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Effect of Environmental Factors on the Efficiency of Public Transit Service

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As part of efforts to improve the productivity 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. Transit performance is thought to be sensitive to the environment in which the system operates. Because 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. By using a sample of 30 California fixed-route transit systems, this paper examines the effect of environmental and institutional factors on efficiency. Operating conditions are found to have a significant impact on transit efficiency and, therefore, these factors must be identified and controlled for when performance comparisons are made. Significant improvements in the efficiency of transit systems will require the cooperation and efforts of both transit operators and policymakers.

During the past decade, public transportation policy underwent a major shift from support of massive capital improvements to an emphasis on maintenance and improvement of 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 use of the system, 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 interest was renewed in developing ways to evaluate the performance of public transit services.

Research in public transit evaluation began with the development of indicators that measure different aspects of performance, such as labor use 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 (1-3). 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 that exist among public transit systems. In general, transit systems are organized as spatial monopolies, and therefore, each operates in an environment that 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; 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, analysts have maintained that the comparability of transit system performamce is severely constrained. If performance comparisons are to be made, environmental factors that 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.

ANALYTICAL FRAMEWORK

In an ideal world of full information, 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 or 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. Although the internal operations of the transit organization are clearly under the control of transit management, labor union work rules may create constraints on efficient labor use, and federally mandated lift-equipped buses may generate additional maintenance costs and reduce fuel efficiency. In addition, decisions about 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 that thinks of performance as a function of environmental and institutional factors as well as the managerial expertise of the firm. Institutional factors are those that derive from the firm itself, such as organization size and age of the firm. Environmental factors are those that derive from the operating environment, such as population density, level of traffic congestion, or size of the service area.

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

$$Y_k = \alpha_0 + \beta_i X_i + \gamma_j X_j + u \qquad (1)$$

where Y_k is the kth performance indicator, $\beta_i X_i$ are institutional factors, and $\gamma_j X_j$ 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 1976-1977 fiscal year were gathered via operator interviews, audit reports, and California State Department of Transportation 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 that may be divided into three areas: efficiency, effectiveness, and impact. Efficiency refers to the production of transit services and measures the transit firms' use of inputs in the process of providing service. Effectiveness measures the extent of service consumption, and impact refers to the indirect effects of transit service on the environment. This discussion is restricted to performance efficiency. Performance efficiency can be measured in two ways. Production efficiency measures the extent of efficient use 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 output produced, 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 the efficiency of labor use. 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 uses its labor force. The indicator is affected both by the use 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 increase, the indicator decreases in value.

The indicator selected to measure the efficiency of vehicle use is revenue vehicle hours per maximum vehicle hours (RVh/MAXVh). There are two important aspects of vehicle use. 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. As the peak to 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 are 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 use is a less important determinant of transit efficiency than labor use, because vehicles account for a much smaller proportion (less than 15 percent) of operating costs. Nevertheless, the effect of vehicle use on overall efficiency is not inconsequential.

The third efficiency indicator is operating expense per revenue vehicle hour (OPEXP/RVh). It is the bottom line production indicator because it measures the firm's ability to combine all inputs to efficiently produce revenue service. Because it measures cost per unit of output, lower values imply greater efficiency. Descriptive statistics for the three efficiency indicators are presented in Table 1.

The unit of output selected for the performance indicators is revenue vehicle hours because it is less affected by network characteristics than is revenue vehicle miles. Traffic congestion, for example, reduces system speed, and as speed declines, it takes more time and therefore more inputs to produce a given quantity of vehicle miles. By using vehicle hours, these external effects are minimized.

ANALYSIS

Labor Use

Factors that affect the efficiency of labor use were organization size, age of the firm, and the area wage rate, as shown in Equation 2. Figures in parenthesis are t-ratios, and figures in brackets are beta coefficients.

$$\begin{aligned} RVh/EMP = {} & 145 - 0.186\ VEH\{(2.5)[0.31]\} - 165\ OPAGE\{(2.6)[0.30]\} \\ & - 73.1\ PEAK\{(1.3)[0.15]\} + 541\ SMALLSIZE\{(5.2)[0.87]\} \\ & + 34.5\ MEDSIZE\{(3.6)[0.62]\} + 1.02\ WAGE\{(3.5)[0.42]\} \end{aligned} \qquad (2)$$

$R^2 = 0.74$, N = 30.

where

VEH = number of vehicles (organization size);
OPAGE = age of firm, dummy; 1 = began operation 1972 or after, 0 otherwise;
PEAK = peak to base ratio;
SMALLSIZE = dummy for small service area; 1 = 100 000 population, 0 otherwise;
MEDSIZE = dummy for medium service area; 1 = 100 000 to 500 000 population, 0 otherwise; and
WAGE = area average monthly wage rate.

