ASSESSING AND QUANTIFYING PUBLIC TRANSIT ACCESS

March 2014

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16. Abstract

Measuring 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 for 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 research reviews previous and current methods of measuring accessibility and selects three methods for application in a case study in Meriden, CT. Inconsistencies are noted across the methods, and a consistent grading scale is presented to standardize scores. This research proposes weighting factors for individual methods to formulate a composite measure based on individual accessibility component measures.

Integrating transit needs into transit accessibility indexing is considered in this research for the evaluation of existing transportation systems and service gaps and for the identification of priority areas for future investments in transportation infrastructure. An accessibility-based transit need indexing model is detailed that focuses on the necessity of evaluating transit needs and transit accessibility simultaneously. A need index is developed to identify areas in high need of public transit services using economic and socio-demographic information. The need for transit service is then modeled as the lack of transit accessibility and correlates different access indicators with their ability to predict transit service need. This model maps areas with different levels of transit accessibility and transit needs using a single score, which may be easily interpreted by planners examining transit equity. The model has been applied to the city of Meriden and New Haven, CT and results have been compared with a general approach for consistency and effectiveness. The research also highlights the model's usefulness through a representative example of its application.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

Measuring access to transit services is important in evaluating existing services, predicting travel demand, allocating transportation investments and making land development decisions on land. A composite index for assessing accessibility of public transit is described in the first portion of this report. Its results are intuitive – better access tends to follow more comprehensive service – though it is the first step in working to establish a transit access performance measure. This measure can be used to passively track system access, it can also be used to make decisions on resource allocation – targeting populations that currently lack service or have high need of public transportation service.

The methodology developed uses simple calculations and data that currently exists and yet represents a more holistic measure of transit accessibility integrating developer, planner and operator perspectives. The research reviews previous and current methods of measuring accessibility and selects three methods for application in a case study in Meriden, CT. Inconsistencies are noted across the methods, and a consistent grading scale is presented to standardize scores. This research proposes weighting factors for individual methods to formulate a composite measure based on individual accessibility component measures.

Integrating transit need (i.e. service gaps) into measuring transit accessibility indexing is useful for the identification of priority areas for future investments in transportation infrastructure. An accessibility-based transit need indexing model is detailed in the second portion of the report that focuses on the necessity of evaluating transit needs and transit accessibility simultaneously. A need index is developed to identify areas in high need of public transit services using economic and socio-demographic information. The need for transit service is then modeled as the lack of transit accessibility and correlates different access indicators with their ability to predict transit service need. This model maps areas with different levels of transit accessibility and transit needs using a single score. The model is applied to the cities of Meriden and New Haven, CT and compared to existing approaches for validating consistency and effectiveness. The research also highlights the model's usefulness through a representative example of its application.

1.0 INTRODUCTION

1.1 RESEARCH PROBLEM STATEMENT

Rapidly increasing fuel prices and environmental awareness have prompted heightened interest in and usage of Connecticut's public transportation system. As evidence, between 2010 and 2011 CTTransit saw a 3.9% increase in transit trips, eclipsing the annual goal of 25 million trips (CTDOT 2011). These events remain at the forefront of the public consciousness and have necessitated increased investment in and expansion of the public transportation system. This result is certainly a silver lining, as an increased investment in public transportation provides many benefits: a sustainable, reliable transportation alternative; a means to increase capacity of the transportation system; a means to manage highway congestion in the long term; and a way to achieve more desirable growth patterns.

Public transportation is not a panacea for concerns with environment, energy, or sustainability. Building public transportation infrastructure alone will not fulfill public transportation's potential. Transit service is unlikely to be utilized as a mode of travel if there is lack of access to the service and the system is not available to potential transit riders. One must connect these systems to the community and the rest of the transportation system. When proper access is provided to public transportation, the system can begin to cultivate a ridership base beyond captive riders and grow as an integral part of the entire transportation system.

There is need for a method to assess and quantify the degree to which public transportation access is currently provided to travelers in Connecticut to identify under-connected areas within a community or region. Recognizing mobility needs and quantifying the level of access to the service will aid in measuring service gaps and for the identification of priority areas for future investments in public transportation infrastructure. The results of this research can also be used to identify areas that currently have public transportation service, yet lack optimal access to the service; spatially, temporally, and with respect to travel demand.

1.2 URGENCY

Connecticut is committed to its public transportation system and infrastructure. For this investment to best serve the traveling public attention needs to be paid now to identify the population with the greatest need for public transportation service along with the corresponding level of access the system provides. The level of access should incorporate the traditional spatial and temporal measures of service coverage alongside concepts such as system connectivity. For public transportation to serve as a crucial, sustainable element of the transportation system ridership must be cultivated though quality, reliable service convenient to users.

