A Composite Index of Public Transit Accessibility

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Abstract

Measuring ease of access to transit services is important in evaluating existing services, predicting travel demands, allocating transportation investments, and making decisions on land development. A composite index to assessing accessibility of public transit is described. It involves use of readily-available methods and represents a more holistic measure of transit accessibility, integrating developer, planner, and operator perspectives. The paper reviews previous and current methods of measuring accessibility and selects three methods for application in a case study in Meriden, Connecticut. Inconsistencies are noted across the methods, and a consistent grading scale is presented to standardize scores. Finally, this paper proposes weighting factors for individual methods to formulate a composite measure based on individual accessibility component measures. The approach aims to provide a robust and uniformly applicable measure that can be interpreted easily by planners to identify shortcomings in service coverage and promote equity in transit accessibility in the community.

Introduction

Public transit is a key component of a sustainable transportation system that improves systemic mobility and can serve to mitigate the economic and environmental burdens that increased auto ownership can impose on the traveling population. Provision of public transit and infrastructure will not, in itself, fulfill public

transit's potential. The system must be accessible and available to the community and its activity centers and connected with the rest of transportation system. In this paper, we consider accessibility to have three primary components: (1) *trip coverage* - travelers would consider public transit accessible when it is available to and from their trip origins/destinations, (2) *spatial coverage* - travelers would consider public transit accessible when it is within reasonable physical proximity to their home/destination, and (3) *temporal coverage* - a service is accessible when service is available at times that one wants to travel. Another key aspect of public transit service is comfort, which addresses the question: "Is sufficient space available on the public transit at the desired time?" (Kittelson 2003). Hence, there is a need to assess and quantify public transit access considering the three aspects of public transit accessibility—trip, spatial coverage, and temporal coverage, along with comfort.

Accessibility measures aid public transit operators and local authorities in the development of appropriate transit service expansion plans and policies by recognizing mobility needs and identifying service gaps. For assessing public transit accessibility in a region and the comparison of results with the existing methods, a consistent grading scale across the methods is warranted. Measures with consistent grading scales can facilitate the assessment of the distribution and quality of public transit service provided within an area, and a composite measure (properly weighted) can provide a single, representative measure.

This paper proceeds with a literature review of existing transit accessibility measures, highlighting their scale of analysis and the measures used in their calculation. The Methodology section focuses on the three methods used in the development of the composite measure, which is then applied in a case study. The section also provides a standardized scaling option for comparison of the results. The Results section presents output of the comparative analysis and composite measure. The final section concludes the paper with a summary of major findings and some discussion on future adoption of the examined method to improve the performance of accessibility measures.

Literature Review

The attempt to develop public transit accessibility index has been discussed in several studies since the 1950s and continues to receive growing attention in transit sector (Schoon et al. 1999). Different measures have been designed to reflect dif-

fering points of view. A customer demand-oriented methodology incorporating the three important categories of accessibility measures (i.e., trip, spatial coverage, and temporal coverage) might be the best for measuring the quantity and quality of service. Such a method should not view transit as a last-resort option, but as a service that should be available for heavily-traveled corridors because it is a good option for travelers. Any method identifying service quality must consider the populations being served, meaning that one must consider the equity aspects of service configuration. The method should be easily understandable to public transit operators and contain fundamental information about the system and the community it serves.

Some of the existing measures of public transit accessibility focused on local accessibility and considered both spatial and temporal coverage. The *Transit Capacity and Quality of Service Manual* (TCQSM) (Kittelson 2003) provides a systematic approach to assessing transit quality of service from both spatial and temporal dimensions. This procedure measures temporal accessibility at the stops by using various temporal measures. Assessing spatial public transit accessibility throughout the system is carried out by measuring the percentage of service coverage area and incorporating the Transit Supportive Area (TSA) concept. The calculation of service coverage area using the buffer area calculation (available in GIS software) is presented as an option.

The Time-of-Day-Based Transit Accessibility Analysis Tool (hereafter referred to as Time-of-Day Tool) developed by Polzin et al. (2002) is one measure that considers both spatial and temporal coverage at trip ends. In addition to the inclusion of supply-side temporal coverage, this tool explicitly recognizes and considers the demand side of temporal coverage by incorporating the travel demand time-of-day distribution on an hourly basis.

