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16. Abstract

This report synthesizes knowledge from existing literature relating to the interpretation and measurement of transit service quality from a customer-oriented perspective. The focus is on the evaluation of fixed-route transit systems. In addition, we review earlier studies that offer conceptual and operational ways of identifying different transit submarkets, their characteristics, and their varying activity and mobility needs. Our review suggests that existing transit service delivery measures are limited in their capabilities of reflecting the ease with which different population subgroups are able to participate in their desired activities using transit. Future effort in transit service delivery modeling needs to develop separate indices for different population subgroups for different trip purposes. There should also be a mechanism to consolidate these indices into successively more aggregate measures and ultimately into a single generalized measure that represents the overall service level for a region.

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Measuring Access to Public Transportation Services: Review of Customer-Oriented Transit Performance Measures and Methods of Transit Submarket Identification

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1. Introduction

The rising traffic congestion levels and the resulting negative air quality in many metropolitan areas have elevated the need for a successful public transportation system to ease the reliance on the private auto. Public transportation is an efficient and environmentally friendly alternative to automobiles. It is also important to the social fabric of a city as it provides access to shelter, food, employment, schooling, medical care, and entertainment to people who, because of age, income, or disability, do not have regular access to private motor vehicles (Jones 1985, Small and Gomez-Ibanez 1999, Iseki and Taylor 2001).

The important role of transit systems to society has led to their heavy subsidization. In 2002 alone, transit providers nationally received about $12.8 billion in capital funds from various sources, with 41% from the federal government, 12% from state sources, 20% from local sources, and the remainder from taxes levied by transit agencies and other directly generated sources (American Public Transportation Association 2005). However, over the last four decades, the modal share of transit has fallen from 3.2% to 1.6% in the country's metropolitan areas, including those in Texas (NHTS 2001)[1]. As a consequence of the public transit share decline, and in order to maintain public support for transit, transit operators are under pressure to provide services that will attract users from a wider market. Such pressure leads to the increased emphasis on commuter-oriented express bus and rail services, at the cost of inadequate service provision to transit dependents (Garrett and Taylor 1999). For example, according to Pucher et al. (1981), in 1978, the population subgroup earning more than $20,000 made up 58% of commuter rail ridership compared with 25% of rapid rail and 20% of bus services. At the same time, the nationwide operating subsidy in 1978 was $1.53 per passenger for commuter rail, $0.41 for rapid rail transit, and $0.37 for bus and streetcar. Thus, the commuter services that serve the most affluent patrons also receive the highest subsidy levels per passenger (Pucher 1981). This uneven allocation of subsidy is also evident in a more recent study by Iseki and Taylor (2001), who examined the trip subsidies in Los Angeles for each type of transit service by various socio-demographic variables. They found that, while per trip bus subsidies do not vary much ($0.38)

[1] This statement is not intended to underplay the role of transit in serving certain important markets (such as to downtown areas) in urban areas today. Rather, it is intended to acknowledge the increased reliance on the private auto than in the past.

across income categories, per trip express bus subsidies for the highest income riders ($9.55) are nearly twice those of the lowest income riders ($4.98). The per trip express bus and light rail subsidies were also found to vary substantially across racial/ethnic groups, with non-Hispanic whites and Asian-Pacific Islanders having the highest per trip subsidies. Iseki and Taylor (2001, p.32) concluded that "… *the benefits of transit subsidies disproportionately accrue to those least in need of public assistance. This raises serious questions regarding the conflicting objectives of transit system policies which seek to deploy services to attract both transit dependent and choice riders.*"

In view of service performance problems such as declining ridership and social inequity, public agencies and transit operators are looking for methodologies to accurately identify where the problems are and quantify the severity of the problems so that appropriate actions can be taken. To date, many performance measures have been developed and used in a variety of ways, reflecting differing perspectives and responding to differing transit problems. For a variety of reasons—particularly federal reporting requirements and the relative ease of obtaining data—many transit agencies have focused on measures that reflect the *agencies'* point of view and concern with transit system *efficiency* (that is, how well a transit system utilizes available labor and capital resources; see Gilbert and Dajani 1975, Fielding et al. 1978, Fielding et al. 1985, Chu et al. 1992, Nolan 1996, Karlaftis 2003). On the contrary, critical aspects of performance that are important to the transit customers, and the community at large, have often been insufficiently addressed (Kittelson & Associates, Inc. et al. 2003). For example, analysis directed toward assessing the effectiveness of subsidies in achieving equitable transit service provision is rarely required or produced (Murray and Davis 2001). It is only recently that the social-welfare role of transit and the need to improve public transportation customer service as a means to increase transit ridership have begun to receive serious consideration. These considerations call for customer-oriented performance measures for evaluating transit service (Takyi 1993, Murray and Davis 2001). Moreover, the notion of equity in travel opportunities by transit requires that these measures reflect how well a transit system meets the customers' needs in accessing the necessities, and perhaps also luxuries, of life. With such measures, one can evaluate service equity of an existing transit system against that of other alternatives. One can also regularly assess the equity in service in an environment of constantly evolving land use and population characteristics to ensure that a transit system continually meets the needs of its customers.

The objective of this report is to synthesize knowledge from existing literature relating to the interpretation and measurement of transit service quality from a customer-oriented perspective. The focus is on the evaluation of fixed-route transit systems, although some of the knowledge is also applicable to demand-responsive systems. Chapter 2 surveys existing measures of transit service quality that reflect the customers' point of view. The chapter also discusses the comprehensiveness and limitations of these existing measures. Chapter 3 represents a synthesis of earlier studies that offer conceptual and operational ways of identifying different transit submarkets and their characteristics. This is important to our objective because we are interested in developing service quality measures that quantify the level of equitable distributions of transit service. Chapter 4 discusses the varying activity and mobility needs of the transit submarkets. Finally, Chapter 5 concludes the report with recommendations for the formulation of transit service quality measures.

2. Review of Transit Performance Measures

This chapter reviews past transit performance studies that reflect a customer-oriented perspective (as opposed to an agency-oriented perspective), with a specific emphasis on the notion of service equity. Before discussing these measures in detail, we first provide in Section 2.1 an overview of the several characteristics along which existing measures may be differentiated. We then define, in Section 2.2, a three-dimensional classification scheme to position past performance measures. Sections 2.3 through 2.5 discuss existing measures as they relate to the three dimensions of our classification scheme. Section 2.6 describes composite measures that attempt to account for more than one of the three dimensions of our classification scheme. Section 2.7 concludes the chapter with a discussion of the limitations of existing measures for the purpose of assessing transit service equity.