Investing now in quantifying access to Connecticut public transportation as a function of spatial, temporal, and demand coverage can play a crucial part in the future success of the system. The tool that will be developed as a product of this research will allow Connecticut transit planners to identify areas in need of transit coverage the corresponding transit need for the particular region.

Good access will encourage travelers to get out of their cars and take the bus or train, helping manage highway congestion. Access to public transportation, correctly measured, can potentially serve as a performance metric to track the availability of service over time. Increased ridership due to improved access to potential transit users may encourage higher property value and dense development about the station, providing the foundation for transit oriented development in highly utilized corridors. Finally, providing good access can help further the goals of the Connecticut transportation system of providing a safe, quality, highly reliable option for travelers.

1.3 RESEARCH OBJECTIVES

The objectives of this research effort are as follows:

- Investigate the current state of the practice of quantifying public transportation access;
- Develop a method for quantifying public transit access that combines existing public transit accessibility indices;
- Develop a transit need measure to identify areas in high need of public transit services;
- Develop an accessibility-based need measure to identify service gaps;
- Apply this accessibility-based service gap measuring approach to a selected Connecticut public transportation corridor as a pilot study;

It should be noted that this study focuses on bus service, however, the methods presented are applicable to rail services provided mode-specific parameters are adjusted (i.e., station coverage buffer distance).

1.4 REPORT ORGANIZATION

This research report contains six chapters including this first introductory chapter. Chapter 2 provides information on the Transit Planner/Provider Survey and discusses what the purpose of this survey is, the findings of survey, and implications of the survey results. Chapter 3 describes the development of a composite accessibility measure. This chapter provides a review of the literature on previous and current indices for measuring transit service accessibility and develops a composite measure considering three important accessibility aspects for assessing transit service accessibility.

The approach utilized for measuring service gaps between transit access and the need for service is presented in Chapter 4. This chapter details an accessibility-based transit need indexing model for measuring service gaps. This model maps areas with different levels of transit accessibility and transit needs using a single score

Both the composite transit accessibility index calculation (Chapter 3) and the accessibility-based transit need indexing model (Chapter 4) have been applied to the public transit system of Meriden, CT. Chapter 5 applies the latter to a larger metropolitan area, New Haven, CT. This chapter is devoted to the validation of this approach.

Conclusions and future research options are presented in Chapter 6. A brief review of results and the potential applications of developed measure to a variety of transit users are described. A wide variety of future research questions and suggestions for further refinement of the accessibility-based service gap measuring tool are also identified.

2.0 TRANSIT PLANNER/PROVIDER SURVEY

This chapter provides information on Transit Planner/Provider Survey and discusses the purpose of this survey, survey findings, and implications of the survey results. This survey is conducted to investigate current public transit planning practices and identify needs at the state, regional and local levels and is designed to collect information on public transportation service planning methods and data needs in the state of Connecticut.

2.1 PURPOSE OF THE SURVEY

This survey is designed to investigate provider's current service information, methods used to collect transit data, and their different coordination activities with other transit agencies. Such data can support analyses for the assessment of current service and provide future coordination options to improve access to public transit. It is a goal of this survey to identify the resolution and consistency of data needs and strategies that could be employed to increase the efficiency of transit data collection.

The objectives of the Transit Planner/Provider Survey were to:

- Develop an assessment of current transit service provided by different agencies in Connecticut by investigating service span, capacity of service, spatial resolution of service and the types of transit data collected and used.
- Evaluate existing coordination activities in transit services at different levels and identify possible coordination activities in order to improve the service access.
- Identify the source of travel demand data and the type of socio-economic and demographic data used by the transit planners in their transit planning model.
- Outline the relative importance of different accessibility measures used to measure transit accessibility for a service area.
- Identify the most critical gaps/unmet needs in existing transit services and the barriers/challenges to accomplish the unmet needs in transit services.
- Obtain future guidelines/strategies that could be employed for improving and enhancing the access to public transit services.

2.2 SURVEY FINDINGS

Important findings from this survey include the following:

- Most of the transit providers collect transit data at service route level and some agencies collect transit data at census tract and regional level. Very few agencies collect transit data using an origin-destination (O/D) study, mostly this is accomplished by ride checking and electronic registering fare boxes.
- This survey identified barriers to coordination activities of public transportation services.

Lack of Funding: Limited resources may prohibit some agencies from providing transportation services under contract to other agencies. It may also preclude some agencies from picking up additional riders.

Lack of Connectivity: There is limited connectivity between the multiple public transportation providers within the region. For example, absence of one-fare payment system between providers.

Lack of Coordination: Lack of coordination and cooperation among different type of transit services in different districts creates problems in transfer from one service to another.

