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The literature of transit research contains few studies which have examined the effects of environmental and operational factors on the performance of public transit. The existence and strength of these effects, however, are often the basis for argument against quantitative evaluation of performance. Environmental conditions such as the location and character of the population being served, the geographic nature of the transit service area, prevailing wage rates in an area, and operational characteristics such as organizational structure, vehicle age, and vehicle passenger capacities certainly affect quantitative performance indicators and their interpretation.

At the same time, little effort has been made toward applying evaluative techniques proven in other fields to the evaluation of transit performance. Procedures do exist--in agriculture, for example--for the aggregation of operational statistics into single indices of technical efficiency.

Extensive collection of operating and financial data from 47 public transit operators in California for UMTA Research and Training Grant CA-11-0014, "Development of Performance Indicators For Transit," facilitated initial analysis efforts in each of these areas.[1] Data was obtained primarily from public documents, with missing, and additional

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[1]This parent study and its findings are contained in: Gordon J. Fielding, Roy E. Glauthier, and Charles A. Lave, Development of Performance Indicators For Transit: Final Report (Irvine, Calif: Institute of Transportation Studies, University of California, December, 1977).

data elements supplied by representatives of each transit property. Even with the high commitment of time and resources made by this project to assembling and verifying this data, its reliability and uniformity were found to be inadequate for statistical analysis.[2]

The following two sections describe the application of the collected operating and financial data to two multivariate statistical techniques. The first technique, production function analysis, examines the use of a unified efficiency measure on public transit. The second technique, multiple regression analysis, investigates the effects of particular operational characteristics on indicators of transit performance.

## PRODUCTION FUNCTION ANALYSIS
## APPLICATION OF FARRELL EFFICIENCY ANALYSIS TO CALIFORNIA TRANSIT PROPERTY DATA*

### Introduction

One useful measure in the evaluation of transit company performance is technical efficiency. Technical efficiency is the term used by economists to describe the ability of a firm to use its productive resources without waste. Comparisons of the technical efficiencies of transit companies would reveal which of those companies made better use of resources under similar production circumstances.

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[2]For a detailed discussion of problems encountered in available operating and financial data, see Ibid, pp. 29.

*The research discussed in this section was conducted by Randall J. Pozdena, Jr., Stanford Research Institute and Mills College, Oakland, California.

The actual measurement of technical efficiency is a conceptually difficult process. Transit companies differ in the kind and quantity of the services they provide, the prices they pay for labor, materials and other inputs, and the financial circumstances under which they operate. To control for all of these differences in a fashion which permits calculation of a single index of comparative efficiency requires a careful conceptualization of the production methodology of the transit company.

The simplest method[3] of constructing measures of comparative technical efficiency is the Farrell method, after the economist, M. J. Farrell, who first identified the technique in 1957.[4] This technique has been applied to the data on 36 California transit properties in an attempt to develop an unambiguous measure of the comparative efficiency of these companies. The type of management (special district vs. city department, for example), the size of the company, or other attributes might partially explain the observed divergence in efficiencies.

The discussion below details the technique employed to perform this analysis and the results of using the California transit property data.

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[3]It is simplest in that it does not require cost data and does not need a precise specification of the production relationships in order to produce useful comparative efficiency indices. A cost function approach, for example, would require both of these elements.

[4]M. J. Farrell, "The Measurement of Productive Efficiency," <u>Journal of the Royal Statistical Society</u>, 1957.

## Calculating Technical Efficiency Indices

The technique employed in calculating technical efficiencies was the Farrell method as used by J. N. Boles[5] and A. Hall[6] in agricultural economic studies and A. Hall and R. Pozdena in previous studies of transit company efficiency.[7]

Figure 1 illustrates the concept of the Farrell efficiency method in a simple two input, one output case assuming constant returns to scale. The curve AA in the figure suggests that there are various combinations of inputs (buses and labor hours) that might be used to produce the same transit output (bus hours) if all inputs were used as effectively as possible. The curve, called an isoquant, is then the production "frontier"[8] because no company can use its inputs more effectively; for example, no firm can use buses and labor in a combination represented by point B on the figure.