2.1 Overview

Much has been written about performance measurement in the transit industry and many performance measures have been developed in the past. Different measures have been designed to reflect differing points of view (e.g., customer versus agency) and for different modes (e.g., fixed-route versus demand-responsive transit). Among the measures that are of interest to this report (i.e., customer-oriented measures for fixed-route service), they may differ in the scale of analysis, the type of mathematical structure used, and the underlying goals and objectives of measurement. Each of these three characteristics is discussed in turn in the next three sections.

2.1.1 Scale of analysis

The scale of analysis may range from individual bus stops to individual routes to the entire transit system. For instance, the Quality of Service Framework proposed in the Transit Capacity and Quality of Service Manual (TCQSM, TRB 2003) consists of different measures for different scales of analysis (see Table 2-1).

Table 2-1. Quality of Service Framework proposed for fixed-route transit in the Transit Capacity and Quality of Service Manual

	Transit Stop	Route Segment	System
Availability	Frequency	Hours of service	Service coverage
Comfort & Convenience	Passenger load	Reliability	Transit-auto travel time

A "bus stop level" analysis enables an understanding of the cause and effect relationship between pedestrian access, activity opportunities, and potential ridership. Often, findings from this micro-level can be aggregated to the route and system level to evaluate system coverage and duplication of service. However, as we will see later in our discussion of past performance measures, some measures (such as network accessibility or trip travel time) are meaningful only at the route or system level.

2.1.2 Type of mathematical structure

As the *TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System* (Kittelson & Associates, Inc. et al. 2003, p.127) suggests, the development of a performance measurement program involves a number of considerations:

1. *The number of measures to be reported—too many will overwhelm users, while too few may not present a complete picture.*
2. *The amount of detail to be provided—general measures will be easier to calculate and present, but more detailed measures will incorporate a greater number of factors influencing performance.*
3. *The kinds of comparisons that are desired—will performance be evaluated only internally or compared with other agencies?*
4. *The intended audience—some audiences will be more familiar with transit services and concepts than others.*

As a trade-off among these considerations, past performance evaluations have been conducted using one or more of the following types of measures: (1) individual measures, (2) ratios, (3) index measures, and (4) level of service (LOS) measures (Kittelson & Associates, Inc. et al. 2003). An <u>individual measure</u> usually reflects a single attribute of a transit system, such as frequency, that can be measured directly. It has the advantage of being intuitive and easy to compute. Yet, in order to describe a complete picture of a transit system, one usually needs to use several individual measures or combine individual measures with other types of measures. Ratios often represent some kind of normalized values for comparison purposes and are typically developed by dividing one transit attribute by another, such as passengers per bus. They too are usually easy to understand, but again suffer from the problem of describing only a single aspect of system performance. One way of overcoming this problem is to use index measures, which are developed to produce a single value to reflect the combined, weighted, result of several performance measures. The main advantage of index measures is the ease of presentation through the minimization of the number of measures reported. The accompanying disadvantages are that they cannot be directly measured in the field, may not be particularly intuitive, and may mask significant changes in their constituting measures. The LOS measures are developed by assigning "A" to "F" letter scores to predefined ranges of values of a particular measure. They are analogous to the roadway LOS measures originally proposed by the Highway Capacity Manual. As with index measures, the LOS measures provide a simple way to present evaluation results to the public and to decision makers, yet they mask performance changes and trends occurring in the underlying measures.

2.1.3 Underlying goals and objectives

Before developing or choosing a performance measure, one must first consider what is meant by "performance" in the context of the agency's goals and objectives. However, it is also not a straightforward task to categorize performance measures based on their underlying goals and objectives. This is because the goals and objectives often overlap each other and their definitions are subject to interpretation. For instance, Table 2-2 shows the eight categories, and the subcategories, of concern to customers, communities, agencies, and motor vehicle drivers as identified in the *TCRP Report 88* (Kittelson & Associates, Inc. et al. 2003). The categories are by no means mutually exclusive and, hence, represent only one way of classifying the common goals and objectives of transit planning and evaluation process. For example, *travel time* measures, which assess "how long it takes to make a trip by transit" may also be considered as an indicator of *mobility*, which is defined as "the ease of traveling between locations within a community." Also, measures of *capacity* are candidates for measuring *service availability* and *service delivery*.

Table 2-2. The eight goals/objectives-based categories used in the TCRP 88 Report to organize past transit performance measures

Categories	Subcategories (if applicable)
Service availability	Spatial availability
	Temporal availability
	Para-transit availability
	Capacity availability
Service delivery	Reliability
	Customer service
	Passenger loading
	Goal accomplishment
Community impact of transit	Mobility
	Outcomes
	Environment
Travel time	Time
	Speed
Safety and security	
Maintenance and construction	
Economic	Utilization
	Efficiency
	Effectiveness
	Administration
Capacity	

In contrast to the overlapped eight-way categorization of goals and objectives outlined in the *TCRP Report 88*, the Transit Capacity and Quality of Service Manual (TCQSM, TRB 2003) makes a distinction between only two broad categories of customer-oriented performance measures: *availability* measures versus *comfort and convenience* measures. Here, measures of *availability* reflect whether or not transit is even a potential mode choice, a definition similar to that of the *service availability* category in the *TCRP Report 88*. Measures of *comfort and convenience* are those that capture the factors influencing a passenger's decision to choose transit (when transit is an option) over a competing mode. This category can be considered as encompassing many of the categories (except for those under *service availability*) listed in Table 2-2.

2.2 Classification Scheme of the Current Review

Our review of literature revealed several past efforts to develop customer-oriented transit performance measures. As summarized in Table 2-3, these measures differ in terms of their scale of analysis, their type of measure, and their underlying goals and objectives. Here, we expand on the approach used in the *TCQSM* and identify three types of goals/objectives of measurement: *local availability*, *network availability*, and *comfort and convenience*. These three types of measurement goals/objectives are the most relevant to transit performance from a customer perspective. The term *local availability* is defined as whether or not transit is available at the trip origin or destination, while *network availability* is defined as how suitable transit is for transporting a customer from a trip origin to a desired destination. Both local and network availability may refer to *spatial availability* (where can one use transit service and how can one get to it) or *temporal availability* (when, how often, and for how long can one use transit service), or both. For the purpose of assessing how well past measures reflect the level of transit service as perceived by the customers, we examine whether past measures account for the characteristics of the transit system (i.e., supply) as well as the needs of the customers (i.e., demand). Measures that account for the supply of transit service, such as bus stop locations and headways, are indicated with an "S" in the last three columns of Table 2-3. Similarly, measures that account for the demand of transit service, such as the desired origins and destinations and time of travel, are marked with a "D."