Organizational Issue: Some coordination activities, such as consolidation of operation with transit agencies or purchase of services from another organization are under the purview of Connecticut Department of Transportation.

Coordinating connections: Frequent change of schedule for MTA transit service results in a barrier to some extent in providing connection information to CT travelers.

- Only one respondent replied that it used O-D travel demand data in their planning model. It also incorporates car availability data, household income and land use data in its travel demand modeling approach.
- ‘More frequent service and better service span’ was found as the most important measure for assessing transit accessibility and ‘more parking availability’ was found as the least important accessibility measure.
- The majority of respondents listed the following unmet transportation needs in their jurisdictions.
  - Adequate transit route connection to the job centers and sufficient access between developments and transit services.
  - Increased frequency, decreased headways, expanded service hours, dedicated transit stops and corresponding schedules.
  - Enhanced inter-district transit route connections and integrated fare collection/fare policy
- Some of the respondents recommend that it is necessary to evaluate the long- term viability of transit routes and stop locations based on passenger boarding information. Respondents recognized that better coordination and planning of land use and public transportation service could maximize access to the public transit services.
- Respondents identified several strategies where they would like to emphasize to increase the efficiency of transit services.
  - Continuous evaluation of existing and new stop locations (i.e. trip origins and destinations)
  - Periodic reviews of transit route performance on the basis of ridership, revenue collection and productivity.
  - Operational analysis of different comparative transit services for a service area.

Survey questionnaire and the details on summary of responses are listed in **Appendix A** and **Appendix B** respectively.

2.3 IMPLICATION OF RESULTS

As the transportation industry moves toward performance-based system management, it is very important for transportation and transit agencies to establish general performance indicators to evaluate their overall quality of service. This is a large and difficult task – something many operators and managers have realized and have been working on for some time. It was a necessary in this study to first identify the current state of the practice prior to suggesting the implementation of any particular performance measures for transit systems. This survey and report seek to meet this need.

Access to transit service is a key component in the evaluation of service quality as it can be used to investigate the quality and affordability of transit options, system connectivity and land use patterns simultaneously. Developing such a measure is one thing –a measure that can be implemented by operators, managers and planners requires an understanding of service planning methods and data needs. This survey's results provide insight to which data might be best (from a practical standpoint) to include in such a measure of access. The results further identify available data on service coverage, hours of operation and the current capacity of the transit services as providing an understanding of level of service. Information on methods of data collection and the resolution level of transit data helps identify the possible sources and quality of data used in planning and applying performance measures.

Coordination of public transportation services is encouraged at the local, regional and statewide level, in part through the Connecticut Public Transportation Commission and its charge in Connecticut General Statutes section 13b-11(c). This survey addressed the coordination activities that currently exist, the coordination activity that transit agencies are interested in undertaking and their associated barriers. This survey also provides information on the type of socioeconomic and demographic data that were used by planners in their demand models. The significant unmet transportation needs are identified (see Table 2.1). Respondents recommended that identification of groups of people that need public transit services is important and that providing service to those who need this service can increase access to community events and jobs.

Table 2.1: Unmet Transportation Needs

Unmet Transportation Needs
Lack of funding to allow expansion of transit service
Poor bus route connection to job centers, need enhanced inter-district connections
Adjusted frequency of local service to enable service to interface with rail and other bus service
Lack of transit service for elderly & disabled service
Lack of ability to transfer passengers from one service agency to another locally and statewide.
Increased frequency/decreased headways, dedicated transit stops and corresponding schedules
Integrated statewide fare policy/ fare collection technology
Real time travel information- delays, location, next arrival (for commuter rail)

Results on the relative importance of different accessibility measures provide a framework for the incorporation of those measures in an accessibility model, or a performance metric. Table 2.2 provides the relative importance of different accessibility measures obtained from responses to the survey. The survey respondents identified ‘More frequent service and better service span’ as the most important measure for assessing transit accessibility and ‘more parking availability’ the least important.

Table 2.2: Ranking of Accessibility Measures (1= the Most Important and 10 = the Least Important)

Accessibility measures	Ranking
More Frequent Service and Better Service Span	1
More Bus Routes and Stops and More Areas Served	2
Better Pedestrian Access to/from Stops	3
Better On-time Performance	4
Safer Environment at Stops and Shelters	5
Better Serving Disadvantaged Population (i.e., Limited Income, Poor English Proficiency)	6
Encouraging Interaction Across Modes (i.e., Bike Racks)	7
Trip Coverage	8
Stop Area Development Density	9
More Parking Availability	10

The major themes of the survey results included a lack of coordination activities between different transit stakeholders and the need for current, reliable data for evaluating transit service performance. Respondents identified several coordination activities for promoting public transit commuting and suggested that an accessibility measure needed to be comprehensive and sensitive to the data available. Furthermore, they indicated that this measure should be easily understandable and contain fundamental information about the system (i.e., service characteristics) and the community it serves. The following chapter describes the development of a composite accessibility index attempting to meet this need.

