public transportation in the system's city and county of operation.
5. The fraction of operators that work full time. This factor influences the wage rate because of the following:
    - Part-timers may be getting paid at a lower rate;
    - The mere allowance of part-time operator use might indicate a diminished union strength, which in turn implies that full-time operators may be forced to accept lower wages; and
    - The union may allow part-timer use as a trade-off for higher full-time operator wages.
6. The ratio of line service hours to total (line plus charter and special) service hours. Driving in a regular line service environment requires more effort than charter and special services do. Operators may, therefore, ask for higher wages as this ratio increases.
7. Average vehicle capacity. The larger the vehicle an operator drives, the more likely it is that he would want to get paid more for his services.
8. Intensity of system use (or utilization) factors such as
    - Passenger-miles/vehicle-mile,
    - Passengers/vehicle-mile,
    - Passenger-miles/vehicle-hour, and
    - Passengers/vehicle-hour.
9. Regional characteristics. The Section 15 variable UMTA Population was used to indicate the size of the urban area, and, to avoid the use of dummy variables, the following were used to describe regional differences:
    - Mean July temperature (degrees Fahrenheit),
    - Mean January temperature (degrees Fahrenheit),
    - Heating degree-days in a year, and
    - Cooling degree-days in a year.
10. The system's organizational and management structure.

Results Obtained

The regression equation that best predicted the average wage rate was

$$Y10 = -11.24 + \underset{\substack{\{0.47\}\\(40.1)}}{0.242\cdot 10^{-2}\cdot X5} + \underset{\substack{\{0.30\}\\(17.0)}}{0.515\cdot X6} + \underset{\substack{\{0.26\}\\(14.4)}}{0.212\cdot 10^{-3}\cdot X7} + \underset{\substack{\{0.22\}\\(10.3)}}{3.22\cdot X8} + \underset{\substack{\{0.15\}\\(4.4)}}{9.64\cdot X9}$$

$$R^2 = 0.648 \text{ (adjusted} = 0.628) \qquad (10)$$

where

Y10 = average base wage rate,
X5 = average monthly earnings for city employees (adjusted for system FYs),
X6 = Ln (vehicles operating in the p.m. peak),
X7 = heating degree-days per year,
X8 = fraction of operators working full time, and
X9 = line service hours/total service hours.

The coefficient signs of the independent variables are in agreement with the hypotheses. The natural log of vehicles operated during the p.m. peak (X6) is the only variable associated with system size that entered the equation. The positive sign of X8 indicates that wages are higher when full-time operators predominate in a system. This implies that, in Item 5 in the preceding list, the first and second hypotheses, but not the third, are correct. The variable heating degree-days per year (X7) acts as a proxy for all regional characteristics descriptors. The positive sign of its coefficient indicates that, other things being equal, systems in the north are paying higher wages. Historical reasons may be the cause of this because transit was developed first in the old, northern, industrial cities. Vehicle capacity, the intensity of use factors, and city population are all reasonably well correlated with the base wage rate (r = 0.30 to 0.40), but they become insignificant when entering the equation along with the other variables. The percentage of work trips made by public transportation in the city was well correlated (r = 0.50) with the wage rate. However, it was also correlated with other independent variables such as system size and city employee wages, and this is the reason for its exclusion from the equation. Variables describing the system's organizational and management structure were not well correlated with the wage rate.

Total Salaries per Platform Hour (Element C)

The total amount paid for salaries per platform hour is a composite variable obtained by the product of the wage rate times the unproductivity factor. This composite variable should be influenced by the same factors that influence its two component parts.

The regression equation that predicted total salaries per platform hour best was

$$Y11 = -45.68 + \underset{\substack{\{0.44\}\\(30.0)}}{0.32\cdot 10^{-2}\cdot X5} + \underset{\substack{\{0.17\}\\(7.2)}}{3.46\cdot X8} + \underset{\substack{\{0.17\}\\(5.7)}}{15.38\cdot X9} + \underset{\substack{\{0.18\}\\(7.8)}}{0.740\cdot X10} + \underset{\substack{\{0.19\}\\(7.2)}}{0.138\cdot X11} + \underset{\substack{\{0.23\}\\(8.4)}}{3.03\cdot X12}$$

$$R^2 = 0.720 \text{ (adjusted} = 0.70) \qquad (11)$$

where

Y11 = total salaries per platform-hour;
X5 = average monthly earnings for city employees (adjusted for system FYs);
X8 = fraction of operators working full time;
X9 = line service hours/total service hours;
X10 = high peak-to-base ratio;
X11 = weekday hours of operation; and
X12 = Ln (county income per capita, 1981).