The transit level-of-service (TLOS) indicator developed by Ryus et al. (2000) provides an accessibility measure that uniquely considers the existence and eminence of pedestrian route connected to stops. It also combines population and job density with different spatial and temporal features to measure transit accessibility. Revealing the association of safety and comfort of the pedestrian route to stops makes this method distinctive in the evaluation of public transit accessibility. Another measure that considers the space and time dimensions of local transit accessibility is the public transport accessibility level (PTAL) index developed in 1992 by London Borough of Hammersmith and Fulham (Cooper 2003, Gent et al. 2005). This index measures density of the public transit network at a particular point (origin), using

walk access time and service frequency and integrating the accessibility index (AI) for all available modes of transport from that point.

Schoon et al. (1999) formulated another set of Accessibility Indices (travel time AI and travel cost AI) for different modes between an O-D pair. Travel Time AIs for a particular mode were calculated by using ratio of the travel time of a particular mode to the average travel time across all modes. Cost AIs were calculated in much the same way. The different methods, their coverage of analysis, the incorporated measures, and the most important features of the methods are summarized in Table 1. Fu et al. (2005) proposed an O-D based approach called Transit Service Indicator (TSI) to evaluate transit network accessibility by combining the various temporal attributes (Table 1) into one composite measure. To develop the Transit Service Indicator (TSI) for a single O-D pair, they used ratio of the weighted door-to-door travel time by auto (WTA) to the weighted door-to-door travel time by transit (WTT).

Hillman and Pool (1997) described a measure to examine how a database and public transit planning software (ACCMAP) comprising GIS can be implemented to measure accessibility for local authorities and operators. This software measured local accessibility as the Public Transport Accessibility Level Index (PTAL), using the combination of walk time to a stop and the average waiting time for service at that stop. Network accessibility was measured between an origin and destination, including walk time from origin to transit stop, wait time at stop, in-vehicle travel time, wait time at interchanges, and time spent walking to destination.

There were few studies that paid attention to the comfort and convenience aspect of transit service. The Local Index of Transit Availability (LITA), developed by Rood (1998), measures the transit service intensity or transit accessibility in an area by integrating three aspects of transit service: route coverage (spatial availability), frequency (temporal availability), and capacity (comfort and convenience). Incorporation of comfort and convenience aspect makes this tool distinctive from the passengers' perspective.

Bhat et al. (2006) described the development of a customer-oriented, utility-based Transit Accessibility Measure (TAM) for use by the Texas Department of Transportation and other transportation agencies. Two types of indices were included in this manual to identify patterns of inequality between transit service provision and the level of need within a population: transit accessibility indices (TAI) and the transit dependence index (TDI). The TAI reveals level of transit service supply and considers various elements of the utility measures in transit service. The transit

Table 1. Summary of Previous Transit Accessibility Measures

Study/ Paper	Type of Measure	Reflecting Local Accessibility		Reflecting Network Accessibility	Incorporated Accessibility Measure(s)	Important Feature	Computational Complexity	Intended Users
		Spatial Coverage	Temporal Coverage					
TCQSM (2003)	LOS	Yes	Yes	No	Service Frequency, Hours of Service, Service Coverage, Demographic Data	LOS Concept	Some Technical Skill	Transit Operator Transit User
Polzin et al. (2002)	Time-of-Day tool (Index)	Yes	Yes	No	Service Coverage, Time-of-Day, Waiting Time, Service Frequency, Demographic Data	Time-of-Day Trip Distribution	Transportation Specialist	Transit Planner
Ryus et al. (2000)	TLOS	Yes	Yes	No	Service Frequency, Hours of Service, Service Coverage, Walking Route, Demographic Data	Availability & Quality of Pedestrian Route	Transportation Specialist	Transit Planner Transit Operator
Schoon et al. (1999)	AI (Index)	No	No	Yes	Travel Time, Travel Cost	Travel Cost	Little Technical Skill	Transit Planner Transit User
Fu et al. (2005)	TSI (Index)	Yes	Yes	Yes	Service Frequency, Hours of Service, Route Coverage, Travel Time Components	Weighted Travel Time	Some Technical Skill	Transit Operator
Hillman and Pool (1997)	PTAL (Index)	Yes	Yes	Yes	Service Frequency, Service Coverage	Agg. Travel Time between O-D Pairs	Transportation Specialist	Transit Planner Transit Operator
Rood (1998)	LITA (Grade)	Yes	Yes	Yes	Service Frequency, Vehicle Capacity, Route Coverage	Comfort and Convenience	Little Technical Skill	Property Developer
Bhat et al. (2006)	TAI & TDI (Index)	Yes	Yes	Yes	Access Distance, Travel Time, Comfort & Parking, Network Connectivity, Service Frequency, Hours of Service, Vehicle Capacity	Transit Dependency Measure	Little Technical Skill	Transit Planner Transit Operator Transit User
Currie et al. (2004)	Supply & Need Index	Yes	Yes	Yes	Service Frequency, Service Coverage, Travel time, Car Ownership, Demographic data	Transport Needs Measure	Some Technical Skill	Transit Planner Transit Operator Property Developer