3.0 COMPREHENSIVE TRANSIT ACCESS

An accessibility measure incorporating different coverage aspects can aid public transit operators and local authorities in evaluating the overall quality of service currently being provided. A consistent and understandable grading scale across different existing methods can help compare public transit access across a region (such as the State of Connecticut). Ideally, a measure of access will capture the most important features of the system (spatial proximity, service frequency, connectivity) that a relevant to a variety of perspectives (operator, planner, traveler)

This chapter commences with a summary of existing transit accessibility measures, highlighting their scale of analysis and the aspects used in calculation. The following section focuses on the three indices used in the development of the composite measure, which is then applied in a case study. This section also provides a standardized scaling option for comparison of the results based on established methods. The results section presents output of the comparative analysis and composite measure.

3.1 EXISTING ACCESSIBILITY MEASURES

The attempt to develop public transit accessibility indices has been discussed in several studies since the 1950s and continues to receive growing attention in the transit sector (*Schoon et al. 1999*). Different measures have been designed to reflect differing points of view. A customer demand-oriented methodology incorporating the three important categories of accessibility measures (i.e., spatial coverage, temporal coverage, and comfort) 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.

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 (Table 3.1). 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 (Table 3.1) 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 and Symonds 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.

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). 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 3.1.

Hillman and Pool *(1997)* described a measure to examine how a database and public transit planning software (ACCMAP) 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.

Table 3.1: 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					
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
Rood (1998)	LITA (Grade)	Yes	Yes	Yes	Service Frequency, Vehicle Capacity, Route Coverage.	Comfort and Convenience	Little Technical Skill	Property Developer
Schoon et al. (1999)	AI (Index)	No	No	Yes	Travel Time, Travel Cost	Travel Cost	Little Technical Skill	Transit Planner Transit User
TCQSM (2003)	LOS	Yes	Yes	No	Service Frequency, Hours of Service, Service Coverage, Demographic data.	LOS Concept	Some Technical Skill	Transit Operator Transit User
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
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
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
Currie et al. (2004)	Supply Index & 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
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	Transportation Specialist	Transit Planner Transit Operator Transit User

Bhat et al. *(2006)* described the development of a customer-oriented, utility-based Transit Accessibility Measure (TAM) for use by TxDOT 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 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 Graham 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 social and psychological concept of subjective well-being. This paper investigates the equity of transit service by identifying the transport disadvantaged groups and evaluating their travel and activity patterns.

3.2 DEVELOPING A COMPOSITE INDEX

The composite index presented in this section seeks to leverage less data-intensive methods for measuring public transit accessibility into a single 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 limitation of data sources. This paper selected existing indices which can address public transit accessibility from differing perspectives (i.e. transit planner, transit operator, the traveler and the property developer). On this basis, three methods: LITA, TCQSM and Time-of-Day tool, were picked to characterize the three transit accessibility coverage aspects. Analysis was conducted on the 17 census tracts of the city 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 are shown in Figure 3.1. The three methods, their data sources, reasons for selection of these particular methods, the intended users, and scales of analysis are explained below.