The results are as expected. Most of the variables that explain this composite ratio appeared also as explanatory variables of either or both of its two component elements (X8 and X9 for the wage rate, X5 for both, and X12 for the unproductivity factors but in a different functional form). The high peak-to-base ratio (X10) replaced X4 (and partly X2) as a service profile characteristic variable, and the weekday hours of operation (X11) entered as a substitute for X6. In addition, X11 serves as a service characteristic descriptor because it leads to higher unproductivity through the payment of night shift premiums.

Fringe Benefits per Platform-Hour (Element D)

This variable is greatly affected by the total salaries per platform-hour because most fringes (FICA, pensions, and so forth) are by legal or contractual provisions in direct proportion to paid salaries. Even fringe categories such as vacation and holiday pay will be directly proportional to wages (the partial correlation between wages per platform-hour and fringes per platform-hour is 0.8). Therefore, fringe benefits per platform-hour would be affected by the same factors that influence the unproductivity factor and the average base wage rate.

The regression equation that best predicts fringe benefits per platform-hour is

$$Y12 = -16.32 + \underset{\substack{\{0.48\}\\(48.0)}}{0.208\cdot 10^{-2}\cdot X5} + \underset{\substack{\{0.16\}\\(5.9)}}{1.90\cdot X8} + \underset{\substack{\{0.23\}\\(11.7)}}{12.23\cdot X9} + \underset{\substack{\{0.32\}\\(21.2)}}{0.759\cdot X10} + \underset{\substack{\{0.20\}\\(7.4)}}{0.088\cdot X11}$$

$$R^2 = 0.682 \text{ (adjusted} = 0.662) \qquad (12)$$

where

Y12 = fringe benefits per platform-hour,
X5 = average monthly earnings for city employees (adjusted for system FYs),
X8 = fraction of operators working full time,
X9 = line service hours/total service hours,
X10 = high peak-to-base ratio, and
X11 = weekday hours of operation.

The strong relationship between total salaries and fringe benefits is confirmed by the fact that all the independent variables of Equation 12 were also used in Equation 11.

Total Operator Cost per Platform-Hour (Element E)

This is the overall composite measure of the operators' cost efficiency and it should be influenced by the combined effects of the variables appearing in all previous equations.

The regression equation that best predicts total operator cost per platform hour is

$$Y13 = -34.34 + \underset{\substack{\{0.55\}\\(75.0)}}{0.616\cdot 10^{-2}\cdot X5} + \underset{\substack{\{0.24\}\\(12.2)}}{6.88\cdot X8} + \underset{\substack{\{0.22\}\\(13.7)}}{26.56\cdot X9} + \underset{\substack{\{0.19\}\\(7.9)}}{1.21\cdot X10} + \underset{\substack{\{0.19\}\\(9.7)}}{0.273\cdot X11} - \underset{\substack{\{0.14\}\\(4.8)}}{0.421\cdot X13}$$

$$R^2 = 0.746 \text{ (adjusted} = 0.726) \qquad (13)$$

where

Y13 = total operator cost per platform-hour,
X5 = average monthly earnings for city employees (adjusted for system FYs)
X8 = fraction of operators working full time,
X9 = line service hours/total service hours,
X10 = high peak-to-base ratio,
X11 = weekday hours of operation,
X13 = mean January temperature (degrees Fahrenheit).

With the exception of X13 all other variables have already been used to explain some of the component parts of this final, composite, efficiency indicator. The mean January temperature entered the equation replacing the number of heating degree-days per year (X7) that was used previously as the geographic region descriptor. Although both X13 and X7 are temperature-related variables, they are negatively correlated and this is the reason why X13 enters Equation 13 with a negative sign, whereas X7 had a positive sign in Equation 10.

SUMMARY OF RESULTS

The results indicate that a major portion of the variation in the operator unproductivity factors, the base wage rate, and the consequent composite operators' efficiency ratios, can be explained by the socioeconomic, regional, revenue, and service characteristics variables that constitute the environment in which a transit system operates. These findings make it possible to make useful and meaningful comparisons among transit systems by accounting for the exogenous factors that affect their efficiency, and thus moving a step further along the difficult, crucial process, which is of interest to every transit manager, of exploring and determining the sources of unit cost variations among transit systems.