dependence index (TDI) measures the level of need for transit service as a function of socio-demographic characteristics of potential transit users.

A new approach to identify the geographical gaps in the quality of public transit service was developed by Currie (2004). This "needs gap" approach assesses the service of public transit by comparing the distribution of service supply with the spatial distribution of transit needs. Another study by Currie et al. (2007) quantifies the associations between shortage of transit service and social exclusion and uniquely links these factors to the social and psychological concept of subjective well-being. This study investigates the equity of transit service by identifying the transport disadvantaged groups and evaluating their travel and activity patterns.

Objectives and Organization

The objective of this paper is to describe a method for quantifying public transit access that combines existing public transit accessibility indices to harness the positive features of each. For the development of a performance/accessibility measure, Transit Cooperative Research Program (TCRP) Report 88 (Kittelson et al. 2003) identified eight categories of performance measures (travel time, service availability, service delivery, safety & security, maintenance & construction, economics, transit impact, and capacity) based on underlying goals and objectives of different transit users. The categories are overlapped to some extent and, hence, require some distinct broad categorization (Bhat et al. 2006). Three methods (LITA, TCQSM, and the Time-of-Day Tool) have been selected to assure that three primary accessibility measures (trip, spatial coverage, and temporal coverage) are being considered. The three methods, individually and collectively, are applied to Meriden, Connecticut, as a case study. The results are compared and contrasted for consistency, completeness, and clarity. Finally, this paper evaluates weighting schemes for individual factors for their inclusion in the composite index.

Methodology

The method presented seeks to leverage less data-intensive methods for measuring public transit accessibility into a single, composite index. For simplicity in calculation, more sophisticated probabilistic modeling methods are not incorporated; the composite index presented requires only straightforward calculations and use of some basic GIS software commands. Selection of methods also considers the intended user of this product and the limitation of data sources. This paper

selected existing measures that can address public transit accessibility from differing perspectives (transit planner, transit operator, traveler, and property developer). On this basis, three methods (LITA, TCQSM and Time-of-Day Tool) were selected to characterize the three transit accessibility coverage (trip, spatial coverage, and temporal coverage) aspects.

Analysis was conducted on the 17 census tracts of Meriden. Accessibility calculations were carried out for three (A, B, and C) public bus routes throughout the city provided by CTtransit. The local bus route network and stop locations for this city are shown in Figure 1. The three methods, their data sources, reasons for selection of these particular methods, the intended users, and scales of analysis are explained below.