In the following sections, we describe in detail how past measures have been formulated to accommodate local availability (Section 2.3), network availability (Section 2.4), and comfort and convenience of transit service (Section 2.5).

Table 2-3. Summary of previous transit service delivery measures

Study	Scale of Analysis	Type of Measure	Goals and Objectives of Measure		
			Local Availability	Network Availability	Comfort and Convenience
Horner and Murray (2004)	Stop	Individual (population in service area)	S, D Spatial availability		
Murray and Davis (1998, 2001)	Stop	Individual (population in service area)	S, D Spatial availability		
O'Neill (1992, 1995)	Route	Individual (population in service area)	S, D Spatial availability		
Hsiao et al. (1997)	Stop, Route, System	Individual (population in service area)	S, D Spatial availability		
Zhao et al. (2002, 2003)	Stop, Route	Individual (population in service area)	S, D Spatial availability		
Cooper (2003), Hillman and Pool (1997), Kerrigan and Bull (1992)	System	LOS	S Spatial and temporal availability		
Polzin et al. (2002)	System	Index	S, D Spatial and temporal availability		
Ryus et al. (2000)	Stop	Index	S, D[2] Spatial and temporal availability		
Hillman and Pool (1997)	System	Index		S (O-D travel time)	
Schoon et al. (1999)	System	Index		S (O-D travel time)	

[2] Only the spatial (i.e., population distribution), and not the temporal aspect of demand is addressed in this part of the study.

Fu et al. (2005)	System	Index		S, D (O-D travel time weighted by travel demand)	
Koskinen et al. (2005)	System	Individual		S, D (multiple O-D based temporal measures weighted by travel demand)	
Tumlin et al. (2005)	System	LOS	S Temporal availability	S (O-D travel speed)	S Reliability, loading
Camus et al. (2005)	Route	Index			S Reliability
Rood (1997, 1998)	System	LOS	S, D[3] Spatial and temporal availability		S, D Capacity

[3] Size of land area is used as a proxy for population size.

2.3 Measures of Local Availability

The availability of transit service is vital for potential passengers: if transit service is not provided to the locations where people want to go and at the times they need to travel, transit is not a viable option (Kittelson & Associates, Inc. et al. 2003). In this section, we review the approaches taken in the past studies for measuring local availability of transit service. Such measures are sometimes referred to as measures of "local accessibility" (Hillmand and Pool 1997) or "access" (Murray et al. 1998).

In the first part of this section, we describe past measures of *local spatial availability* (i.e., measures of how easy it is to have access to transit from a trip origin or destination). These measures usually focus on the quality of the transit stops and the configuration of walk networks in relation to transit stops. The second part of this section is devoted to past measures of *local temporal availability* (that is, measures of the opportunity for transit use based upon attributes such as service frequency and operation hours). The third part of the section reviews measures that account for both local spatial and temporal availability.

2.3.1 Local spatial availability

Because most transit riders walk from their trip origins to bus stops and from bus stops to their trip destination, local spatial availability is often evaluated in terms of pedestrian (walk) access, as opposed to park and ride or transfers (Hsiao et al. 1997). Assessment of local spatial availability typically requires estimating the population in the service area of a transit stop or route, thus accounting for the location characteristics of both the supply and demand of the transit service. The estimation of the population served involves a two-step procedure: (1) identifying the service area that is accessible by pedestrians and (2) estimating the potential ridership based on the population and/or land use within the service area. As discussed below, there are a number of different ways to implement the two steps of the procedure.

2.3.1.1 Identifying service area

The identification of service areas is typically achieved using the buffering operation (using GIS) by constructing lines of equal proximity around each transit stop (for example, see Hsiao et al. 1997, Ryus et al. 2000, Murray and Davis 2001, Zhao 2003) or each transit route (for example, see O'Neill et al. 1992 and Polzin et al. 2002). The buffering operation clearly involves at least two decisions. The first decision is, of course, whether routes or stops should be used as the reference of measurement. As Horner and Murray (2004) demonstrated in their empirical study, the two approaches may lead to very different values of spatial availability. Horner and Murray contend that transit stops offer a more appropriate basis than routes for estimating service area coverage because stops are the actual locations where transit users access the system. The other decision involved in the buffering operation is the buffer size. A common practice in transit planning is to assume that people are served by transit if they are within 0.25 mi (or 400 m) of either a transit route or stop (Murray 2001, Peng et al. 1997, Ramirez and Seneviratne 1996). However, a study conducted by Alshalalfah et al. (2005) suggests that the 0.25 mi criterion underestimates how far people are willing to walk to access transit.

Once a distance threshold is defined, buffers are created around the transit features. Some studies measure the distance based on air, or Euclidean, distance (Murray et al. 1998, Murray and Davis 2001), while others use network distance (that is, the walk distance computed using the street network to reach a transit feature; O'Neill et al. 1992, O'Neill 1995, Hsiao et al. 1997, Zhao 1998, Horner and Murray 2004). Since the network distance between two locations in space is greater than, or equal to, the corresponding air distance, the size of a coverage area defined by the network distance will be smaller than, or equal to, that defined by air distance (see Hsiao et al. 1997, and Horner and Murray 2004, for comparative analysis of the two distance measures). Network distance measures are likely to be more realistic because they reflect the configuration of the street network and recognize the presence of any man-made barriers preventing direct access to transit features.

In addition to using the above mentioned distance measures, past researchers have also suggested the use of travel time to transit features as a measure of proximity (Murray et al. 1998 and O'Neill et al 1992). Using travel time is preferable to distance as a measure of proximity because travel time measures account for such pedestrian-unfriendly factors as steep terrains. However, because of the additional data requirements and the amount of processing effort involved, travel time measures have rarely been used in practice.

2.3.1.2 Identifying population served

Once a service buffer is constructed, the next step is to overlay the buffer onto other polygons, such as census tracts, for which socio-demographic data is available (hereafter we refer to these polygons as the "analysis zones")[4]. Typically, a service buffer (denoted as i) intersects, either fully or partially, with more than one analysis zone j ($j = 1 \ldots J$). The population served by the transit service in buffer i, P_i, is thus equal to the sum of the population in each of the intersecting areas, P_{ij}:

$$P_i = \sum_{j=1}^{J} P_{ij},$$

where P_{ij} is often estimated based on the amount of interaction between service buffer i and analysis zone j.