This equation indicates that labor efficiency is

Table 1. Descriptive statistics of performance indicators.

Statistic	RVh/EMP	RVh/MAXVh	OPEXP/RVh ($)
Mean	1222.77	0.48	20.70
SD	279.83	0.19	7.34
Minimum	702.14	0.15	11.28
Maximum	1733.21	1.00	42.73

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 to base ratio, is insignificant, although the sign is in the expected direction. As the peak to base ratio increases, the efficiency of labor use decreases, mainly because work rules that limit 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 0.65. In order to minimize the problem of multicollinearity, dummy variables were used for service area size. The effect of all size variables is negative: Efficiency of labor use 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 do small operators. Large firms, which operate in large metropolitan areas, provide more peak-period service and generally have longer service hours, which require additional supervisory shifts. 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 the efficiency of labor use. 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 and 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, and the overhead is absorbed by other departments. Thus, municipal firms tend to score higher on measures of efficiency of labor use than do nonmunicipal firms. In this sample, the municipal firms are also small firms.

Equation 2 also indicates that new firms are less labor efficient than old firms. New firms operate in areas that 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 nonservice-producing employees, new firms produce less revenue service per employee.

The area wage rate appears to have a positive effect on efficiency of labor use. 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 that pay higher wages are able to use labor more efficiently. Thus, if size and age of firm are held constant, higher wage rates induce more efficient use of labor.

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, unionized firms would be expected to be less efficient than nonunion firms. In fact, a unionization variable was found to have no significant relationship with efficiency of labor use. 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. The crucial factor seems to be the degree to which work rules conflict with requirements for service provision. For example, spread time limitations would affect firms that provide highly peaked service more than firms that do not. It is the degree to which the labor contract constrains the efficient use of transit employees that is important rather than the simple fact of unionization.

Vehicle Use

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 use in spite of the fact that the form of the indicator was chosen so as to control for this factor (Equation 3). The hours-of-service variable may be interpreted as a more general service variable because high peak to base ratios are correlated with long service hours.

$$\text{RVh/MAXVh} = 0.937 - 0.698\ \text{HRSERVC}\{(6.26)[0.76]\} \quad (3)$$

$R^2 = 0.58$, N = 29.

where 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 use, 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 that provides 24-h service, for example, would provide less nighttime service than daytime service and, thus, would have a lower rate of vehicle use than does a firm that provides 12 h/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. Note that service parameters are related to environmental variables. Equation 4 indicates that the service area characteristics of size and population density have a significant effect on hours of service; large, high-density areas are associated with the longest service hours.

$$\begin{aligned} \text{HRSERVC} = 1.03 &- 0.310\ \text{SMALLSIZE}\{(5.3)[0.67]\} \\ &- 0.244\ \text{MEDSIZE}\{(4.7)[0.60]\} \\ &- 0.301\ \text{MEDDEN}\{(5.3)[0.72]\} \\ &- 0.180\ \text{LOWDEN}\{(3.3)[0.42]\} \end{aligned} \tag{4}$$

$R^2 = 0.72$, N = 30.

where MEDDEN = 1 if density is 3000-6000 people/mile², 0 otherwise; and LOWDEN = 1 if density is <3000 people/mile², 0 otherwise.

The variation in service hours may be interpreted as a reasonable response to transit market conditions. Firms that operate in small cities, where few commercial activities take place during evening or nighttime hours, may restrict service accordingly. Firms that operate 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 (i.e., older systems) have not cut back service hours but have reduced frequency of service in response to declining demand.

The analysis here has shown that the efficiency of vehicle use 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 that exists 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 agency) 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, the efficiency of vehicle use must be evaluated within the context of the goals of the sponsor and operator.