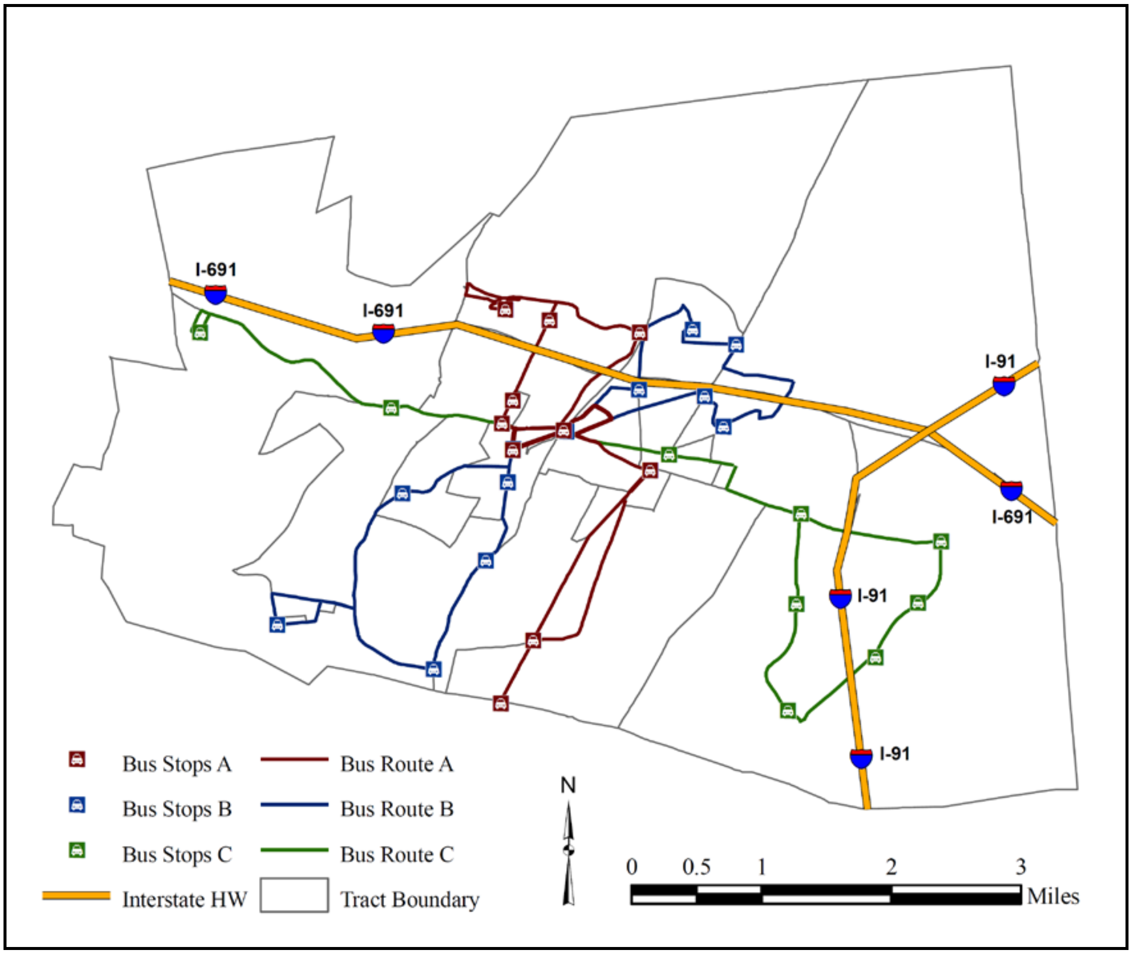

Figure 3.1: Three Local Bus Routes and Stop Locations of Meriden, Connecticut

3.2.1 Index 1: The 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 2001)*. 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 considers the time-of-day distribution of travel demand and reflects 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. This measure plays an important role to the public transit planners in determining the importance of transit service provided in each time period of the day.

3.2.2 Index 2: 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 includes full route maps and schedules of all transit lines serving the study area, locations of transit stops, and transit vehicle capacities. Census data encompasses total land area, resident population, and number of employees in each tract. All transit data were collected from the transit provider and census data from 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 aid the development of land use plans and policies for areas with different levels of transit accessibility.

3.2.3 Index 3: The Transit Capacity and Quality of Service Manual (TCQSM)

The Transit Capacity and Quality of Service Manual *(Kittelson 2003)* incorporates service coverage measure to assess transit accessibility and requires the same datasets (i.e., transit and census data) as LITA. Two techniques are used to calculate service coverage: GIS method and the Manual (Graphical). For this research, detailed GIS was used. To identify the spatial service coverage area, a 0.25 mile radius buffer area is applied around transit stops to capture the spatial coverage of a public transit system.

3.2.4 Scaling

One purpose of this study is to examine how consistently the three indices 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.

Table 3.2: Existing Scaling of Three Methods and the Developed Consistent Grading Scale

Grading Scale of Three Methods			*New Consistent Grading Scale*		
Time-of-Day Tool	**LITA+5 Score Scale Range (Grade)**	**TCQSM Score Scale Range (LOS)**	**Scale Range**	**Grade**	**Level of Accessibility**
No Grading Scale	≥ 6.5 (A)	90.0 – 100.0% (A)	$(\mu + \frac{3}{2}\sigma) \geq$	A	Very High
	5.5 – 6.5 (B)	80.0 – 89.9% (B)	$(\mu + \frac{1}{2}\sigma)$ to $(\mu + \frac{3}{2}\sigma)$	B	High
	4.5 – 5.5 (C)	70.0 – 79.9% (C)	μ to $(\mu + \frac{1}{2}\sigma)$	C	Average
	3.5 – 4.5 (D)	60.0 – 69.9% (D)	$(\mu - \frac{1}{2}\sigma)$ to μ	D	Low
	< 3.5 (F)	50.0 – 59.9% (E)	$\leq (\mu - \frac{1}{2}\sigma)$	F	Very Low
		<50.0% (F)			