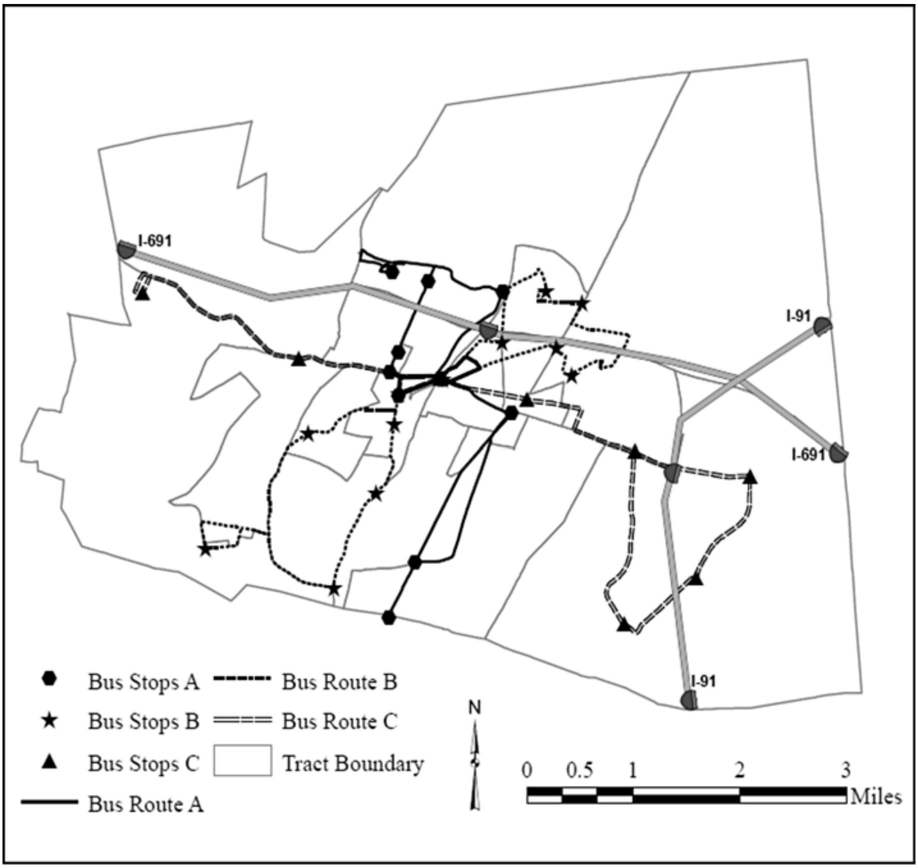

Figure 1. Three local bus routes and stop locations in Meriden, Connecticut.

Method 1: The Local Index of Transit Availability (LITA)

LITA (Rood 1998) measures the transit service intensity of an area, and two basic types of data are required: transit data and census data. Transit data include full route maps and schedules of all transit lines serving the study area, locations of transit stops, and transit vehicle capacities. Census data encompass total land area, resident population, and number of employees in each tract. All transit data were collected from the transit provider, and census data are from the U.S. Census (2000).

This method considers the comfort and convenience facet of transit service by appending the vehicle capacity measure in calculation. LITA scores are intended to be useful to property developers by revealing where transit service is most intense and to aid in the development of land use plans and policies for areas with different levels of transit accessibility. LITA scores can be calculated for any unit of land area (i.e., census tract, traffic analysis zone, etc.), depending on the availability of transit and census data.

Method 2: Transit Capacity and Quality of Service Manual (TCQSM)

TCQSM (Kittelson 2003) incorporates a service coverage measure to assess transit accessibility and requires the same datasets (transit and census data) as LITA. Two methods are used to calculate the service coverage: the GIS method and the manual (graphical) method. For this research, a detailed GIS method was used as it requires less effort to calculate the service coverage area than the manual method, which requires overlying of different maps (i.e., study area map, transit map, etc.). To identify the spatial service coverage area, a 0.25-mile radius buffer area is applied around transit stops. This method was selected for this research to account for spatial coverage in public transit accessibility assessment. TCQSM offers a comprehensive guide for use by the transit operators to make decisions for infrastructure enhancements that could enrich the level of accessibility to the transit system. This method provides the scale of accessibility measure from individual bus stops to individual routes to the entire transit system.

Method 3: Time-of-Day Tool

The Time-of-Day Tool (Polzin et al. 2002) measures transit service accessibility using time-of-day travel demand distribution and provides the relative value of transit service provided for each specific time period. This tool requires data on temporal distribution of travel demand on an hourly basis in addition to the transit and census data required for the previous two methods. The time-of-day distribution of travel demand data and a daily trip rate of 4.09 trips per person were adopted from the 2001 National Household Travel Survey (NHTS). Tolerable

wait time was defined as 10 minutes in accordance with NHTS data. The fractional distribution for each tract that falls within the 0.25 mile buffered transit route was calculated using GIS software.

The Time-of-Day Tool was considered by this paper as the only tool to account for time-of-day distribution of travel demand and reflect the temporal coverage of transit accessibility. The calculation and interpretation of data from several different sources makes this tool more difficult to use and requires some transportation expertise. In spite of having complexity in calculations and difficulty in comparison of accessibility results with other methods, this tool is as straightforward as we found for covering temporal accessibility. This measure is important to public transit planners in determining the importance of transit service provided in each time period of the day. The tool can assess the degree of accessibility of a transit system for an individual zone or at the census tract level, depending on the availability of transit and census data.