Firms which are not technically efficient enough to use buses and labor in a ratio that lies on the frontier will lie to the northeast of

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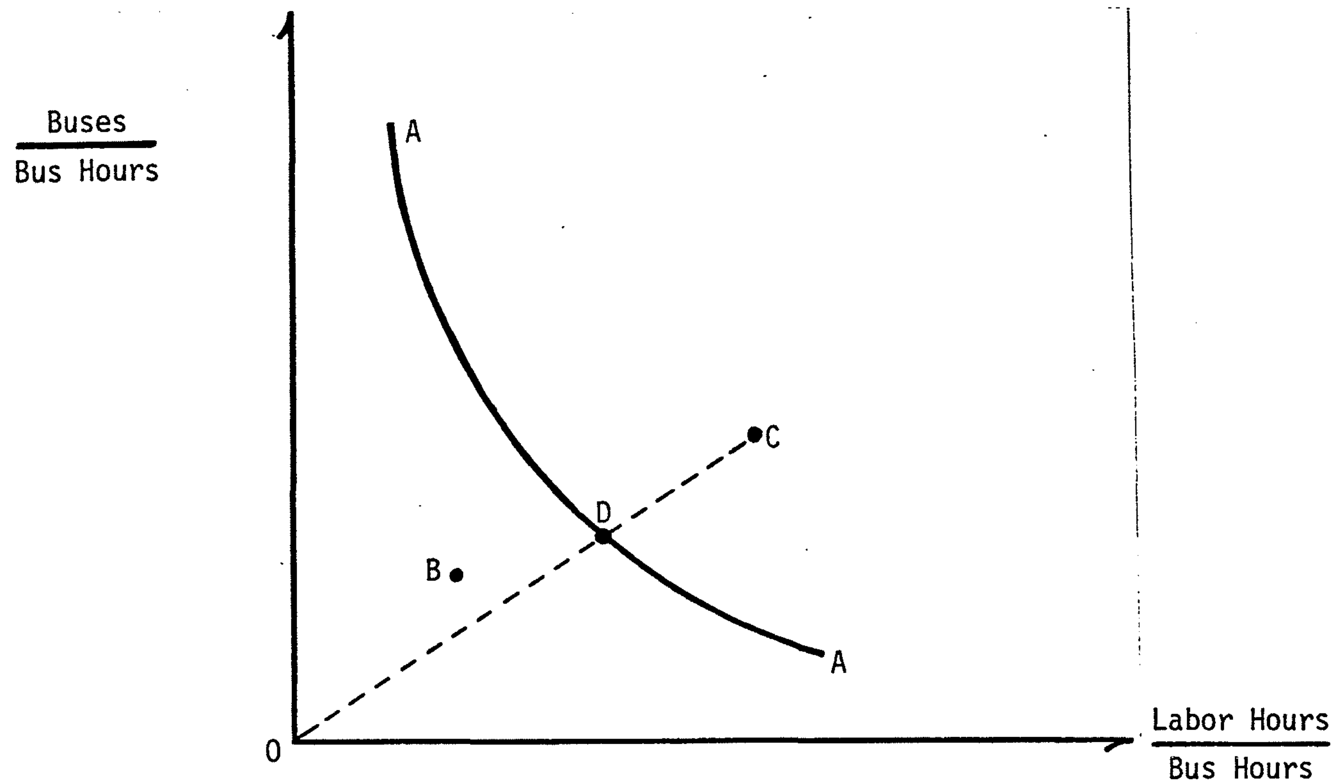
[5] J. N. Boles, "The 1130 Farrell Efficiency System," Division of Agricultural Sciences, University of California, February, 1971.

[6] A. R. Hall. The Efficiency of Post-Bellum Southern Agriculture. Doctoral Dissertation in Economics, University of California, 1975.

[7] A. R. Hall and R. J. Pozdena, "Introduction to a Transit Evaluation System," Stanford Research Institute, 1976.

[8] Without the assumption of constant returns to scale, this diagram would have to contain one "frontier" isoquant for each level of output. However, with the simplifying assumption of constant returns to scale and the use of input measures per unit of output on the axes, the diagram can be simplified such that AA represents the entire production of the frontier.

FIGURE 1: Bus Services Production Relationship




the frontier as in the case of point C. The farther away from the frontier (that is, the farther to the northeast) that a firm's combined use of labor and buses is situated in Figure 1, the less technically efficient the firm may be said to be. The so-called Farrell efficiencies on which our study was based are calculated as the distance OD divided by the distance OC. Thus, they are single numbers ranging from 1.0 (the firm is producing on the frontier) to, in the limit, 0.0 (the firm is infinitely far to the northeast of the frontier).[9]

[9]There are some assumptions implicit in this type of efficiency measure. Most importantly, the use of a measure which is calculated at a fixed factor ratio (all points on the line OC uses the inputs or factors in a fixed ratio) implies that whatever factors cause the inefficiency (called "quasi-factors") enter the production process multiplicatively rather than additively. That is, they have the same percentage effect on a firm regardless of the size of the firm. This is a reasonable, but not unchallengeable assumption.