A common approach for estimating P_{ij} is to assume that the population is uniformly distributed within the analysis zone. This is known as the area ratio approach:

$$P_{ij} = \frac{A_{ij}}{A_j} P_j,$$

where P_j is the population in zone j; A_{ij} is the area of intersection between buffer i and zone j; and A_j is the total area of zone j. The area ratio approach has been criticized for providing a realistic population estimate only if the underlying street network is an evenly spaced fine mesh grid. O'Neill (1992) suggested the network ratio method as an alternative approach:

$$P_{ij} = \frac{L_{ij}}{L_j} P_j,$$

where P_{ij} and P_j are defined as before; L_{ij} is the total street miles within the intersection of buffer i and analysis zone j; and L_j is the total street miles in zone j. Essentially, the network ratio method assumes that the population is uniformly distributed on streets in a zone. This assumption is realistic for residential areas, but may be weak for zones of mixed housing types or mixed land uses. To relax the simplistic assumption regarding population distribution, Zhao (1998) proposed a modified network-ratio method that uses data about the structure of the dwellings (number of housing units in multi-family housing and number of bedrooms in each dwelling unit) in an analysis zone to estimate the population distribution within the zone. Later,

[4] This is done in the absence of data about the exact population distribution within the service buffer.

Zhao et al. (2003) suggested the use of a distance decay function to reflect the observation that transit use deteriorates exponentially with walking distance to transit stops. Specifically, the population size in each dwelling unit (household) is weighted by a decay function of the distance between the dwelling and the transit feature i. The sum of the weighted household sizes across all households in zone j forms an estimate for the population served by transit feature i in zone j. In their application of the distance decay method coupled with the modified network-ratio method, Zhao et al. (2003) found that their approach results in a much lower (up to 50%) estimate of the population served than those given by the area-ratio and the network-ratio methods.

2.3.1.3 Scale of analysis and type of measurement

The procedure described above for assessing the local spatial availability of a transit service gives an individual measure (i.e., population size in the service area) of service performance. If the measure is based on the buffer around a transit stop, we consider it a stop-level measure. Because of the simple nature of the measure, one can aggregate the measurements for the stops along a route to give a route-level assessment (see Hsiao et al. 1997). Alternatively, if the measure is based on a buffer around a transit route, then it is by nature a route-level analysis (see O'Neill 1992). Both types of route-level measures can be used to compare the transit performance of multiple transit routes. They can also be aggregated over multiple routes in a region to evaluate an existing transit system against a proposed one, as done in Hsiao et al. (1997).

2.3.2 Local temporal availability

The studies described in the preceding section evaluate transit service solely based on spatial access to stops or routes and do not address the temporal dimension associated with the availability of transit service. Yet, the temporal aspect of transit availability is important because a service within walking distance is not necessarily considered as available if wait times beyond a certain threshold level are required. This wait time for transit is related to the frequency of the service as well as the threshold for tolerable waits for potential riders (Polzin et al. 2002).

As part of their efforts in developing a comprehensive measure of transit availability, Polzin et al. (2002) devised a measure of temporal availability. Data on the temporal distribution of travel demand and service frequency are used to calculate the service availability weighted by the time-of-day distribution of travel demand. Specifically, the temporally weighted service availability of route i during service period p, M_{ip}, is defined as

$$M_{ip} = f_{ip} \cdot t_{ip} \cdot P_p,$$

where f_{ip} is the service frequency of route i in period p, t_{ip} is the tolerable wait time on route i in period p, and P_p is the fraction of daily travel demand that falls within period p. The total daily service availability for route i is then given by

$$M_i = \sum_{p=1}^{n} M_{ip}$$

where n is the number of time periods for which service is available. Essentially, the formulation allows service in periods of high demand to be weighted more heavily than service in periods of low demand.

2.3.3 Local spatial and temporal availability

Based on their proposed temporal measure of service availability (as described in Section 2.3.2), Polzin et al. (2002) developed a measure that accounts for both spatial and temporal availability at trip ends. The calculation involves first computing the total equivalent population in zone j as:

$$Q_j = P_j + \left(w \cdot E_j \cdot \frac{P}{E} \right),$$

where P_j and E_j are the population size and the number of employed individuals in zone j, respectively. P and E are the total population size and number employed, respectively, in the study area. w is the employment weight factor that converts employment to equivalent population. The total exposure to transit route i in zone j is calculated by applying the demand-weighted service availability to the total equivalent population in the zone:

$$X_{ij} = z_{ij} \cdot M_i \cdot Q_j,$$

where z_{ij} is a user-specified value indicating the fraction of zone j that falls within the service buffer of route i. Summing across I transit routes in the system and converting trip end exposure to daily trips yields the total daily trips in zone j exposed to transit service:

$$T_j = \frac{\sum_{i=1}^{I} X_{ij} \cdot r}{2 \cdot 60 \cdot 24},$$

where r is the daily person trip rate. Finally, the daily trips per capita in zone j exposed to transit service are then calculated as

$$A_j = \frac{T_j}{Q_j}.$$

The final transit accessibility measure, A_j represents a system-level index that can be used to evaluate service and compare transit accessibility across zones.

The Transit Capacity and Quality of Service Manual (TCQSM, TRB 2003) also suggests the need to account for both the spatial and temporal dimensions of transit service when evaluating service quality. As shown in Table 2-1, the Manual recommends the combined use of service frequency at the stops (temporal availability), hours of service of the routes (temporal availability), and service coverage of the transit system (spatial availability). Based on the TCQSM concept, Ryus et al. (2000) developed the transit level-of-service (TLOS) indicator that considers a person to have access to transit at a given time if all of the following conditions are met: (1) the person lives within a user-defined walking distance of a transit stop; (2) the pedestrian environment provides safe and comfortable walking routes to transit stops (as defined by the user); and (3) a transit vehicle arrives in a user-defined wait time once the person arrives at a stop. The TLOS performance measure is computed as the product of (1) the percentage of the people in zone j with access to transit stop i and (2) the percentage of the time the transit service is available within a time window of an hour, yielding the percentage person-minutes served for zone j by stop i. Even though this method accounts for the spatial and temporal dimensions of the service supply, only the spatial dimension of the service demand (i.e., population size) is considered and not the variation in temporal demand.

The public transport accessibility level (PTAL) index developed in London, England is another measure that considers both the space and time dimensions of local transit availability (see Kerrigan and Bull 1992, Hillman and Pool 1997, Cooper 2003). It is essentially a measure of the density of the transit service at a point of interest in space. The computation of the index involves first calculating a measure of scheduled waiting time (SWT) based on scheduled service frequency. A mode-specific reliability factor is then added to the SWT to produce the average waiting time (AWT). The sum of the AWT and the walk time from the point of interest to a transit access point gives the total access time, which is then converted to an Equivalent Doorstep Frequency (EDF) such that:

EDF (min) = 30 / total access time (min).