Scaling

One purpose of this paper is to examine how consistently the three methods rated transit accessibility for each tract of study area. To do this, accessibility grades from each method were compared for each census tract. This presented some problems, as the results were given on three different scales. In LITA, the overall scores obtained from three standardized scores (frequency, capacity, and service coverage) were rescaled by adding five for greater ease of interpretation. Then, the rescaled LITA scores were assigned to five grades (as shown in Table 2), A through F (excluding E). Grade A corresponded to a LITA+5 rating of 6.5 or higher, indicating the highest level of accessibility.

Table 2. Existing Scaling of Three Methods and the Developed Consistent Grading Scale

Grading Scale of Three Methods			New Consistent Grading Scale	
LITA+5 Score Scale Range (Grade)	*TCQSM Score Scale Range (LOS)*	*Time-of-Day Tool*	*Scale Range*	*Grade*
≥ 6.5 (A)	90.0 – 100.0% (A)	No Grading Scale	≥ 1.50	A
5.5 – 6.5 (B)	80.0 – 89.9% (B)		0.75 to 1.49	B
4.5 – 5.5 (C)	70.0 – 79.9% (C)		0.00 to 0.74	C
3.5 – 4.5 (D)	60.0 – 69.9% (D)		-0.75 to -0.01	D
< 3.5 (F)	50.0 – 59.9% (E)		≤ -0.76	F
	<50.0% (F)			

TCQSM adopted the level-of-service (LOS) concept, introduced in the *Highway Capacity Manual* (HCM) (Transportation Research Board 2000), for measuring quality of transit service. Scores were measured as the percentage of service area covered by transit system and were grouped in six LOS, A through F, as shown in Table 2. The Time-of-Day-based transit accessibility analysis tool measures transit accessibility by the number of daily trips per capita (in each census tract) that are exposed to transit service. The Time-of-Day Tool did not characterize the accessibility results with any grading system as LITA and TCQSM did.

For a more consistent comparison of accessibility results, the calculated scores for the TCQSM and Time-of-Day Tool methods were standardized (as in LITA) across all the census tracts for relative accessibility scores. To get the standardized score for a tract in a method, first, the difference between the raw score for this tract and the mean of scores for all tracts was calculated, and then the difference was divided by the standard deviation of scores for all tracts. For ease of interpretation of these standardized scores, this paper develops a common grading scale (as shown in Table 2) with five grades A through F (excluding E). Grade A represents a score of +1.5 or higher, indicating the highest level of accessibility, and grade F represents a score lower than -0.75, indicating poor level of accessibility. As an example, the detailed process of standardizing the scores and assigning grade to the standardized scores for census tract 1702 is shown in Table 3. In LITA, the raw score (as shown in Table 3) was already standardized, but for this paper, we ignored the concept of rescaling (i.e., adding 5 to the standardized scores to make all scores positive).

Table 3. Example of Standardization of Raw Scores for Different Methods

Standardization	LITA	TCQSM	Time-of-Day Tool
Raw Score for Tract 1702 (Grade)	5.465 (C)	62.36 (D)	0.0229 (No Grade)
Mean of Scores for All Tracts	-	41.93	0.0113
Std. Deviation of Scores for All Tracts	-	30.55	0.0081
Standardized Score for Tract 1702 (Consistent Grade)	0.465 (C)	0.668 (C)	1.44 (B)

The development of the composite index on the basis of the three selected methods comprises several steps. First, the raw scores were standardized for each method, as mentioned earlier. Next, the accessibility metrics used for calculations across the three methods were identified (see Table 4). Individual weighting factors (WF) were then assigned to each of the individual measures. The summation of all weighting factors for the individual measures was assigned as the final weighting factor for each method.