LITA was scored to five grades (as shown in Table 3.2), A through F (excluding E). Grade "A" corresponded to a LITA+5 rating of 6.5 or higher, indicating the highest level of accessibility. TCQSM adopted the level-of-service (LOS) concept, introduced in the Highway Capacity Manual (HCM), for measuring quality of transit service. Scores were grouped in six LOS, A through F (including E). The Time-of-Day-based transit accessibility analysis tool measures transit accessibility with regard to the number of daily trips per capita (in each Census Tract) that is provided by the transit service. For a more consistent comparison of accessibility results, Standardized Scores (SS) were calculated for each method to get relative accessibility scores across all the census tracts. The scores were standardized by finding the difference between a specific score and the mean of scores and then dividing that difference by the standard deviation of scores for all tracts. For ease of interpretation, this paper develops a common grading scale (as shown in Table 3.2) 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 was shown in Table 3.3. In LITA, the raw score (as shown in Table 3.3) 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 3.3: Example of Standardization of Raw Scores for Different Methods

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

The development of the composite index on the basis of the three selected indices comprises several steps. First, the raw scores were standardized. Next, the accessibility metrics used for calculations across the three indices were identified (see Table 3.4). 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 index. Finally, the composite accessibility index for a tract was calculated using Equation (3-1).

$$\textbf{Composite Accessibility Index} = \frac{(SS_{Time-of-Day} * WF_{Time-of-Day}) + (SS_{LITA} * WF_{LITA}) + (SS_{TCQSM} * WF_{TCQSM})}{(WF_{Time-of-Day} + WF_{LITA} + WF_{TCQSM})} \quad \textbf{(3-1)}$$

Three weighting schemes were considered to assign weighting factors to the measures. In Scheme # 1, WF were allotted according to the occurrence of a measure in the indices (i.e. if a measure is common in all the three indices then its weighting factor was assigned as 3). Scheme # 2 assigns a WF of one to all measures and Scheme # 3 assigns the WF such that the weights for common measures sum to one and unique measures simply receive a weight of one. The weighting factors of individual elemental measures and the total weighting factors for the three indices are shown in Table 3.4.

Table 3.4: Development of Weighting Factors (WF)

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

3.3 RESULTS

Table 3.5 depicts the accessibility results for all census tracts in original scales. With the actual scales one can interpret the accessibility results according to that method's grading system. Table 3.5 shows that the obtained results vary greatly across the methods. To get a comparable picture of accessibility 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 this tool 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 indices. The results of the standardized scores (SS) shown in Table 3.5 provide less variable results across the indices.

Table 3.5: Comparison of Results in the Raw Scores and Standardized Scores for the Three Methods

Census Tract	Raw Score					Standardized Score (SS)					
	Time-of-Day Tool Score(Daily exposure 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	0.027	12.97	A	76.89	C	1.97	A	7.97	A	1.14	B
1702	0.023	5.46	C	62.36	D	1.44	B	0.46	C	0.67	C
1703	0.012	3.99	D	40.94	F	0.88	C	-1.00	F	-0.03	D
1704	0.003	3.45	F	5.23	F	-1.03	F	-1.54	F	-1.20	F
1705	0.002	4.25	D	11.39	F	-1.07	F	-0.74	D	-0.99	F
1706	0.006	4.83	C	21.37	F	-0.61	D	-0.16	D	-0.67	D
1707	0.012	4.85	C	50.65	E	0.16	C	-0.15	D	0.28	C
1708	0.009	5.25	C	29.21	F	-0.18	D	0.25	C	-0.42	D
1709	0.019	7.69	A	83.09	B	1.04	B	2.69	A	1.35	B
1710	0.022	4.72	C	69.63	D	1.33	B	-0.27	D	0.91	B
1711	0.006	4.20	D	17.10	F	-0.58	D	-0.79	F	-0.81	F
1712	0.004	3.71	D	13.42	F	-0.88	F	-1.29	F	-0.93	F
1713	0.009	4.80	C	39.53	F	-0.32	D	-0.19	D	-0.08	D
1714	0.017	8.16	A	91.28	A	0.71	C	3.16	A	1.61	A
1715	0.013	5.42	C	83.51	B	0.26	C	0.42	C	1.36	B
1716	0.003	4.50	C	14.24	F	-1.03	F	-0.49	D	-0.91	F
1717	0.001	1.97	F	2.91	F	-1.30	F	-3.02	F	-1.28	F

The standardized scores shown in Table 3.5 do still show some variation across the indices (e.g. census tracts 1703, 1710, and 1714). Table 3.6 presents the grades for the standardized scores using three weighting schemes from Table 3.4. As an example, in order to calculate the composite score for census tract 1702 in Scheme #2, first, the standardized scores for three methods (1.44, 0.46, and 0.67 from Table 3.5) were multiplied by the method weights (5, 4, and 1, respectively, from Table 4). After that, the sum of these multiplied scores was averaged over the sum of index weights, and the composite score was found as 0.97, which lies in between the range of $(\mu + \frac{1}{2}\sigma)$ to $(\mu + \frac{3}{2}\sigma)$ (Table 3.2) and was assigned as accessibility grade B (Table 3.6).