The EDF values corresponding to all the routes within the catchment area of the point of interest are combined to give an accessibility index (AI):

$$AI = EDF_{\max} + \left(0.5 \cdot \text{Sum of All Other } EDF\text{s}\right).$$

In the above equation, the EDF values for all but the most accessible or dominant route is halved to compensate for the fact that (1) the number of routes actually considered by a user are likely to be fewer than that included in the calculation; and (2) riders often have to change routes in order to reach the desired destination, leading to significant transfer delays to the journey. If more than one transit mode is present in the catchment area, the AI calculation is repeated for each available mode and the values are summed across all modes to give the public transport accessibility index (PTAI). The value of the PTAI is then mapped to six levels of PTAL, with level 1 being the lowest level of accessibility and 6 being the highest. It should be noted that, since the computation of PTAL is with reference to a point of interest and not the customers themselves, the measure accounts for the supply, but not the demand, of the transit service.

2.4 Measures of Network Availability

Measures of network availability are concerned with how easy it is to get from an origin to a specific destination by using transit. These measures reflect the configuration of the transit network itself and, therefore, are applicable to the route or system level analysis and not the stop level. In the literature, the measures are also known as measures of “network accessibility” (Hillmand and Pool 1997) or simply “accessibility” (Murray et al. 1998). Typically, past measures of network availability represent a combined assessment of the quality of the transit system in terms of both the spatial and temporal dimensions.

Hillman and Pool (1997) described a measure that has been applied by the London borough of Croydon to generate an index around a new sports arena and examine the effects on network accessibility of the implementation of a proposed new tram service. This measure of network accessibility is calculated by defining a set of destinations (such as schools, hospitals, and other activity centers) and identifying the transit routes that link residential zones (i.e., origins) to the destinations. For each origin, the time taken to walk from the origin to a stop, the time spent waiting at the stop, the time spent traveling and waiting at any interchanges, and the time spent walking to the destination from the bus stop is aggregated to give a total travel time using transit.

Hillman and Pool's (1997) idea of assessing network accessibility by travel time between O-D pairs is also used in several later studies. Schoon et al. (1999) described an accessibility index (AI) for comparing the accessibility by alternative modes between an O-D pair. For a given mode, say, transit, the AI is defined as:

$$AI_{bus} = \frac{\text{travel time by bus}}{\text{averaged travel time across all modes}}.$$

The travel time by bus includes the on-board travel time, access to and from bus stops, and waiting time at stops. The travel time by car includes in-vehicle travel time and access time between parking facility and destination. Similarly, the travel time by cycling includes the cycling time and access time at the destination.

Fu et al. (2005) also take the approach of comparing travel time by transit against that by car when evaluating transit network accessibility. Their approach differs from that of Schoon et al. (1999) in that the travel time between each O-D pair for a given time period of the day is weighted by the associated travel demand (observed or forecasted). The weighted travel times are then summed over all the time periods and normalized by the total daily travel demand. The weighting allows the demand aspect, together with the supply characteristics, to be incorporated into a single index measure.

Koskinen et al. (2005) also take the O-D based approach to examine transit performance. Instead of combining the various temporal attributes into one composite measure, as is done in Fu et al. (2005), Schoon et al. (1999), and Hillman and Pool (1997), Koskinen et al. developed a tool that can calculate and display graphically on a map the individual measures for each O-D pair. These measures include the number of connections required, the different components of transit travel time (in-vehicle time, walking time, waiting time), transit-auto travel time ratio, travel speed, headway, number of boardings, and service coverage. The tool has the capability of identifying multiple optimal and feasible paths on the transit network between an origin and a destination for an individual for multiple desired arrival and departure times. The average, minimum, and maximum values over the optimal and feasible paths are then calculated for each of the aforementioned measures. The average of a performance measure can be further weighted by the O-D demand and summed across all origins for a given destination. This gives the accessibility by transit for a given zone.

2.5 Measures of Comfort and Convenience

As has been argued in several past studies of transit performance, when measuring the perceived performance of transit service from the customer's point of view, it is important to take into consideration factors other than those related to spatial and temporal availability (Benn 1995, Potts 2002, Kittelson & Associates, Inc. et al. 2003, TRB 2003, Tumlin et al. 2005). In this report, we adopt the terminology used in the Transit Capacity and Quality of Service Manual (TCQSM, TRB 2003) by lumping these factors into the category of comfort and convenience, which may include factors relating to safety and security (such as accidents), service delivery (such as on-time performance and headway adherence), capacity (and passenger loading), and passenger environment condition (such as vehicle cleanliness).

The comfort and convenience associated with transit service is usually excluded from existing transit performance measures because data about these factors are often unavailable and many of the factors are, in fact, difficult to quantify. Of the many factors in this category, reliability is perhaps the one that is easiest to measure in the field. Tumlin et al. (2005) suggest using the coefficient of variation in headway gap, calculated by the standard deviation of headway divided by the scheduled headway. Alternatively, the probability of a vehicle's headway being off by more than one-half of the scheduled headway may be a more intuitive measure of reliability. Or, the probability of different degrees of headway variation occurring can be mapped to predefined LOS grades. In addition to the reliability indicator, Tumlin et al. (2005) also define in their study separate LOS indicators for frequency, span of service, loading, and travel speed. Passenger load, which is measured in terms of percentage of vehicle capacity, is considered as another important measure of comfort. Notably, a high vehicle capacity is viewed positively from a transit system efficiency standpoint, but a high vehicle capacity is viewed negatively as a measure of passenger comfort.

The study by Camus et al. (2005) is devoted to the assessment of transit reliability. The proposed measure, which the authors refer to as the "weighted delay index," is defined as:

$$R = \frac{\sum_{k=1}^{H} k.p(k)}{H}$$

where *H* is the scheduled headway, *k* is the generic delay value in minutes ($0 \le k \le H$), and *p(k)* is the observed probability for delay *k*. R is expected to take a value between 0 and 1, with a higher value indicating lower reliability. This reliability measure takes into consideration both the amount of delay associated with transit trips compared to single-occupant vehicle trips and the number of late trips due to transit service failure.

