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The Effect of Environmental Factors on the Efficiency of Public Transit Service

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ABSTRACT

As part of efforts aimed at improving the productivity and effectiveness of public transit systems, performance evaluation techniques have received a great deal of attention among transit analysts. Development of performance evaluation methodologies applicable to groups of systems has been limited by the issue of comparability. It is generally claimed that transit performance is sensitive to the environment in which the system operates. Since operating conditions vary from one system to another, performance comparisons may not be appropriate. However, the extent to which operating conditions affect performance has not yet been established. Using a sample of 30 California fixed route transit systems, this paper examines the effect of environmental and institutional factors on performance efficiency. It is found that operating conditions have a significant impact on transit efficiency, and therefore these factors must be identified and controlled for when performance comparisons are made. It is concluded that significant improvements in transit system efficiency will require the cooperation and efforts of both transit operators and policy makers.

THE EFFECT OF ENVIRONMENTAL FACTORS
ON THE EFFICIENCY OF PUBLIC TRANSIT SERVICE

During the past decade, public transportation policy underwent a major shift from support of massive capital improvements to an emphasis on maintaining and improving existing services. In an effort to put a lid on rapidly escalating costs and subsidy requirements, better management of the transportation system, aimed at more effective system utilization, became a major focus of public transit policy. Under the rubric of Transportation System Management (TSM), a number of transportation and traffic engineering improvement techniques were implemented, and a renewed interest in developing ways to evaluate the performance of public transit services emerged.

Research in public transit evaluation began with the development of indicators which measure different aspects of performance, such as labor utilization or cost-efficiency. These indicators were found to be useful for identifying areas of potential improvement within the transit organization and for monitoring progress toward specified goals (1,2,3). It became apparent, however, that performance indicators had limited utility for performance evaluations between transit operators, primarily because the extent of comparability between transit firms had not yet been established. Performance comparisons between different transit modes, such as between fixed rail and conventional buses, are limited because of differences in technology and type of service provided. Within the same transit mode, the issue of comparability centers on the locational differences which exist between public transit systems. In

general, transit systems are organized as spatial monopolies, and therefore each operates in an environment which is to some extent unique. Locational differences between public transit systems are an important consideration for two reasons. First, the institutional framework through which transit service is provided varies from place to place. Second, public transit service interfaces with the operating environment on two levels. On the supply side it must operate within the structure of the existing transportation network, and on the demand side, its ability to compete with other modes is a function of both population characteristics and existing travel patterns. Because of these place specific variations, it has been maintained that the comparability of transit system performance is severely constrained. If performance comparisons are to be made, environmental factors which affect performance must be identified and taken into account.

This paper analyzes the extent to which the operating environment affects the performance efficiency of fixed-route transit service.

The Analytical Framework

In an ideal, full information world, the appropriate model for such an analysis would be one in which transit performance is conceptualized as a function of two sets of factors: those within the control of the operator/manager, and those outside operator control. Performance evaluation should be aimed at the first set of factors; it should evaluate the outcomes of decisions the transit firm has made.

Unfortunately, the extent of operator control is difficult to determine. While the internal operations of the transit organization are clearly under the control of transit management, rigid labor union work rules may

create constraints on efficient labor utilization, and federally mandated lift-equipped buses may generate additional maintenance costs. In addition, decisions regarding service parameters such as route realignments or fare changes are generally subject to external review and approval.

Since the actual extent of operator control is not easily determined (and may also vary from place to place), a more workable model of performance is one in which performance is conceived as a function of environment and institutional factors, as well as the managerial expertise of the firm. Institutional factors are those which derive from the firm itself, such as organization size and age of the firm. Environmental factors are those deriving from the operating environment, such as population density or the level of traffic congestion.

There is no reason to assume that environmental and institutional factors have a uniform effect on every aspect of performance. Rather, it is more likely that the importance of different factors varies from one indicator to another. Thus the performance indicators are analyzed individually, utilizing a regression model of the form,

$$Y_k = \alpha_0 + \beta_i X_i + \gamma_j X_j + u$$

where Y_k is the k^{th} performance indicator, the $\beta_i X_i$ are institutional factors, and the $\gamma_j X_j$ are environmental factors. Each indicator is a linear combination of these factors, and managerial expertise (individual firm differences), is treated as a residual.