The results shown in Table 3.6 indicate that the composite scores are consistent across the schemes and the only dissimilarity is for tract 1703, where Scheme #1 provided composite grade as ‘D’ rather than ‘C’ in Scheme # 2 and Scheme # 3. In Scheme #2, 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 #1 evaluates transit accessibility addressing the spatial aspects (i.e. service coverage) extensively and Scheme #3 reflects emphasis on the temporal dimension of 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 (spatial, temporal, and both spatial & temporal) combinations of accessibility measures were considered in different schemes. Based on the discussion above, Scheme # 2 was selected in this research for calculating the composite accessibility index.

Table 3.6: Comparison of Results for Three Schemes and Grades for Composite Measure

Census Tract	**Composite Grade**		
	Scheme#1	Scheme # 2	Scheme # 3
1701	A	A	A
1702	B	B	B
1703	D	C	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

3.3.1 Spatial Distribution of Accessibility Results

TCQSM considers a much smaller coverage area than the other two indices. 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 3.1), there is disagreement on that extent for the middle of the accessibility spectrum (see Figure 3.2). 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.

3.3.2 Comparative Example

Figure 3.2 maps the grades of accessibility scores across indices 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 (e.g. census tracts 1703, 1710 and 1711) chosen to represent difference in accessibility intensity across the methods are indicated in Figure 3.2.