2.6 Other Composite Measures

The Local Index of Transit Availability (LITA), developed by Rood (1998) for the Sacramento-based Local Government Commission, is one of the more comprehensive performance measures as it combines three aspects of service: route coverage (spatial availability), frequency (temporal availability), and capacity (comfort and convenience). By relating the amount of transit service in an analysis zone to the population (residents and employed) in the zone, the LITA addresses both the supply and the demand of the service in one composite LOS score. The computation of the overall LITA score involves first calculating separate scores for route coverage, frequency, and capacity. The service coverage score is given by the number of stops in a zone divided by the square mileage of the land area in the zone. The frequency score is defined as the total number of transit vehicles for the line. The capacity score is in seat-miles per capita, calculated as total daily seats on a transit line (which is vehicle capacity multiplied by number of vehicles per day) multiplied by route-miles of transit line in zone, and then divided by the total population in the zone (residential population plus worker population). Each of these three scores is then standardized across all the zones in the study area to provide a measure of relative accessibility. The standardization is achieved by (1) taking the difference between the raw score and the mean of the distribution and (2) dividing the difference by the standard deviation of the distribution of that score. The overall LITA score is the average of the three standardized scores. For ease of interpretation, the authors add 5 to the overall score so that the score is always positive and takes a value from 1 to 10. The adjusted score is then mapped to grades A through F, with grade "A" corresponding to an adjusted score of 6.5 or higher, indicating the highest level of accessibility. Figure 2-1 illustrates the application of the LITA score to the Riverside County, California, by the Riverside Transit Agency. The map shows that the central city and the rail station areas in the northwest side of the county have the highest LITA value – an indication of great potential for infill development, redevelopment, and transit oriented new development (Rood, 1998).

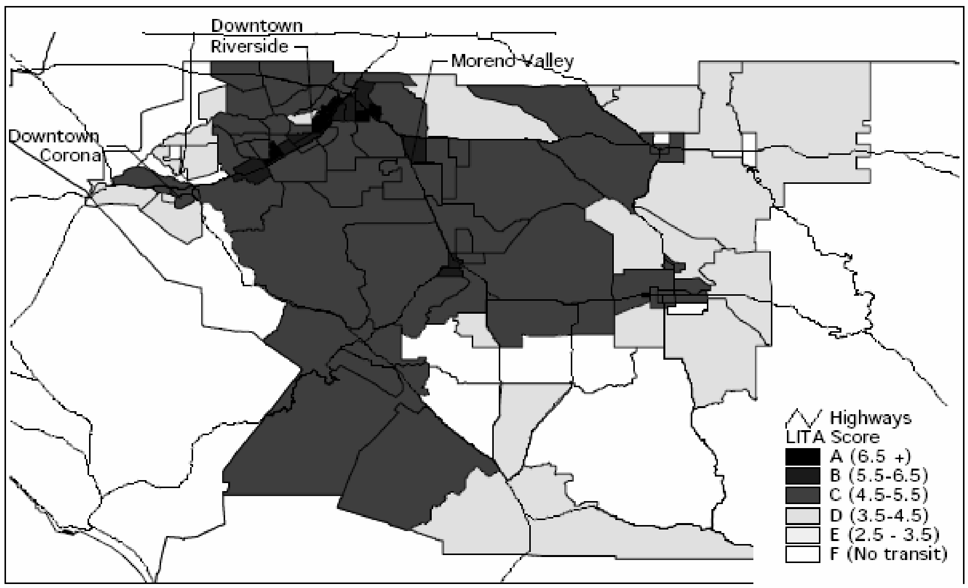

Figure 2-1. The LITA score for the Riverside County, California (Source: Rood, 1998)

2.7 Limitations of Existing Measures

As can be observed from Table 2-3, previously proposed measures of transit service quality tend to focus on the local availability and, in particular, the spatial availability in terms of the population within the assumed coverage area. As Polzin et al. (2002) suggested, the conventional simplistic measures of service coverage tend to overestimate the population size with transit access. Among the studies that consider the temporal as well as the spatial coverage at the local level, Polzin et al. (2002) are the only researchers that take into account the time-of-day distribution of travel demand to reflect the relative value of the transit service provided in each time period of the day.

Past measures of network availability all seem to be based on travel time or travel speed between pairs of origin and destination zones. The measures developed by Fu et al. (2005) and

Koskinen et al. (2005) are the only ones that reflect the spatial distribution of travel demand. Very few studies have given attention to the comfort and convenience aspect of transit service, with the LITA by Rood (1998) being the only composite measure that addresses local availability, comfort, and convenience of transit service.

As revealed in our literature review, an area for additional research in transit performance measure development is the formulation of a single comprehensive measure to simultaneously address local availability, network availability, comfort, and convenience. Moreover, in order for such a measure to be truly “customer-oriented,” the measure needs to contain three principle sets of variables (Hillman and Pool, 1997): (1) the location and characteristics of the individual or person type, for example, where they live, their mobility and car ownership; (2) the opportunities available within their area for the necessities (and perhaps luxuries) of life—for example, jobs, shops, schools, and medical facilities; and (3) the transport systems that link the two together, including walk and cycle routes, roads and car parks, and public transport services. This need is supported, in part, by the empirical findings of Alshalalfah et al. (2005) that the location characteristics and socio-demographic characteristics of transit users have a significant impact on the perceived local accessibility of transit. Yet, past studies on the subject have made little or no distinction among transit users of different socio-demographic characteristics.

For the purpose of assessing equity in transit service delivery, it is especially important to factor into the performance measures the different service needs of various population groups. The development of such comprehensive and customer-oriented measures requires as a basis a good understanding of the differences among transit customers—their personal characteristics, their activity preferences, and their specific travel needs. It also requires a means to identify individual transit market sectors across space, so that the level of service experienced by individual sectors can be measured separately. We discuss these issues in the next two chapters of this report.

3. Transit Submarkets

This chapter examines three different transit user groups: transit-dependents, transit-inclined, and choice-users. We also examine how these user groups are operationalized in empirical studies to identify specific transit submarkets.

3.1 Transit Dependent Users

The term "transit-dependent" is often used in transit planning literature without being specifically defined (Benson 1974, Cervero 1981). There also seems to be no consensus regarding this term among those researchers who do offer a definition. These definitions range from: the carless and those dependent on transit for all non-walking trips (Falocchio et al. 1972); low-income households and households with few or no cars (Kendall 1980); the poor, elderly, young, and the carless (Doxsey and Spear 1981, McLaughlin and Boyle 1997, Grengs 2001); and the elderly, poor, and the handicapped (Perrin 1982). It has been largely left to the individual researcher to define the transit-dependent population in a way suitable for his or her research.

The American Public Transportation Association (APTA) offers a broader definition of "transit-dependent" in the 1997 Transit Fact Book:

> People in the transit dependent market have no personal transportation, no access to such transportation, or are unable to drive. Included are those with low incomes, the disabled, elderly, children, families whose travel needs cannot be met with only one car, and those who opt not to own personal transportation.