The empirical research reported here was conducted on a sample of 30 California fixed route transit operators. Operating data for the 1976-77 fiscal year were gathered via operator interviews, audit reports, and

California State Department of Transportation (Caltrans) records. Demographic and geographic data, gathered from several state and federal sources, were matched to the service area of each operator. In spite of its small size, this set of transit systems represents a wide range of operating conditions, and therefore provides an appropriate basis for analysis.

Efficiency Indicators

Transit performance is a multifaceted concept which may be divided into three areas: efficiency, effectiveness, and impact. Efficiency refers to the production of transit services, and measures the transit firms' utilization of inputs in the service provision process. Effectiveness measures the extent of service consumption, and impact refers to the indirect effects of transit service on the environment. The discussion here is restricted to performance efficiency. Performance efficiency can be measured in two ways. Production efficiency measures the extent of efficient utilization of specific inputs, such as labor or vehicles, in the service production process. Cost-efficiency measures the ratio of expenses paid to all inputs to produced output, or the dollar cost of each output unit.

Three efficiency indicators were selected for analysis. Revenue Vehicle Hours per Employee (RVH/EMP), where employees are computed in full-time equivalents, measures labor utilization efficiency. Labor is by far the most important input in the transit service provision process, as labor costs make up about 80 percent of transit operating costs (4). Thus service efficiency is primarily determined by the way in which the transit firm utilizes its labor force. The indicator is affected both by

the utilization efficiency of driver personnel (i.e., by how closely paid driver hours match revenue service hours), and by the proportion of non-service producing personnel within the firm. As non-service producing personnel increases, the indicator decreases in value.

The indicator selected to measure vehicle utilization efficiency is Revenue Vehicle Hours per Maximum Vehicle Hours. There are two important aspects of vehicle utilization. One is the size of the fleet relative to service needs, and the other is vehicle reliability. The size of the fleet is primarily determined by peak vehicle needs, and as the peak/base ratio increases, the average service hours produced per vehicle declines. Similarly, vehicle productivity also depends on the firm's hours of operation; the maximum amount of service each vehicle can produce is determined by the number of hours per day that service is available. In an effort to control for the effect of different service hours (hours of operation), revenue vehicle hours is measured as a proportion of maximum possible vehicle hours, or the average revenue hours produced per vehicle as a fraction of the total possible hours each vehicle could be in service. Vehicle utilization is a less important determinant of transit efficiency than labor utilization, because vehicles account for a much smaller proportion (less than 15%) of operating costs. Nevertheless, the effect of vehicle utilization on overall efficiency is not inconsequential, and therefore it merits investigation.

The third efficiency indicator is Operating Expense per Revenue Vehicle Hour (OPEXP/RVH). It is the "bottom line" production side indicator, as it measures the firm's ability to combine all inputs to efficiently produce revenue service. Since it measures cost per unit of

MEDSIZE = Dummy for medium service area; 1 = 100,000 to 500,000
population, 0 otherwise

WAGE = Area average monthly wage rate

This equation indicates that labor efficiency is determined to a large extent by factors outside the control of the transit operator. The one variable in the equation that is subject to operator control, the peak/base ratio, is insignificant, although the sign is in the expected direction. As the peak/base ratio increases, labor utilization efficiency decreases, mainly because work rules limiting split shifts and spread time reduce the revenue service produced per driver.

Organization size is strongly correlated with size of the area in which the firm operates. If all transit firms provided the same density of service (units of service per unit of area), the two size variables would be perfectly correlated. In fact, density of service does vary and the simple correlation between organization size and service area size is .65. In order to minimize the problem of multi-collinearity dummy variables for service area size were utilized. The effect of all size variables is negative: labor utilization efficiency declines both with increasing organization size and increasing service area size.

These results contradict recent research which indicates that there are no diseconomies or economies of scale in bus transit service (5). That is, size should have no effect on efficiency. There are several possible explanations for the results observed here. First, they may simply be the result of this particular sample, in which several small operators are very efficient. Second, large operators may provide a different type of service than small operators. Larger firms, operating

in large metropolitan areas, provide more peak period service and generally have longer service hours, requiring additional supervisory shifts, etc. The spatial distribution of services also may increase with size. As routes become longer and more dispersed, coordination of drivers and vehicles may become more difficult, and deadhead time may increase. All of these factors could reduce labor utilization efficiency. Finally, many transit analysts claim that very large transit systems, like other public institutions, tend to become top heavy with administrative personnel and, therefore, less labor efficient.