The vehicle use 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 use. 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

Cost efficiency measures the efficient use of all input factors. Because labor is the predominant factor in transit service, labor use, in large part, determines the cost of providing transit service. Consequently, factors that affect the efficiency of labor use should also affect cost efficiency. In general, this proved to be the case, as Equation 5 illustrates. Significant factors that affect cost efficiency were found to be the peak to 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.

$$\begin{aligned} \text{OPEXP/RVh} = 4.48 &+ 7.27\ \text{PEAK}\{(4.6)[0.59]\} \\ &+ 0.063\ \text{VEH}\{(3.4)[0.42]\} + 3.72\ \text{OPAGE}\{(2.0)[0.24]\} \\ &+ 4.55\ \text{UNION}\{(2.0)[0.24]\} \end{aligned} \tag{5}$$

$R^2 = 0.63$, N = 28.

where UNION = 1 if unionized firm, 0 otherwise. 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, although only five of the sample of properties are nonunion, the average operating cost per hour for this group is $14.21, or 31 percent less than that of the whole sample average, which was $20.70. Thus, although nonunion firms may be no more able to use their labor efficiently (and indeed may have less incentive to do so), they achieve lower unit costs as the result of low wage rates.

The peak to base ratio emerged as a major factor that affects cost efficiency, in spite of the fact that it was not a significant variable in the labor use efficiency equation. To some extent, this is due to a peculiarity of this sample, in which one firm has a peak to 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 to base ratio has, at best, a weak negative effect on efficiency of labor use, it, like long hours of service, has a strong negative effect on vehicle use. Its combined influence on both aspects of production efficiency results in significantly higher unit operating costs for firms that provide highly peaked service. The peak to base ratio is positively correlated with population density and traffic congestion, and consequently may be considered to represent more generalized environmental effects associated with services heavily oriented toward a central city.

Finally, the effect of size on cost efficiency is negative. Note that the organization size variable that appears in Equation 5 is interchangeable with other measures of size, such as size or population of service area. 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 use 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 that 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, although all of the largest firms in the sample operate in large urban areas, some of the smaller firms also operate in large urban areas, and presumably face 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 that operate in smaller cities. In other words, the effect of the wage rate on cost efficiency is minimal at best. Second, if the size variable actually reflects the general wage rate, then it should have had no significant effect on a pure (i.e., cost-free) measure of efficiency such as RVh/EMP.

In light of the results presented here, other possible explanations must be developed. One explanation may be called a union power hypothesis. Large transit systems may be less effective at the bargaining table because of their sensitivity to labor strikes. Transit strikes in large urban areas inconvenience center city commuters and leave concentrations of transit dependents with no means of transportation. Because they are dependent on public opinion for political support, large systems may be more willing to accept higher wages and more restrictive work rules in order to avoid service interruptions. Over the years, this process may have resulted in more stringent union contracts (and therefore better working conditions for employees) among large transit operations.

A second explanation might be called a service hypothesis. Large transit firms provide more peak service, longer service hours, and more route miles than do smaller operators. The complexity of the route system and its spatial extent may create inefficiencies for large transit systems. As the route system becomes spatially dispersed, more deadhead time may result, which in turn leads to less efficient use of labor and, therefore, higher costs. The fact that the suburban systems (which have more dispersed route patterns) have somewhat higher operating costs and lower efficiency of labor use than do the large urban systems (where service focuses on a central business district) lends support to the argument.

Another 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 efficiency of labor use 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 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 are to be made between transit systems. As public sponsors move toward tying subsidy allocations to performance standards (as has already begun in Pennsylvania and New York), it will be necessary to identify all the significant variables that 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 that transit analysts have considered to be relatively unaffected by environmental factors. Performance effectiveness, which measures the consumption of transit service, depends on market conditions and fare policy as well as on the ability of the firm to provide a service that 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 that affect 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 to be a truly exogeneous factor. All the others have been influenced to some degree by public policy. Firm size is determined by the quantity of service provided. During the past decade, improvement in the quality of transit service and provision of greater accessibility throughout the urban area have been major federal policy goals that have resulted in more hours and miles of service.