A computer program was used to make these calculations and to construct the frontier itself from the available data. That is, the information from the most efficient firms in the sample was used to calculate a version of the frontier AA as in Figure 1 (although it was done in more output and input dimensions).[10]

The data used as output measures included one intensive measure (bus hours) and one extensive measure (route-miles). In various runs, either bus hours or both measures were used. The intput vector was in five dimensions including data on three categories of employees (operating, maintenance, and administrative), a measure of energy consumption, and the number of revenue vehicles for all runs. This data was available for 36 properties, but because of inconsistencies in the way that different

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[10]The computational technique is essentially a sequence of linear programming problems of the following form:

For the ith of N firms, select a set of x's to maximize :

$$\sum_{j=1}^{N} x_j Q_j \leq Q_i + \pi Q_i \ ,$$

$$x_j \geq 0 \ , \ j = 1,\ldots,N$$

subject to the constraint

$$\sum_{j=1}^{N} x_j I_j \leq I_i$$

where $Q_j$ is the output of the jth firm and $I_j$ is the vector of inputs of the jth firm.

properties measure route miles,[11] only 27 of these data points were usable in a run that used both output dimensions.

The results of the efficiency analyses are presented in Figure 2. Properties received an efficiency rating with a maximum value of 1.000. Lower values imply (ordinally) lower efficiency. This figure contains the results of 3 different efficiency analyses:

> One output (bus hours) with five inputs ("Run 1"). All 36 properties could be used in this analysis.
>
> Two outputs (bus hours and route miles) with five inputs ("Run 2"). An attempt was made to arrive at a sample with consistent definition of route miles as per footnote 11. This sample was limited to 28 properties.
>
> Two outputs (bus hours and route miles) with five inputs and the 8 properties with one-way non-duplicating route miles included ("Run 3").

## Results and Interpretation of Analyses

The technique employed to rank the properties functioned (in a technical sense) as expected, and, for each of the 3 cases, provided an index of the firms' technical efficiency. However, patterns in the efficiencies did not emerge in as clear detail as anticipated. This was

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[11]The properties variously had calculated route miles as one-way with duplicating segments, one-way with non-duplicating segments, and two-way round trip. The largest sample with a consistent measure was 20. This turned out to be too small for the computational procedures used. A sample was then constructed using those properties with one-way duplicating route-mile data if available or two-way round trip route miles divided by two if not available. This is not a precisely correct relationship between these two concepts of route miles, but this approximation and pooling were required by the limitations of the sample. The various route-mile definitions are appended to this report.

FIGURE 2: Efficiency Indexes of California Sample-Production Function Analysis Technique

| Property | Run 1 | Run 2 | Run 3 |
|---|---|---|---|
| AC Transit District | .522 | .834 | .530 |
| Arcata-Mad River Transit System | .835 | 1.000 | .856 |
| Banning, City of | .713 | 1.000 | 1.000 |
| Camarillo, City of | 1.000 | - | 1.000 |
| Chula Vista City Bus Lines | .765 | - | 1.000 |
| Culver City, City of | 1.000 | 1.000 | 1.000 |
| Eureka Transportation Service | .526 | - | .526 |
| Fresno Transit | .804 | 1.000 | .857 |
| Gardena Municipal Bus Lines | .683 | 1.000 | .718 |
| Gold Country Stage | .938 | 1.000 | 1.000 |
| Golden Empire Transit District | .630 | .917 | .675 |
| GGBH&TD (Golden Gate) | .365 | .675 | .511 |
| Healdsburg, City of | 1.000 | 1.000 | 1.000 |
| Laguna Beach Municipal Transit Lines | .212 | .328 | .285 |
| Long Beach Public Transportation Co. | .543 | - | .543 |
| Modesto, City of | .649 | - | .649 |
| Montebello Municipal Bus Lines | 1.000 | - | 1.000 |
| Monterey Peninsula Transit Authority | .479 | .781 | .601 |
| Napa, City of | .731 | 1.000 | .963 |
| North County Transit District | .493 | .861 | .715 |
| Orange County Transit District | .459 | .773 | .535 |
| Pacific Grove, City of | 1.000 | - | 1.000 |
| Placer County | .340 | 1.000 | 1.000 |
| San Diego Transit Corp. | .489 | .759 | .547 |
| San Francisco Municipal Railway | .446 | .663 | .447 |
| Santa Barbara Metro. Transit District | .649 | 1.000 | .718 |
| Santa Cruz Metro. Transit District | 1.000 | 1.000 | 1.000 |
| Santa Rosa, City of | 1.000 | 1.000 | 1.000 |
| Sebastopol, City of | .722 | - | .722 |
| South Coast Area Transit | .828 | .922 | .833 |
| Southern California Rapid Transit District | .595 | .810 | .633 |
| South Lake Tahoe, City of | .266 | .386 | .355 |
| Stockton Metro. Transit Dsitrict | .437 | .792 | .503 |
| Tahoe Area Regional Transit | .619 | .898 | .898 |
| Torrance Transit System | .812 | 1.000 | .970 |
| Vallejo, City of | .493 | - | .550 |