Some of the negative effect of size observed here can be attributed to what is frequently called the "municipal effect." Although all of the sample firms are public operations, some are owned by municipalities while others are organized as independent transit districts or authorities. Municipally owned firms frequently benefit from integration with other municipal operations by sharing administrative services and overhead costs. In some cases, only actual service inputs are assigned to the transit operation, while the overhead is absorbed by other departments. Thus municipal firms tend to score higher on measures of labor utilization efficiency than non-municipal firms. In this sample, the municipal firms are also small firms.

Equation 1 also indicates that new firms are less labor efficient than old firms. New firms operate in areas which were either passed over by private enterprise (presumably for good economic reasons), or in areas of recent population growth, that is, low density suburban areas. Suburban areas are characterized by dispersed travel patterns and low transit demand. These firms must attract ridership through substantial marketing and planning efforts. New firms also tend to be rapidly

growing firms. Service is expanded into new areas, and service frequency increases as ridership is established. These planning and expansion efforts require substantial administrative staff. By increasing the proportion of non-service producing employees, new firms produce less revenue service per employee.

The area wage rate appears to have a positive effect on labor utilization efficiency. From an economic standpoint this is an expected result; as the cost of labor increases, the efficient firm tries to increase labor productivity. The interpretation here is that transit workers are willing to substitute higher pay for less stringent work rules, and consequently firms which pay higher wages are able to utilize labor more efficiently. Thus, holding size and age of firm constant, higher wage rates induce more efficient labor utilization.

One of the major beneficiaries of the conversion of the transit industry from private to public ownership has been the transit labor force. Increased wages and benefits, job protection, and a legislative mandate to determine work rules and conditions have come with public subsidies. To the extent that unionized firms are subject to more stringent work rules and employee benefits, it would be expected that unionized firms are less efficient than non-union firms. In fact, a unionization variable was found to have no significant relationship with labor utilization efficiency. Apparently, the influence of unions is more complex. Transit properties operate under different union contracts, and some contracts are no doubt more restrictive (from the point of view of management) than others. It would seem that it is the degree to which the labor contract constrains the efficient utilization of transit employees that is important, rather than the simple fact of unionization.

Vehicle Utilization: RVH/MAXVH

Hours of service (the number of hours per week in which service is available) provided by the transit operator proved to be the primary determinant of vehicle utilization in spite of the fact that the form of the indicator was chosen so as to control for this factor. (Equation 2). The hours of service variable may be interpreted as a more general service variable, since high peak/base ratios are correlated with long service hours.

$$RVH/MAXVH = .937 - .698 \text{ HRSERVC} \quad (2)$$

$$[.76] \quad R^2 = .58 \quad N = 29$$

HRSERVC = hours of service measured as a fraction of total hours (168) per week

These results indicate that as the hours of operation increase the quantity of service provided per hour decreases. This reduction in vehicle utilization which comes with longer hours is not necessarily inefficient. If it is assumed that transit firms always choose to operate during the hours of highest demand first, then as service hours are extended, less service per hour should be provided. A firm providing 24 hour service, for example, would provide less nighttime service than daytime service, and thus would have a lower rate of vehicle utilization than a firm providing 12 hour per day service, all other things being equal. It would no doubt be even less efficient to run more buses when little service demand exists. Thus the indicator must be evaluated in the context of service parameters, and of course the interesting question is whether operators have much control over service parameters. Equation 3 indicates that the service area characteristics size and population

density have a significant effect on hours of service, with large, high density areas associated with the longest service hours.

$$\begin{aligned}
 \text{HRSERVC} = & 1.03 - .310 \text{ SMALLSIZE} - .244 \text{ MEDSIZE} \\
 & (5.3) \qquad (4.7) \qquad (3) \\
 & [.67] \qquad [.60] \\
 & - .301 \text{ MEDDEN} - .180 \text{ LOWDEN} \\
 & (5.3) \qquad (3.3) \\
 & [.72] \qquad [.42]
 \end{aligned}$$

$$R^2 = .72 \quad N = 30$$

MEDDEN = 1 if density is 3,000 - 6,000 pop/mi², 0 otherwise

LOWDEN = 1 if density is < 3,000 pop/mi², 0 otherwise

The variation in service hours may be interpreted as a reasonable response to transit market conditions. Firms operating in small cities where few commercial activities take place during evening or night time hours may restrict service accordingly. Firms operating in large central cities, on the other hand, may provide long service hours not only to service the higher level of evening and weekend activity, but also to provide service to a relatively concentrated population of transit dependents. Moreover, large, central city systems (that is, older systems) have not cut back service hours as service demand has declined, but have reduced frequency of service.