Table 4. Development of Weighting Factors (WF)

Methods	Accessibility Metrics	Scheme # 1 Metric Weight	Scheme # 1 Method Weight	Scheme # 2 Metric Weight	Scheme # 2 Method Weight	Scheme # 3 Metric Weight	Scheme # 3 Method Weight
Time-of-Day Tool	*Service Coverage*	1	5	3	9	⅓	10/3
	Service Frequency	1		2		½	
	Demographics	1		2		½	
	Travel Demand	1		1		1	
	Waiting Time	1		1		1	
LITA	Service Coverage	1	4	3	8	⅓	7/3
	Service Frequency	1		2		½	
	Demographics	1		2		½	
	Capacity	1		1		1	
TCQSM	Service Coverage	1	1	3	3	⅓	1/3

Three weighting schemes were considered to assign weighting factors to the measures. Scheme # 1 assigns a WF of 1 to all measures; in Scheme # 2, WF were allotted according to the occurrence of a measure in the methods (i.e., if a measure is common in all the three methods, then its weighting factor was assigned as 3). Scheme # 3 assigns the WF such that the weights for common measures sum to 1 and unique measures simply receive a weight of 1. The weighting factors of individual elemental measures and the total weighting factors for the three methods are shown in Table 4.

Results

Table 5 depicts the accessibility results for all census tracts in original scales for each method. With the actual scales for an individual method, one can interpret the accessibility results according to that method's grading system. Table 5 shows that the obtained results vary greatly across the methods. To get a comparable picture of accessibility using the results of these methods, the results must be interpreted in terms of the applicable scale. Furthermore, the accessibility results of the Time-of-Day Tool cannot be compared with the other methods because it does not provide any grading or scaling system by which one can easily interpret or compare the accessibility results. Thus, for a meaningful comparison of transit

accessibility between the tracts that can be easily understood, this paper standardizes the results, providing a picture of the relative difference in accessibility between methods. The results of the standardized scores shown in Table 5 provide less variable results across methods.

Table 5. Comparison of Results in Raw Scores and Standardized Scores for Three Methods

Census Tract	Raw Scores					Standardized Scores					
	Time-of-Day Tool Score (Daily Trips per Capita)	*LITA Score (Rescaled Overall Score, Grade)*		*TCQSM Score(% of Service Area Served, LOS)*		*Time-of-Day Tool Score,Grade*		*LITA Score, Grade*		*TCQSM Score, Grade*	
1701	0.0273	12.97	A	76.89	C	1.976	A	7.973	A	1.144	B
1702	0.0229	5.46	C	62.36	D	1.44	B	0.465	C	0.668	C
1703	0.0119	3.99	D	40.94	F	0.88	C	-1.001	F	-0.032	D
1704	0.0028	3.45	F	5.23	F	-1.03	F	-1.545	F	-1.201	F
1705	0.0025	4.25	D	11.39	F	-1.072	F	-0.742	D	-0.999	F
1706	0.0062	4.83	C	21.37	F	-0.614	D	-0.161	D	-0.673	D
1707	0.0125	4.85	C	50.65	E	0.162	C	-0.146	D	0.285	C
1708	0.0097	5.25	C	29.21	F	-0.182	D	0.25	C	-0.416	D
1709	0.0196	7.69	A	83.09	B	1.036	B	2.694	A	1.347	B
1710	0.0220	4.72	C	69.63	D	1.327	B	-0.272	D	0.906	B
1711	0.0065	4.20	D	17.10	F	-0.581	D	-0.792	F	-0.812	F
1712	0.0041	3.71	D	13.42	F	-0.876	F	-1.286	F	-0.933	F
1713	0.0086	4.80	C	39.53	F	-0.316	D	-0.194	D	-0.078	D
1714	0.0170	8.16	A	91.28	A	0.712	C	3.164	A	1.615	A
1715	0.0133	5.42	C	83.51	B	0.2586	C	0.42	C	1.361	B
1716	0.0028	4.50	C	14.24	F	-1.03	F	-0.492	D	-0.906	F
1717	0.0007	1.97	F	2.91	F	-1.298	F	-3.023	F	-1.277	F

The standardized scores shown in Table 5 do still show some variation across the methods (e.g., census tracts 1703, 1710, and 1714). Table 6 presents the grades for the composite accessibility scores using the different weighting schemes from Table 4. As an example, in order to calculate the composite score for census tract 1702 in Scheme #1, first, the standardized scores for three methods (1.44, 0.465, and 0.668 from Table 5) were multiplied by the method weights (5, 4, and 1, respec-

tively, from Table 4). After that, the sum of these multiplied scores was averaged over the sum of method weights, and the composite score was found as 0.97, which lies in between the range of 0.75 to 1.49 (Table 2) and was assigned as accessibility grade B (Table 6).