Total Properties Included: 36

primarily because of data problems, but also because the relatively small sample size which was imposed on the analysis (in part also because of data problems) strained the ability of the technique to function on a sample from which problematic observations had been purged.

The data problems consisted mainly of inaccuracies in the original data (some of the data was in fairly crude form or had to be derived from data maintained in another form). In addition, however, certain types of necessary data were simply not available from the properties analyzed. For example, a consistent measure of route miles was not available for a significant subset of the properties, forcing a very imprecise definition of this variable to be used in the analyses, if it was used at all. Also, certain categories of labor services (particularly maintenance) are contracted for outside the transit company and the data on the dimension of these services was unavailable in some cases.

As a result, the data base contained fairly gross inaccuracies for a significant portion of the properties studied. Since the technique used is one which sets up a ranking of properties as they perform relative to other firms in the sample, the entire ranking process is disrupted by inaccurate observations.

For example, Banning, Culver City, and Santa Rosa in Figure 2 receive ratings of 1.000 in all runs, implying that they are operating hyper-efficiently. However, inspection of the data for these properties reveals that they report no maintenance labor requirements. While obviously incorrect, this reporting tends to make all the other firms in the sample appear relatively less efficient. That is, the frontier is constructed around data from properties for which there are substantial uncertainties concerning the quality of the information supplied.

Trying to eliminate the problematic observations from the sample was a fairly ad hoc process, since much of the data was of suspicious quality. However, when the sample was thinned in an experimental run, the number of firms in the sample dropped so sharply that the technique was unable to produce useful rankings; namely, a frontier was constructed that contained <u>all</u> of the firms without violating the underlying mathematical requirements of the technique. Thus, so many firms received a rating of 1.0 that the technique was unable to provide useful evaluations of samples smaller than 25 or so.

While it is unfortunate that useful results could not be derived from this technique with the current sample, the analyses point up the unreliability of current transit data bases. More precisely, accurate and consistent accounting of the activities of the properties on both the output and input side is lacking.

Without regular application of evaluation techniques and accurate surveillance of the transit properties through data reporting, the effectiveness of transit assistance efforts and transportation system management strategies will be difficult to assess.

## AN ALTERNATIVE PERFORMANCE FUNCTION**

### General Considerations

A transit performance measure is needed which standardizes for the many different transit operating environments. The various comparisons made above, e.g., types of ownership, or service area densities are quite useful for exploration of the data. They also have the advantage of having easily comprehensible, intuitively clear results. Their disadvantage is that they are only able to control for one source of variation at a time, when it is obvious that many different factors are operating simultaneously to determine the performance of a transit system.

What is needed is a multivariate measure of performance, one that standardizes for all of the various factors simultaneously. The linear programming, production function approach attempted immediately above is one such measure: it computes output as a function of several different input variables. Through such analysis, we discover the relationship between, for example, revenue vehicle hours of service and various kinds of labor and maintenance inputs. Unfortunately, our data on the inputs to the production process was not good enough to permit an accurate estimate of the production function.

An alternative approach is to look at output as a function of environmental factors rather than as a function of inputs. That is, we may compute service output as a function of things like population density,

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**The research discussed in this section was conducted by Charles A. Lave, School of Social Sciences, University of California, Irvine.

type of ownership, and type of service. This approach has the advantage that we have much better measures of the transit systems' operating environments than we do of their production inputs. To enable the analysis to look at many environmental factors simultaneously, multiple regression analysis is used as the principal statistical tool.

## Possible Performance Measures

Before we can attempt a regression analysis, we need to choose a reasonable dependent variable to work with. There are two competing measures of output: provided service, and consumed service. The first of these is well measured by annual revenue vehicle hours of service: this statistic indicates the extent to which the transit system is making services available to the user. It may very well be that the potential users do not choose to actually use the service, because the alternatives to transit are more attractive, but a system which does a good job of making the service available is an efficient system. The second indicator, utilized or consumed transit service, is reasonably measured by annual passenger trips.