Explaining the total cost variations is, without a doubt, a much easier process than explaining unit cost variations, as the following model demonstrates:

$$\begin{array}{ll} Y14 = 0.757 + & 1.148 \cdot X14 \\ & \{0.98\} \\ & (1{,}828) \\ & R^2 = 0.956 \text{ (adjusted = 0.956)} \end{array} \qquad (14)$$

$$\begin{array}{llll} Y14 = -0.0247 + & 1.013 \cdot X14 + & 1.085 \cdot X15 + & 1.072 \cdot X16 \\ & \{0.86\} & \{0.20\} & \{0.08\} \\ & (19{,}524) & (1{,}017) & (181) \\ & R^2 = 0.999 \text{ (adjusted = 0.998)} & & \end{array} \qquad (15)$$

where

Y14 = Ln (total operators' cost),
X14 = Ln (platform-hours),
X15 = Ln (average base wage rate), and
X16 = Ln (unproductivity factor Y1).

Platform-hours explain almost all the variation in total operators' cost (Equation 14), and the addition of two more variables produces a perfect fit. However, this is a rather trivial exercise because Equations 14 and 15 can only be used for forecasting purposes and are completely useless as diagnostic tools. On the other hand, Equations 1 through 13 can be used for diagnostic purposes and can pinpoint the sources of operators' inefficiencies.

OBSERVATIONS AND CONCLUSIONS

Although the diagnostic equations presented here have reasonably good fits, their applicability, validity, and accuracy are a function of the following considerations that should be kept in mind before system comparisons are undertaken:

1. Most variables were derived from Section 15 data, the uniformity of which provides unique research opportunities. However, Section 15 data are far from perfect. Detailed examinations of each transit system had to be performed to ensure data validity (see paper by Bladikas and Papadimitriou in this Record). Missing data are a minor problem compared with possible definitional ambiguities in the data definitional elements that cause erroneous entries that are harder, and occasionally impossible, to identify.
2. Layover time--the time spent at the end of a route before the commencement of another run--is included in the platform-hours of service, and, therefore, it is counted as productive time even though vehicle and driver are idle and are not serving passengers. Layover time provides leeway for variations in the running time and is used to maintain schedule adherence. There is, therefore, a trade-off between efficiency and quality of service because long layover times practically guarantee strict schedule adherence, whereas short layover times imply a high risk of scheduling abnormalities.
3. Deadheading hours--traveling to and from the first (last) passenger stop from (to) the bus yard--are included in the platform-hours. Although deadheading hours should be minimized, the problem here is not one of driver productivity but one of route structure and garage location.
4. The wage rates calculated and used here include only 1 year of observations, although most labor contracts are in effect for more than a year. It may, therefore, make a difference if the wage rates used represent wages that a contract stipulates for its first or last year. Pooled wages from 3 consecutive years of data could be used in further research.
5. The wage rate also affects the quality of hired and retained personnel. It is safe to assume that low wages will not attract good drivers and will also induce high turnover rates, thus creating unproductive times during the training of new drivers. Employee dissatisfaction and absenteeism could also be the product of low wage rates.
6. The service characteristics variables used represented supplied and not demanded service. For example, the actual high peak-to-base passenger demand may be three, but the high peak-to-base ratio calculated from service supplied data is two. This is because transit managers find it more cost effective to run vehicles during the midday period and incur the running costs than to pay operators to remain idle.

In spite of the limitations that are inherent in these models, the results indicate that the addition of a limited number of environmental variables to the Section 15 data is sufficient to analyze the factors that influence variations in operators' costs. The variables identified and used in the equations are to a large extent and for all practical purposes outside the system operator's control. This provides the opportunity to make valid comparisons of transit systems because inefficiencies are diagnosed in terms of variables that cannot be affected by the system operators' managerial skills. However, a system operator is not completely helpless, even if the operator's efficiency is a function of mostly exogenous variables.

Using the models presented here, transit managers can determine their efficiency relative to other systems and thus know if they are above or below industry norms. Although no indexing measure has been developed to determine the exact position of a transit system among the rest, it is sufficient to know at least if a system is over- or underperforming. With the assistance of the models that diagnose each individual cost component, a system operator may take corrective action to improve efficiency in any of the cost components. Future labor contracts could be less generous with clauses that affect efficiency, and wage increases could be tied to productivity improvements. Steps can also be taken to reduce the detrimental effects of peaking characteristics by using more part-time labor, using operators for other functions during the midday, and purchasing transportation during peak periods.

It is difficult to solve or even discuss the extremely delicate problems of labor efficiency. The issue is not only highly political, it also deals with human resources that cannot be manipulated or treated like inanimate objects. However, in view of the financial difficulties of the transit industry, it behooves both labor and management to improve the system's efficiency. The proper diagnosis and understanding of the problem is in the best interest of all parties concerned with the viability and survivability of public transportation.

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