Table 6. Comparison of Results for Three Schemes and Grades for Composite Measure

Census Tracts	Composite Grade		
	Scheme #1	*Scheme #2*	*Scheme #3*
1701	A	A	A
1702	B	B	B
1703	C	D	C
1704	F	F	F
1705	F	F	F
1706	D	D	D
1707	C	C	C
1708	D	D	D
1709	A	A	A
1710	C	C	C
1711	D	D	D
1712	F	F	F
1713	D	D	D
1714	A	A	A
1715	C	C	C
1716	F	F	F
1717	F	F	F

The results shown in Table 6 indicate that the composite scores are consistent across the schemes, and the only difference is that Scheme #2 is somewhat more conservative in grading, specifically census tract 1703. In Scheme #1, each individual measure is treated equally, and the presence of a particular measure in all methods gives it additional weight in the combination process. Scheme #2, defined in Table 4, evaluates transit accessibility addressing the spatial aspects (service coverage) extensively, and Scheme #3 reflects emphasis on the temporal dimension of transit accessibility measures. In Scheme #3, temporal distribution of travel

demand and service frequency are used to calculate the transit accessibility more heavily weighted than the spatial data. Therefore, three combinations of accessibility measures (spatial, temporal, and both spatial & temporal) were considered in developing the different schemes.

Spatial Distribution of Accessibility Results

TCQSM considers a much smaller coverage area than the other two methods. While there is broad agreement that the best coverage is concentrated in a relatively small area (which is expected, given the service map in Figure 1), there is disagreement on the extent for the middle of the accessibility spectrum (Figure 2). LITA considers a much larger area to have moderate accessibility, but this may be due, in part, to its target audience: developers. LITA is designed to broadly identify good investment possibilities near transit, leaving more detailed analysis to those regions a developer may want to target. TCQSM is concerned with spatial coverage only and, therefore, follows the layout of lines and stops closely. The Time-of-Day Tool considers measures of demand, which reflect that some tracts that are not well-covered spatially may, in fact, serve high demand populations. It is important to remember that these scaled versions are comparing a particular tract against the average measure for the entire system. These values are not absolute.

Comparative Example

Figure 2 maps the grades of accessibility scores across methods and illustrates the grading scale of the accessibility scores. This graphical view shows relative accessibility intensity, which is helpful for the comparison of accessibility between different tracts. Three census tracts (1703, 1710, and 1711) chosen to represent difference in accessibility intensity across the methods are indicated in Figure 2. LITA represents lower scores for tracts 1703 and 1710 than the other methods. This method provides a relatively lower score to the densely populated smaller area (already-developed area) and gives a moderate accessibility result to the larger areas (census tracts 1705 and 1716, Figure 2). This is due primarily to the intended users' viewpoint of this method. A higher LITA score for a census tract indicates that this tract has more potential for future transit oriented development or redevelopment.

The TCQSM method results in higher accessibility scores than the LITA method for census tracts 1703 and 1710. TCQSM is intended to characterize transit accessibility generally by the existence of transit stops and transit lines in the service area and counts for the percentage of 0.25-mile radius buffer area around the bus stops exist in area. Therefore, census tract 1703 results in a higher accessibility score in TCQSM than in LITA.