These two competing measures have quite different characteristics. A given transit system might be very efficient in providing revenue vehicle hours of service, while actually carrying very few trips: it might be operating in an area where the population is geographically diffuse, trips are widely spread, and highway alternatives are excellent. Likewise a given system might be relatively inefficient while carrying a large number of passengers (i.e., effective), simply because it has the fortune to be in an area of concentrated housing patterns, concentrated trips, and historically poor highway alternatives.

Ultimately, of course, it is passenger-trips that we wish to produce, not revenue vehicle hours, but it may very well be that the efficiency of providing revenue vehicle hours is a better overall indicator for our purposes, since it is a better indicator of management skill: the number of circumstances where a property might luckily attract many passengers seems higher than the number of circumstances where a property might luckily provide many hours of service at a reasonable cost. In any event, we will perform our analysis using both of these output measures.

Neither of the measures, revenue vehicle hours or passenger-trips, can serve as an adequate measure until it is standardized by some input measure; after all, a transit system may be providing many units of service at the cost of a ridiculously high quantity of inputs. The most obvious measure of inputs is total expenses, and, consequently, we utilize the indicators revenue vehicle hours per dollar (hours/$) and number of trips per dollar (# trips/$), where the dollar is defined as total system operating expenses. The strong point of these two indicators is that the required data is generally available and relatively accurate. Another advantage is that the total operating expense variable summarizes all of the different production inputs to the system; hence standardizing by dollars of operating expense is a way of standardizing the total resources used.

Unfortunately, standardizing by dollars of operating expense had one major disadvantage too: the largest component of total expenses is labor costs, and wage rates vary enormously between systems.[12] Thus, when calculating revenue vehicle hours per dollar, a particular property might look bad simply because it is in an area where unions have historically been very strong. We could adjust between properties by using some sort of comparative wage index, but this presents two problems: first, it is quite difficult to construct a reasonable wage index for this purpose; and second, to some extent the high wages paid by a system are in part a consequence of poor management, that is, the system could simply be doing a very poor job of labor negotiating. Clearly, using total operating expenses to standardize between systems is not a perfect measure, but the accuracy of its input data may make up for its conceptual problems.

We can also standardize by the number of employees and the number of vehicles, as an alternative to using dollar measures. We consider using number of buses first. This generates revenue vehicle hours per vehicle (hours/vehicle) as a possible performance measure, which is, in fact, an excellent measure of a system's capital utilization. A system which looks good on this indicator is a system which is obtaining the maximum possible use of its capital. It is economizing on the use of buses. But is this the most important criterion for judging a successful bus system? Economic theory tells us that we ought to economize on whatever resource is currently using up most of the budget. Since depreciation on buses is only a very small part of the total expenses (when included at

[12] Analysis of transit drivers' wages in California during 1975 revealed a variation in wage rates of $3.33 per hour to $7.66 per hour.

all), it makes little sense to give high honors to a bus system which does the best job of economizing on use of bus capital. It may even be true that systems which have a high ratio of peak to off-peak buses, hence few hours/vehicle, are actually making the most efficient use of their expensive labor resources.

Given that labor constitutes the overwhelmingly largest item in the budget--82-87% of total operating expense[13]--it seems reasonable to standardize by labor input, using a measure like revenue vehicle hours per employee or total trips per employee. A system which scores well on these measures is doing a good job of economizing on its most expensive inputs (i.e., labor). Notice that these measures get around the problem produced by noncomparable wage rates, because the labor input is measured in terms of people, not dollars.

Although standardizing by the number of employees is the best alternative, it does create a data problem for some properties. In particular, municipal transit systems whose maintenance and many administrative functions are done in joint facilities used by other municipal departments often seem to keep poor records concerning the distribution of these maintenance and overhead hours between their transit system and their other municipal functions. Thus, the municipal systems often

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[13]U.S. Department of Transportation, Urban Mass Transportation Administration, Office of Policy and Program, Transit Operating Performance and the Impact of the Section 5 Program, November, 1976, p. 23.

report an artifically low figure for number of transit employees. The simplest way around the problem for this analysis is to standardize by number of drivers, which is reported more accurately, rather than by number of employees. Since the drivers are the majority of the transit labor force, this should work reasonably well.