The analysis here has shown that vehicle utilization efficiency is largely determined by service parameters, and that service parameters are in turn related to environmental characteristics. Presumably, these characteristics are indicative of the demand for transit service existing

in the area, and operators and sponsors are responding to this demand. Service parameters are determined by the transit firm's perception of demand for service and the sponsor's (i.e., funding agencies) perception of transit needs. The appropriateness of the parameters chosen must be evaluated in terms of system (and sponsor) goals and objectives, and in terms of system effectiveness. Consequently, vehicle utilization efficiency must be evaluated within the context of the sponsor and operator goals.

The vehicle utilization indicator RVH/MAXVH was not successful in controlling for service parameters. The analysis, however, did reveal the extent to which these service parameters affect vehicle utilization. In order to better measure this aspect of performance, more specific indicators, such as the ratio of peak vehicles to total in service vehicles, or revenue vehicle hours per scheduled service hours, might be more informative and appropriate.

Operating Expense per Revenue Vehicle Hour (OPEXP/RVH)

Cost-efficiency measures the efficient utilization of all input factors. Because labor is the predominant factor in transit service, labor utilization in large part determines the cost of providing transit service. Consequently, factors which affect labor utilization efficiency should also affect cost-efficiency. In general this proved to be the case, as equation 4 illustrates. Significant factors affecting cost-efficiency were found to be the peak/base ratio, organization size, age of the firm, and unionization. The impact of firm age is easily explained: new firms tend to have higher unit costs because of the additional overhead required to develop and establish new operations, and

also perhaps because of the spatially dispersed configuration of new suburban services, as described earlier.

$$\begin{aligned} \text{OPEXP/RVH} = & 4.48 + 7.27 \text{ PEAK} + .063 \text{ VEH} + 3.72 \text{ OPAGE} + 4.55 \text{ UNION} \\ & (4.6) \quad (3.4) \quad (2.0) \quad (2.0) \quad (4) \\ & [.59] \quad [.42] \quad [.24] \quad [.24] \\ \text{UNION} = & 1 \text{ if unionized firm, } 0 \text{ otherwise} \quad R^2 = .63 \quad N = 28 \end{aligned}$$

The union variable adds an interesting dimension to the explanation of cost-efficiency. The effect of unionization on wages may be much stronger than its effect on labor productivity. In fact, while only 5 of the sample of properties are non-union, the average operating cost per hour for this group is \$14.21, or 31 percent less than the whole sample average of \$20.70. Thus while non-union firms may be no more able to efficiently utilize their labor (and indeed may have no incentive to do so under the circumstances), they achieve lower unit costs as the result of low wage rates.

The peak/base ratio emerged as a major factor affecting cost-efficiency, in spite of the fact that it was not a significant variable in the labor utilization efficiency equation. To some extent, this is due to a peculiarity of this sample, in which one firm has a peak/base ratio of 4 (compared to the average of 1.3) and operating cost per hour of \$42.73. When this case is removed, the peak variable is reduced in magnitude and significance. Although the peak/base ratio has at best a weak negative effect on labor utilization efficiency, it, like long hours of service, has a strong negative effect on vehicle utilization. Its combined influence on both aspects of production efficiency results in significantly higher unit operating costs for firms

providing highly peaked service. The peak/base ratio is positively correlated with population density and traffic congestion, and consequently may be considered to be representing more generalized environmental effects associated with services heavily oriented towards a central city.

Finally, the effect of size on cost-efficiency is negative. It is to be noted that the organization size variable which appears in equation 4 is interchangeable with other measures of size, such as service area size or service area population. Thus the variable is picking up both institutional and environmental effects. Given that these results are again contrary to findings of constant returns in bus transit, how can they be explained?

Part of the explanation may be that the size variable reflects other factors. As pointed out in the discussion of the labor utilization efficiency indicator (RVH/EMP), smaller properties are generally municipal properties, and municipal properties are able to hold down costs by integrating transit services with other municipal operations.