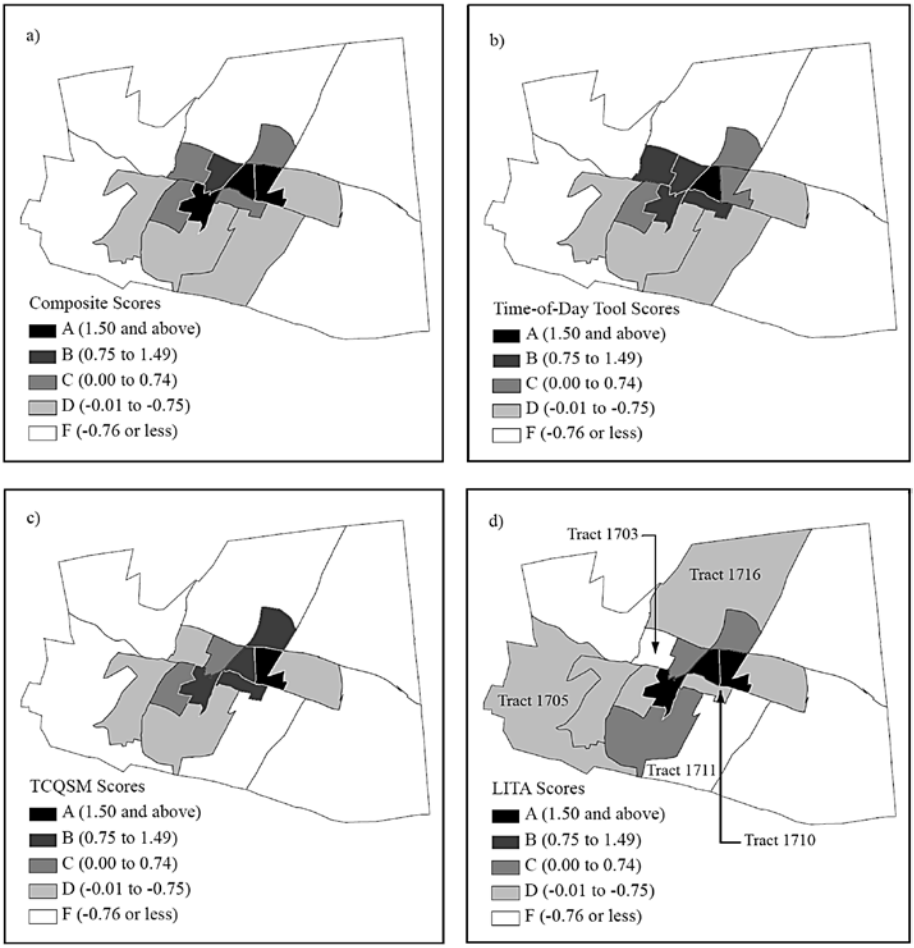

Figure 2. Accessibility scores for different methods: a) Composite, Scheme #1; b) Time-of-Day Tool; c) TCQSM; d) LITA.

The Time-of-Day Tool considered time-of-day travel demand distribution for an area and did not consider the spatial distribution of transit routes as in TCQSM. Tract 1711 appears as a moderately-accessible tract in the Time-of-Day Tool, but this tract has poor accessibility in the TCQSM and LITA methods. This reveals that some tracts that have poor spatial coverage of transit may have considerable temporal coverage to serve the high demand population for this tract.

The composite scores (Scheme #1) mapped in Figure 2 provide a single accessibility score for tracts that show variability between methods. This score represents three

stakeholder perspectives and, if a single metric is to be used, may be a more robust measure than one of the individual methods.

Conclusions

This paper examined the benefit of a consistent grading scale across different stakeholder groups and formulated a composite accessibility measure. Individual accessibility results were calculated to examine consistency in the results as well as in the grading scales across methods. The composite accessibility measure was developed by integrating three methods, which may be useful as a reliable and defendable measure for stakeholders (i.e., if the composite index obtained from three simple methods indicates high accessibility in an area rather than from one single method, then it is likely that the area truly is highly accessible). From the perspective of policy makers, an assessment of transit accessibility must consider different user viewpoints (i.e., transit planner, provider, property developer, etc.). Therefore, this composite measure is intended to combine the three simple methods that encompass several user perspectives. This paper standardized individual raw scores and adopted a common grade scale. Several permutations of a combined weighting scheme were tested. This paper helps planners select a set of accessibility measures and presents a method of combining them to produce a more defensible and robust accessibility result for their customers. The results of a composite measure can be taken as a basis for adjusting the priorities of public transport services and addressing lack of service in public transport provision. The composite index provides a relative accessibility measure of the degree to which transit is reasonably available at the origin of a trip. This information is important for zonal service equity analysis and understanding transit supply provision in the community.

The limiting feature of this research is that this method cannot be directly generalized to all areas or to those that need to measure the level of transit accessibility with methods that are more sophisticated. This composite accessibility result cannot reflect the changes in accessibility level for the micro-level changes in socio-economic and demographic characteristics (i.e., car ownership, income level, etc.) of transit users. In addition, the composite accessibility index can have different meanings in different areas. The most significant limitation of this method is that it is limited in its ability to determine real accessibility of an area, as it does not consider the transit user beyond the quarter-mile buffer of a stop location.

Further development and refinement of the measure would be useful in several areas. In addition to the accessibility measures in this study, a needs gap (Currie 2004, Bhat et al. 2006) assessment in transit service would address the transportation disadvantaged population and its relationship to systemic spatial coverage.

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