Thus, taking account of all these considerations, we have four possible performance measures:

a) Two measures of provided transit service

| | | |
|---|---|---|
| Labor-Efficiency of Provided Service | : | hours/driver |
| Dollar-Efficiency of Provided Service | : | hour/$ |

b) Two measures of consumed service

| | | |
|---|---|---|
| Driver Productivity Based on Consumed Service | : | #trips/driver |
| Dollar-Effectiveness of Consumed Service | : | #trips/$ |

where the variables are defined as follows:

| | |
|---|---|
| hours | = number of annual revenue vehicle hours |
| #trips | = number of annual revenue passenger trips |
| driver | = number of full time equivalent drivers employed |
| $ | = total yearly operating expenses for the system |

## Data Preparation

Before running regressions, a great deal of time was spent on screening and preparing the data. First, the Bay Area Rapid Transit (BART) was screened out because it makes no sense to put a rail system into the same equation as a group of bus systems; they are inherently different. We also screened out all of the demand-responsive systems because they also run a much different kind of operation. The remaining properties were all fixed-route bus systems.

When we started calculating basic indicators, we also discovered a number of instances where the transit property had reported apparently erroneous data. For example, when annual hours/driver were calculated, some rather odd figures were obtained: a normal work year is 2000 hours, and, since the driver must spend some time outside of the bus, a figure of 2000 hours/driver seemed to be about the highest reasonable number. In fact, there were six transit properties that reported figures between 2500 and 4400 hours/driver. These properties were deleted from the sample. This left a total of 30 properties in the sample, which is an adequate number for multiple regression analysis in terms of customary econometric standards.

It was necessary to create a population density variable since it seemed obvious that this variable might explain much of the difference in performance between transit systems. The measures which the systems reported were the service area square miles and population, both based on the political boundaries of the transit property rather than the area which is actually covered by the bus routes.[14]

The properties did report the number of people living within their coverage area, but, in general, not the size of the coverage area. Accordingly we had to compute this lesser area by assuming that each bus route served a half-mile corridor (one quarter mile on each side of the line); we multiplied the number of non-duplicating one-way route miles times one-half to compute the coverage area. One problem here was that only about 60% of the systems report their one-way non-duplicating route miles. For those properties which reported two-way route miles, that figure was divided by two to obtain one-way miles. The relationship between one-way non-duplicating route miles and one-way duplicating route miles was then examined and it was found that the non-duplicating figure was generally about 75% of the duplicating route mile figure. Consequently, for those cases which reported neither the one-way non-duplicating figure nor the two-way figure, we used .75 times the one-way duplicating figure. Coverage area density was then computed by dividing the coverage area population by our computed coverage area estimate.

This generation procedure for coverage area density is admittedly crude, but allows us to obtain a figure which reflects the area actually served rather than artificial boundaries. The subsequent results support the value of this statistic.

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[14]Definitions of "service area," coverage area" and route mile statistics are appended to this paper.

## Results

The mean, standard deviation, and range for each variable are shown in Figure 3, and the correlations for the variables in the regression are shown in Figure 4. We now take up the dependent variables in order: the first one yields the poorest results, and the last two yield the most interesting results.

The first equation utilizes the indicator hours/driver as the dependent variable. This indicator measures the labor-efficiency of provided service.

Equation (1) shows the regression results.

$$\text{hours/drive} = .000019 - \underset{(3.8)}{265}\ \text{mode} \tag{1}$$

$n = 30 \quad R^2 = .312$ (t ratio in parentheses)

No other variables would enter the equation with significant coefficients. The mode variable is a measure of the average bus seat-capacity of vehicles operated by the property. Values for this mode appear in Figure 5.

Thus, the equation indicates that those properties characterized by small buses produce the fewest hours/driver. Presumably this effect is a reflection of the fact that properties which have small buses generally run them infrequently. Overall, equation (1) is somewhat disappointing in terms of new insights. These results might be due to poor data for the dependent variable: it will be recalled that we already had thrown out six cases because they contained absurdly high values on this variable.

FIGURE 3: Means, Standard Deviations, Minimums and Maximums of Regression Variables

| Variable | Mean Value | Standard Deviation | Minimum Value | Maximum Value |
|---|---|---|---|---|
| Bus Hours/ Driver | 1,409 | 437 | 332 | 2,000 |
| Bus Hours/ $ | $ .065 | $ .029 | $ .028 | $ .147 |
| # Trips/ Driver | 32,210 | 17,071 | 2,448 | 66,390 |
| # Trips/ $ | $ 1.31 | $ .54 | $ .29 | $2.37 |
| Service Area | 325 | 601 | 2 | 2,280 |
| Service Area$^2$ | 456,100 | 1,245,153 | 4 | 5,198,000 |
| Service Area Density | 3,135 | 3,010 | 37 | 14,960 |
| Coverage Area Density | 2,376 | 1,259 | 293 | 6,039 |
| Mode* | 1.7 | .96 | 1.0 | 4.0 |
| Vehicle Age | 6.3 | 3.9 | 1.0 | 18.5 |
| Union yes=1 no=0 | .63 | .49 | 0.0 | 1.0 |

Sources: Available data obtained from Transportation Development Act, Annual Reports to the Secretary, FY 1976, and from individual property audit statements. Data elements were verified and additional data collected by telephone from property representatives.