Based on this definition, Polzin et al. (2000) found that, in 1995, 30% of the U.S. population over five years of age was transit-dependent.

3.2 Transit-Inclined and Transit-Choice Users

The subgroup of the population who are likely to use transit is referred to as the "transit-inclined" user groups. According to McLaughlin and Boyle (1997) and Grengs (2004), these are low-income individuals residing and working in high-density areas. The "transit-choice" users, on the other hand, are those that use transit because "[it] is superior to other choices in regard to time, cost, convenience, and comfort." (Beimborn et al. 2003). For example, Crepeau (1996) considers the high-income but carless households in New York City to be choice users because these households most likely can afford a car but choose not to do so. The definition offered by

Garrett and Taylor (1999) is narrower in that, while the poor, minority, central city residents are considered transit-dependent, choice riders are those who are white, have a car, and live in the suburbs.

3.3 Methods for Identifying Transit Submarkets

Although many researchers go through the task of defining the complete gamut of transit submarkets, operationalization is often a more challenging task. There are three main sources of data that past researchers have used to identify their target submarket of transit: local/customized travel survey data, national travel survey data, and census data.

3.3.1 Use of local/customized Travel Survey Data

Beimborn et al. (2003) define the transit-dependent as zero-vehicle households. For their analysis, they use the Portland, Oregon, 1994 Household Activity and Travel Dairy Survey to identify their target population. In a study of the Central Brooklyn poor, Falcocchio et al. (1972) used a local statistical handbook to identify the major characteristics of the Central Brooklyn area, and then relied on their own survey data to present findings relating to income and travel. They observed a direct correlation between income and car ownership and noted that low income households used transit (bus and subway) at a higher rate than households with higher incomes.

3.3.2 Use of National Travel Survey Data

Polzin et al. (2000) used the National Household Travel Survey (NHTS) data to study transit travel. Their analysis is conducted using the APTA definition of transit-dependent as cited above less those households whose travel needs cannot be met by only one car. All other households are designated as choice riders. Since the national travel survey data has been weighted, it was used to estimate the national figures of the transit-dependent population from 1969 through 1995. Polzin et al. note that the increase in household car ownership has decreased the transit-dependent population over the time period being studied.

Crepeau (1996) also uses the NHTS data for his analysis of the carless. By definition, his interest is strictly on households that do not have a vehicle available. He uses the national survey data from 1990 (minus New York City residents) to construct a socio-demographic description of carless households. Crepeau finds that carless households typically do not include people who are in the workforce, have a lower than average income, and are situated in the central cities of urban areas. In addition, they are often made up of elderly people or single adults without children. Most carless households are headed by women (Crepeau 1996). Crepeau also found that recent immigrants are less likely to own vehicles; however, the longer they are in the U.S., the more likely they are to own a vehicle.

3.3.3 Use of Census Data

The census data is the most commonly used source for identifying transit submarkets. McLaughlin and Boyle (1997) use census block group level data to identify the population below the poverty line, the young, the elderly, and households without a car, as well as residential density as a proxy for incentive to use transit.

Grengs (2001) focused on “vulnerable” households; that is, those households who do not have a vehicle or reasonable access to transit. In his development of a measure of accessibility to grocery stores, Grengs relies on U.S. Census topographically integrated geographic data files as well as socioeconomic data. Assuming that census tracts are homogeneous with respect to socioeconomic factors and generally larger than the Transportation Analysis Zones (TAZ), Grengs uses the census data to describe the TAZ, which are his unit of analysis. In a later study, Grengs (2004) measures transit accessibility using block-group level data. He contends that, since access to transit is associated with short distances that might not be well represented using TAZ-level measures, the block-group areas are better suited to a study of transit accessibility. The actual unit of his analysis is a “neighborhood,” which consists of four to six census tracts that meet his definition of being racially isolated and high in poverty. In creating his accessibility measure, Grengs uses the U.S. Census Bureau TIGER files for street, infrastructure, and census tract boundaries; the Economic Census ZIP Code Files for employment and trade service data; and the Census of Population and Housing for demographic and socioeconomic data.

A variety of U.S. Census Bureau products are also used by Kawabata (2003) to assess access to employment by low-skilled workers from zero-vehicle households. Three U.S. metropolitan areas are examined in this research, with the unit of analysis being the TAZ. Kawabata relies on the 1980 Urban Transportation Planning Package and the 1990 Census Transportation Planning Package (CTPP) for employment data (number of workers by job type) and the 5% Public Use Microdata Samples (PUMS) to calculate the percentage of low-skill workers in each occupation category. The PUMS data is identified by the Public Use Microdata Area (PUMA). Because PUMAs are larger than tracts, the author has to aggregate TAZ-level data (the jobs-access measure) in order to make her final comparison of job access to low-skilled workers. The CTPP is also the source for car ownership in this study.

4. Transit Needs

As discussed in Section 2.7, the quality of transit service may be perceived differently by different users because of their specific activity and mobility needs. The questions associated with the differing needs of transit submarkets are especially relevant to the assessment of equity issues of transit service allocation. Where, or what services, do users need access to? When do they need transit service the most? What other transit service needs do they have? Do the needs differ for different user groups? Below, we examine the literature that addresses some of these questions.

4.1 Location and Activity Needs

One way to assess where people need to go is to consider what their travel reveals about where they go already. The 2001 National Household Travel Survey collects data regarding individuals' travel to a wide variety of places, as shown in Table 4-1. This long list of places can be collapsed further into a smaller number of categories as shown in Table 4-2. The list reflects the type of destinations and services that a transit system can potentially access.

Table 4-1. Trip purposes defined in the 2001 National Household Travel Survey

Home	Visit public place: historical site/museum/park/library
Go/Return to work	Other social/recreational
Attend business meeting/trip	Family personal business/obligations
Other work related	Use of professional services: attorney/accountant
Go to school as student	Attend funeral/wedding
Go to religious activity	Use personal services: grooming haircut/nails
Go to library: school related	Pet care: walk the dog/vet visits
Other school/religious activity	Attend meeting: PTA/home owners association/local government
Day Care	Transport someone
Medical/dental services	Pick up someone
Shopping/errands	Take and wait
Buy goods: groceries/clothing/hardware store	Drop someone off
Buy services: video rentals/dry cleaner/post office/car service/bank	Meals
Buy gas	Social event
Go to gym/exercise/play sports	Get/eat meal
Rest or relaxation/vacation	Coffee/ice cream/snacks
Visit friends/relatives	Other
Go out/hang out: entertainment/theater/sports event/go to bar	

Table 4-2. Summary of NHTS trip purposes

To work	Shopping
Work-related	Other family and personal
Return to work	Social recreation
School	Eat meal
Religious	Serve passenger
Medical/dental	Return home

Several other sources suggest other lists of what are the most important or essential places for households to reach. These are summarized in Table 4-3 and described below.