Efficiency is not discouraged by encouraging the production of more transit service and increasing the size of transit firms. However, federal policy has also encouraged the spatial dispersion of service by providing subsidies on the basis of service area populations. Federal policy has also enabled the development of powerful transit unions. Both of these conditions adversely affect performance efficiency. At the same time, transit firms have been able to maintain their monopolistic position. Clearly, differentiated service areas prevent competition among 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 that affect 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 policymakers. If union work rules severely constrain the use of transit labor, then some way must be found to mitigate their effect. If labor-management negotiations are not a feasible 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 or off-hour service) will either have to be reduced or, as recently suggested by Oram (5), provided by other sources (i.e., private contractors). Similarly, if new services add disproportionately to costs, the expansion of transit service into new areas should be reevaluated.

In recognition of 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.

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Abridgment

Modeling Transit Service Areas

JEROME M. LUTIN, MATTHEW LIOTINE, AND THOMAS M. ASH

Transit access is defined as a measure of the ability or propensity of a population to use transit. Transit access modes are usually defined as walking, park-and-ride, kiss-and-ride, paratransit feeder, transit-feeder, taxi, or bicycle. This research is directed toward the development of tools for planning access to transit systems that address the impact of access characteristics on ridership and aid in the normative definition of the area served by transit. A methodology to evaluate and plan for access is developed. Nonlinear models based on empirical data are developed to estimate cumulative distributions for (a) walk to local bus, (b) walk to suburban bus, (c) walk to express bus, (d) park-and-ride to express commuter rail, and (e) park-and-ride to express bus. Equations are presented that can be used to determine ridership percentages that originate within user-specified times or distances around a transit stop, and the access distances or time within which normatively specified ridership percentages originate.

The means of getting to and from transit systems and the ease or difficulty with which that portion of the journey is made can affect the traveler's decision to use transit as much as can conditions and service on the system itself (1). That portion of a journey that is spent on the transit vehicle or waiting at stops is known as the line-haul portion of the trip. Those portions of the journey spent in getting to the transit system from the trip origin and to the destination from the transit system are know as the access-egress portions of the trip, or simply the access portion. Thus, accessibility to transit, or transit access, deals with characteristics of the trip portions not on the transit system.

Planning for transit access is becoming more of a concern for transit planners. Given the impact of access characteristics on ridership and the need for a normative definition of the service area accessed by transit, the development of a methodology to evaluate and plan for access is being undertaken. This research is directed toward the establishment of empirical tools for planning access to transit systems.

DEFINITION OF TRANSIT SERVICE AREAS

That portion of the urban area from which a transit line derives its patronage is known as its service area. No universal quantitative definition of transit service area can be given because its limits are not fixed, except by the habits (actual or expected) of the transit patrons. A service area centered on a transit stop, or transit line, varies in radius according to the characteristics of the line-haul mode, mode of access, and socioeconomic characteristics of the population to be served. In practice, service area boundaries can be described as follows:

1. Empirically--as the inclusive boundary for the xth percentile of origins and destinations observed for patrons that use a stop, or
2. Normatively--as the arc of maximum distance for convenient or desirable travel to the transit stop.

The terms tributary area or commuter shed have also been used to describe service area. Two of the most-important questions that face transit planners are, How far from the transit line does one draw the boundary of the service area? and, What is the relationship between this distance and some standard of desirable transit accessibility?

DEVELOPMENT OF MODELS OF TRANSIT SERVICE AREAS

The objective of this research is to develop a concept that could be used by planners to determine a set of service area standards (2). These standards could be applied to existing and proposed transit systems to determine the proportion of the urban area served by a transit system. It is known that many factors, such as destinations served, transit travel time, frequency of service, hours of service, fare, security, reliability, accommodations for handicapped, and comfort, must be considered in judging whether transit service is available to an individual. However, access distances and service areas should be included among system evaluation criteria and, indeed, are among the most basic indicators of transit availability.

Development of useful standards for service areas requires the answering of a fundamental question, How close to a transit stop or station should a given location be in order for one to consider that location well-served by transit? One must also define the appropriate unit for measuring closeness. It is not within the scope of this report to unequivocally state specific standards. Rather, we will examine data obtained from a variety of sources and present models that show the cumulative percentile of transit riders included within a given distance or travel-time interval from a transit stop, as derived from observed behavior. These models can then be used in two ways. First, such a model could be used to determine, for a given location at a distnce from a transit line, the percentile access distance score for that location. Second, given a desired percentile score to be used as a normative access standard, the model can be