FIGURE 4: Correlation Values For Regression Variables

| | Bus Hours/ Driver | Bus Hours/$ | # Trips/ Driver | # Trips/$ | Service Area | Service Area$^2$ | SerArea Density | CovArea Density | Mode | Vehicle Age | Union |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus Hours/ Driver | 1.00 | | | | | | | | | | |
| Bus Hours/$ | .17 | 1.00 | | | | | | | | | |
| # Trips/ Driver | .54 | -.38 | 1.00 | | | | | | | | |
| #Trips/$ | .29 | .26 | .63 | 1.00 | | | | | | | |
| Service Area | -.15 | -.44 | -.08 | -.42 | 1.00 | | | | | | |
| Service Area$^2$ | -.11 | -.35 | -.01 | -.28 | .96 | 1.00 | | | | | |
| SerArea Density | .03 | -.20 | .48 | .31 | -.31 | -.22 | 1.00 | | | | |
| CovArea Density | .19 | -.21 | .56 | .50 | -.06 | -.02 | .12 | 1.00 | | | |
| Mode | -.58 | .35 | -.72 | -.39 | -.04 | -.09 | -.32 | -.37 | 1.00 | | |
| Vehicle Age | .08 | -.22 | .54 | .41 | -.08 | -.03 | .58 | .28 | -.36 | 1.00 | |
| Union | .40 | -.41 | .58 | .13 | .13 | .14 | .19 | .34 | -.63 | .43 | 1.00 |

FIGURE 5: Mode Designators

| Mode | Passenger Capacity of Vehicle |
|---|---|
| 1 | 35 or more passengers |
| 2 | 25 - 34 passengers |
| 3 | 15 - 24 passengers |
| 4 | 8 - 14 passengers |

Note: properties may be assigned a decimal value for mode to designate a mixed fleet; e.g. a property having ten large buses (mode 1) and ten mode 2 vehicles would be assigned a mode value of 1.5.

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Following these initial results, we tried screening the data still further. This time five cases were discarded which were unusually low in reported hours/driver, from 330-1000. Unfortunately, this did not improve the results. It is likely that better data would make a substantial difference for this equation.

The next regression equation used the dependent variable hours/$, which is a measure of the dollar-efficiency of provided service.

Equation (2) shows the results:

$$\text{hours/\$} = .100 - 016 \text{ Union} - .0000792 \text{ SerArea}$$

(1.9) (3.2)

$$+ .0000000276 \text{ SerArea}^2 - .00000375 \text{ SerDensity} \qquad (2)$$

(2.4) (2.5)

$n = 30 \quad r^2 = .423$ (t ratios in parentheses)

Since dollar-efficiency measures are strongly influenced by the local wage structure it should be no surprise that the local wage variables dominate the equation. The Union variable is coded as 1 for those properties which are unionized and 0 otherwise. Thus, the negative coefficient implies that unionized districts produce fewer hours/dollar. The next two variables, Service Area and (Service Area)$^2$ form a quadratic function to show the non-linear relationship between service area and the dependent variables. The overall shape of this function is strongly negative within the range of observed values. Given that both the service area function and the Service Density variable have a negative relationship to the efficiency indicator, we can say that large, dense areas produce fewer hours/$. What seems to be occurring here is that these variables are serving as a proxy measure of the general wage level in the area, independent of unionization. Large, dense areas have generally higher wage levels than small, low density areas. Hence, the overall expenses of bus properties in the large, dense areas are likely to be higher. The union variable shows that even after holding the general wage level constant, it still makes a difference whether or not the bus system is unionized. In terms of relative influence, the union variable accounts for only about one-third as much of the variance in the efficiency measure as the general wage level variables.

The next equation uses the dependent variable #trips/driver, which is a measure of the driver productivity based on consumed services.