In activity and travel destination analysis studies, researchers typically concentrate on a small number of destinations: work, school, grocery stores, and medical facilities. These can all be considered "essential" purposes. Other destinations that are considered important include religious facilities, social and recreation activities, and public services such as banks and the post office. These seven types of destinations appear to be the minimum necessary destinations for people to lead a "basic" life in society.

Scholars of equity issues have developed their own lists of places to which people should have access. Miller (2003) discusses the UK's Index of Multiple Deprivation. One dimension is called "Geographic Access to Services" and describes the need for people to reach post offices, food shops, basic medical care, and primary schools. Another section of the Index discusses the need for people to reach employment opportunities.

Researchers at the Victoria Transport Policy Institute refer to both inclusion and exclusion when discussing transportation equity (Litman 2004). When discussing inclusion, Litman mentions education, employment, public services, and social and recreational activities. Exclusion, on the other hand, includes not being able to access emergency services (police, fire, ambulance, etc.), health care, basic food and clothing, education and employment (commuting), public services, mail, freight distribution, and social and recreational activities.

Another approach to assess what activity destinations are important for people to access is to ask the people with limited access where they go, and where they would like to go more often if they were less restricted in their travel modes. This is the approach taken by Paaswell and Recker (1976). Their research subjects in Buffalo, New York listed the following five priority activities: friends who do not live in their neighborhood, clothes shopping, grocery shopping, parks, and recreation. Their expanded list of activities include convenience shopping, medical facilities, friends in the neighborhood, banks, religious places, group social activities, school, children's activities, bars, and ice cream and coffee shops.

Table 4-3. Destination needs as suggested in past studies

Destination Analysis Studies	
Employment School Groceries Medical	Religious facilities Social and recreation activities Public services (e.g. banks, post office)
UK Index of Multiple Deprivation *(Miller 2003)*	
Post office Food shop Medical	Primary school Employment
Victoria Transport Policy Institute *(Litman 2004)*	
Education Employment School Park Groceries	Mail and freight Post office Medical Emergency services
Paaswell and Recker *(1976)*	
Friends in and out of the neighborhood Clothes shopping Groceries Parks Recreation/group social activities Convenience shopping	Medical Bank Religious School Bars, ice cream and coffee shops

4.2 Differential Needs Among User Groups

As revealed by many activity-based travel analysis efforts, the activity and travel needs may differ significantly for people of different socio-demographic characteristics. For instance, Schintler et al. (2000) point out that women exhibit more trip-chaining behavior than do men, with over 60% of American women making stops on their way home from work and 25% making more than one stop. The destinations of travel also differ, with women tending more often to visit schools, daycare centers, and shops, while men are more likely to visit restaurants or bars. Age is also an important factor that leads to different travel patterns. In studying the departure time choice for non-work trips, Steed and Bhat (2000) find that, while older individuals are most likely to participate in recreational and shopping activities during the mid-day, employed individuals and students are most likely to do so during the latter parts of the day. Moreover, individuals with very young children (under 5 years) in their households are unlikely to pursue recreational activities during the p.m. peak and evening. In his study that discusses transit service quality specifically from the perspective of older travelers, Burkhardt (2003) used focus groups of older travelers to probe their travel preferences and perceptions concerning transit services. The study revealed that seniors value the following features the most: reliable departure and arrival times, door-to-door service, frequent service, and connection between a wide range of origins and destinations. Comfortable vehicles and waiting areas were also key factors.

The specific needs and demands of different population groups have significant implications on evaluating transit service performance—whether against social equity or other goals. For instance, since women are more likely to combine work and non-work activities into one journey, their value of time may differ from that of men. This difference needs to be reflected in the evaluation of transit service quality. Similarly, as seniors have less tolerance for wait time than other population groups, measure of transit service frequency should be weighted by demographic classes. By reflecting the differential needs of users, as opposed to treating the population as one homogeneous group, transit availability and accessibility measures will be more effective in assessing the service quality as perceived by the transit users.

5. Conclusions

Many performance indicators and measures have been developed and used in the transit industry in response to a wide range of planning and operational goals and objectives. One of the goals that has become increasingly important to the industry is the provision of equitable and “fair” public transport services. This is important because, for certain population groups, access to adequate transit may be the difference between holding a job or not, or between getting poorly paid and better paid work. At the same time, improving the access to areas with a high proportion of transport disadvantaged groups (such as senior citizens, physically challenged individuals, and low income earners) or areas with specific dwelling types (such as high occupancy buildings or public housing) will also help increase the efficiency and the sustainability of the public transport system (Murray et al. 1998). Administrative agencies and transit operators are therefore looking for measures to accurately identify where the disparities in service delivery are and to quantify the severity of the problems so that development projects can be prioritized appropriately to maximize investment benefits in a regionally equitable and cost-effective manner. The measurement outcome may also help provide incentives for continual public funding in transit service.

In this report, we have examined existing performance measures that are relevant to a comprehensive evaluation of service delivery. In particular, we reviewed measures that address the aspects of transit service that are crucial to service delivery: availability, comfort, convenience, and accessibility. We find that common to the studies reviewed is the consideration of the spatial and, to a lesser degree, the temporal dimensions of transit availability. The comfort and convenience level and accessibility of transit service tend to be overlooked.

We have also synthesized literature from the areas of transit planning and activity-based travel analysis to examine the different user groups of transit. We find that the definitions of the transit-dependent, transit-inclined, and choice-users are not always clear and sometimes overlap. However, it is apparent that, depending on their socio-demographic status, individuals have different activity and travel needs and therefore different levels of transit dependency and preference. Of course, one’s sociodemographic status evolves over time and so do the transit needs of the community as a whole. It is therefore important for the transit service delivery to be evaluated in relation to the level and distribution of potential need for the service.

Our overall recommendation for the future development of transit service delivery measures is to emphasize the ease with which people are able to participate in activities they would like to pursue using transit service. This puts service evaluation in the context of demand-supply interaction along the spatial, temporal, and other dimensions, such as comfort and convenience, at the local as well as the network level. Preferably, separate indices should be developed for different population subgroups for different trip purposes. At the same time, there should be a mechanism to consolidate these indices into successively more aggregate measures and ultimately into a single generalized measure that represents the overall service level for a region. The generalized measure will be useful for comparative analysis of equitable distribution between service regions.

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