It is frequently maintained that it is not size that generates higher costs, but rather the higher wage rates that prevail in larger (metropolitan) areas which push up the cost of labor and therefore result in higher costs for large operators. The results of this research indicate that the size relationship cannot be attributed to the effect of the general wage rate. First, while all of the largest firms in the sample operate in large urban areas, some of the smaller firms also operate in large urban areas, presumably facing the same high wage rates. However, these smaller firms are more cost-efficient than the large firms, though generally less cost-efficient than their counterparts

A second consequence of large size relates to the spatial arrangement of fixed facilities. Large transit operations usually have multiple plant sites. Because of logistical problems involved in organizing bus movements within the facility and because of the distances involved in traveling between service routes and the garage, the entire fleet cannot be housed at a single facility. These multiple facilities may add to overhead, and therefore lead to reduced labor utilization efficiency and increased costs.

Conclusions

The analysis of three performance efficiency indicators suggests that environmental and institutional factors have a major effect on the performance of public transit systems. The extent to which performance is affected by external factors has important policy implications. Transit operators have long maintained that the comparability of public transit systems is limited because of differences in operating conditions. This research supports that position, and shows that many factors must be controlled if valid performance comparisons between transit systems are to be made. As public sponsors move toward tying subsidy allocations to performance standards (as has already begun in Pennsylvania and California), it will be necessary to identify all the significant variables which affect performance, and determine the extent to which performance improvements are within the control of the operator.

This paper has concentrated on only one aspect of performance, but it is one which transit analysts have considered to be relatively unaffected by environmental factors. Performance effectiveness, which measures the consumption of transit service, depends upon market conditions and fare

policy, as well as on the ability of the firm to provide a service which matches local travel demands. This analysis has shown that market conditions have an indirect effect on efficiency as well, by means of the parameters of service--the hours in which service is available, and the amount of peak service provided. These decisions are made in response to service demands as perceived not only by the transit operator, but also by sponsoring agencies and institutions.

In addition to service parameters, the major factors identified here affecting performance efficiency are size (both organizational size and service area size), age of the firm, unionization, and the general wage rate. Of these, only the wage rate can be considered a truly exogeneous factor. All the others have been influenced by public policy to some degree. Firm size is determined by the quantity of service provided, and during the past decade one of the major goals of federal policy has been to improve the quality of transit service, meaning shorter headways and greater accessibility, all of which translates into more hours of service.

Encouraging the production of more transit service and increasing the size of transit firms does not of course discourage efficiency. However, federal policy has also encouraged the spatial dispersion of service by providing subsidies on the basis of service area populations, and has supported the development of powerful transit unions, both of which adversely affect performance efficiency. At the same time, transit firms have been able to maintain their monopolistic position. Clearly differentiated service areas prevent competition between operators, and restrictions on the provision of transit services by other providers (i.e, private providers) protect operators from competition from other

sources. Again, these conditions have been fostered by public policies of service planning and coordination.

The fact that many of the factors affecting efficiency can be associated with existing public transit policy suggests that the extent of transit operator control is limited and that significant improvements in service efficiency will require the cooperation of both operators and policy makers. If union work rules severely constrain the utilization of transit labor, then some way must be found to mitigate their effect. If labor-management negotiations are not a viable option (that is, if relaxation of work rules must be compensated by commensurately higher wages), then the more costly forms of transit service (peak service, off-hour service) will either have to be reduced, or, as recently suggested by Oram, provided by other sources, i.e., private contractors (5). Similarly, if new services add disproportionately to costs, the expansion of transit service into new areas should be re-evaluated.

Recognizing the need to rebuild and maintain the industry, public support for transit has been provided with the expectation that ridership would recover once service was improved. However, ridership gains have proven to be small compared to increases in service costs. If transit services are to be maintained and improved, the efficiency of subsidized transit must be increased. This research indicates that efficiency is largely a function of transit service policy and the distribution of services in time and space. Efficiency improvements will require adjustments in public policy as well as changes in the distribution of services.

TABLE 1. DESCRIPTIVE STATISTICS OF PERFORMANCE INDICATORS

	Revenue Vehicle Hours per Employee RVH/EMP	Revenue Vehicle Hours per Maximum Vehicle Hours RVH/MAXVH	Operating Expense per Revenue Vehicle Hour OPEXP/RVH
Mean	1222.77	.48	\$20.70
Standard Deviation	279.83	.19	7.34
Minimum	702.14	.15	11.28
Maximum	1733.21	1.00	42.73

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