Equation (3) shows the results:

$$\#trips/driver = .0000031 - \underset{(4.2)}{.0000915}\ Mode + \underset{(2.3)}{.0000122}\ VehAge + \underset{(2.4)}{3.93}\ CovDensity \quad (3)$$

n=30 $R^2$ = .651 (t ratios in parentheses)

The Coverage Density variable has a positive coefficient indicating that it is easier to deliver service to dense areas, which is an expected result. The Mode variable indicates bus size (Figure 5), thus the negative coefficient says that we deliver less bus service per driver with small buses than large ones, again not a surprising result. This result, though, does indicate that transit management is making some effort to match bus size to the expected passenger loads. The Vehicle Age variable may be acting as a proxy for the age of the bus system itself: systems that show young average vehicle ages may have only been formed recently.[15] If we make the assumption that historically the presence or absence of a bus system in a town reflected the existence of a demand for services, then this positive coefficient is quite reasonable. The old, established systems are in areas easily served by transit, whereas the new systems may be in marginal areas. It is also possible that the young

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[15] The correlation coefficient between vehicle age and organization age for this sample was .46. However, the organization age variable used is questionable due to the high number of mergers, acquisitions and takeovers which have taken place in the transit industry in recent years.

properties are still in the patronage-building process and that this variable merely reflects start-up problems. In terms of relative importance, the age and density variables explain about an equal amount of the observed variance in the efficiency indictor, and the bus size variable explains about 1.5 times as much variance as either of the other two variables.

The next equation used the dependent variable #trips/$, which is a measure of the dollar-effectiveness of consumed service.

Equation (4) shows the results:

$$\begin{aligned}\#trips/\$ = .931 &+ \underset{(1.6)}{.0305\ VehAge} + \underset{(2.8)}{.000164\ CovDensity} \\ &- \underset{(3.2)}{.00132\ SerArea} + \underset{(2.5)}{.000000496\ SerArea^2} \qquad (4)\end{aligned}$$

$n=30 \quad R^2 = .501$ (t ratios in parentheses)

The vehicle age and coverage density play the same part here as they did in equation (3), which seems reasonable since both factors would be expected to produce a large number of trips, the numerator of the indicator. Again, as in equation (2), it seems likely that what is occurring here is a wage structure effect: large service areas have a generally higher wage level, and, hence, increase the denominator of the ratio. In terms of the relative importance of the three variables, density and area explain about equal amounts of the variance in the dependent variable, and the age variable explains about half as much as either of them.

## Use of the Results

The general idea in running these regressions was to try to hold constant certain external factors not in the system's control which affect its relative performance. The last three equations all do a reasonable job of this, and were consequently used to predict an expected performance score for each of the bus systems. That is, how well would we expect a bus system operating in that environment to perform. This list of predicted values may then be compared to the actual, measured performances. The difference between these two scores would be a measure of how well each system performed. Those systems that perform better than their predicted scores are probably doing something right, and those systems that do not perform as well as predicted may be doing something poorly. Since there is still considerable unexplained variance for each equation, we should limit our attention to those properties which do either much better or much worse than predicted. When this analysis was attempted, the three equations tended to pick out similar bus systems as operating very well or very poorly, which lends some support to the use of this technique. These properties are not listed, however, since it is possible that any given "outlier" may merely be the result of a random data error. Given better data, this approach ought to produce highly interesting, and possibly valuable, results.

# CONCLUSION

The two statistical techniques analyzed above were unsuccessful due primarily to the unreliability and limited nature of the available transit operating and financial data. Changes in data collection, maintenance, and reporting in response to Section 15 of the Urban Mass Transportation Act (amended) will produce more uniform and widely available data. Future research, therefore, using these and similar statistical techniques, should be more successful.

Through statistical analysis, the understanding and interpretation of quantitative performance indicators may be improved by knowledge of how various operational, environmental, and organizational factors affect transit. This better understanding will also facilitate development of better analytic and predictive models of performance, which will benefit public policy determination and management decision making.

# APPENDIX

Coverage Area: a measure of accessibility to scheduled, fixed-route bus service defined by a quarter-mile band width each side of the transit route; overlapping routes and route-crossings do not cause multiple countings. (This statistic is also used for express bus and rail transit, yet the weighting factors for parking facilities and feeder-bus service are not established).

Route Miles: various definitions exist for this statistic:

"One-way, Duplicating"

total mileage of route, where the road segments of each route are summed up in one direction. (also titled miles of route)

"One-way, Duplicating"

total mileage of routes, where a particular road segment is only counted once regardless of number of routes or direction of travel on that segment. (also titled "line miles")

"Two-way Mileage"

total mileage of each route covered from start to finish. No attention is given to direction of routes or number of routes using any particular segment.

Service Area: the jurisdiction in which the transit property operates. For properties not operating within particular political boundaries, this would be the population falling within a line connecting the extreme points of the property's regularly scheduled service routes.