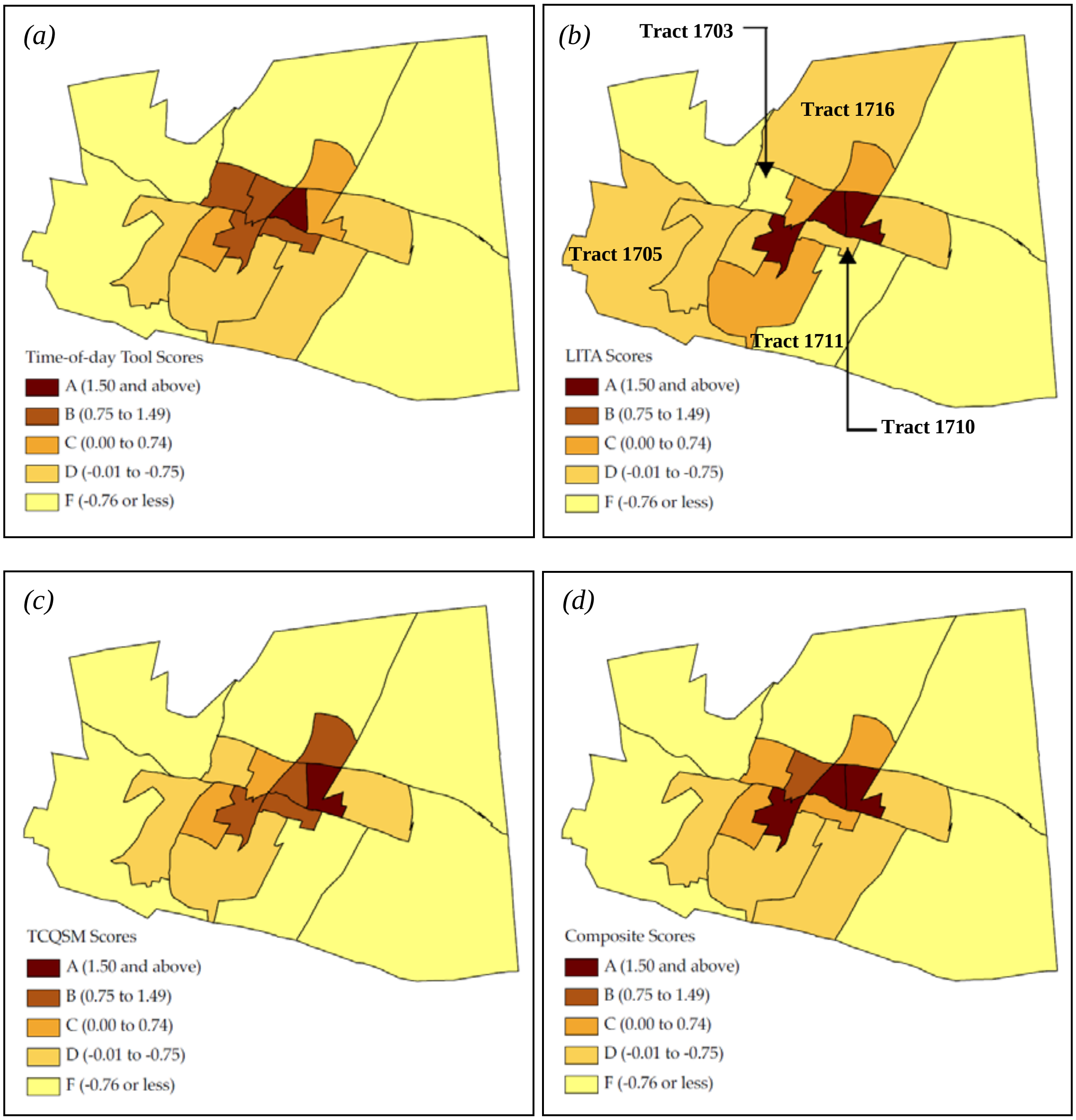

Figure 3.2: Accessibility Scores for Different Methods: (a) Time-of-Day Tool; (b) LITA; (c) TCQSM; (d) Composite, Scheme # 2

LITA represents lower scores for tracts 1703 and 1710 than the other indices. This method provides relative lower score to the dense populated smaller area (i.e. already developed area) and gives a moderate accessibility result to the larger areas (e.g. census tracts 1705 and 1716, Figure 3.2*(b)*). This is primarily due to the intended users' viewpoint of this method. Higher LITA score for a census tract indicates that this tract has more potential for future transit oriented development or redevelopment.

The TCQSM method provides higher accessibility scores than the LITA method for the 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. Therefore census tract 1703 results in a higher accessibility score in TCQSM than in 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. Census tract 1711 appears as a moderate accessible tract in the time-of-day tool but this tract has poor accessibility in TCQSM and LITA method. 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 # 2) mapped in Figure 3.2*(d)* provide single accessibility scores for tracts that addressed 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 indices.

The purpose of this chapter has been to discuss the indices employed in developing a practical tool for evaluating public transit accessibility. By means of a literature review and the survey results obtained from transit provider/planner standpoint an effort has been made to assess accessibility of public transit. As concern about the importance of increasing transit ridership has grown in recent years, attention is needed to identify the potential transit users besides the evaluation of transit accessibility. A parallel evaluation of transit accessibility and transit service need might provide an efficient measure to identify service gaps for supporting future service improvement decisions. Therefore, a transit need index is calculated and an accessibility-based need index is developed in the next chapter, which is intended to identify areas most in need of transit service.

4.0 TRANSIT ACCESSIBILITY AND TRANSIT NEED

The rise in personal income, increase in household car ownership, and substantial public investment in the construction of new streets and freeway systems led to a reduction in demand for public transit (*Garrett and Taylor 1999*) that has been reversed in recent years, as suggested by statistics in Connecticut (CTDOT 2011). In either case – whether in waxing or waning demand for public transportation, many people with and without regular access to automobiles depend on public transit as their primary mode of transportation. For this portion of the population, the continued availability of public transit is vital for access to jobs, medical care, and other necessities of social life. Hence, careful attention should be paid to provide transit infrastructure investment to improve accessibility for those who have limited transport options.

The simultaneous recognition of transit needs and identification of spatial gaps in transit accessibility can help a region provide more equitable transit service. Therefore, a single public transit service index that combines need for transit service and the accessibility to the service would be an excellent measure for improving the existing accessibility models. This chapter describes the formulation of a model for identifying the service gap with only one index value by integrating both the supply and need measures into one measure. This model intends to quantify the impact of service attributes on providing access to needy households within an area.

The next section of this chapter reviews existing measures that evaluate service gaps or transit disadvantaged areas using transit accessibility scores and transit need scores. The methodology section describes the development of transit need index, unmet transit need index, the interaction between unmet transit need and accessibility scores (as described in Chapter 3), the basic technique of developing an accessibility-based need index regression model, and the accessibility variables used in this model. The combined accessibility and need index is then presented in result section.

4.1 EXISTING SERVICE GAP MEASURES

Some researchers have approached the accessibility problem by examining service gaps in transit service provision and they compared the transit access and transit need indices to evaluate service gaps in an area. Currie and Wallis (*1992*) identified a method to assess the relative quality of public transport services with respect to transit needs. A single transport need index was developed using socio-economic and transport-need related indicators to quantify the distribution of needs in the community. The transport supply index, measuring the availability of transport to the transport disadvantaged, was calculated as the density of transit vehicle-kilometers during daytime shopping periods on weekdays. Another approach for identifying geographical gaps in the service coverage was developed by Currie (*2004*). He developed a 'Needs Gap' approach to assess public transport services by comparing the distribution of the supplied services with the spatial distribution of transport needs. The supply index was calculated using a transit network supply model, which measures the network supply costs for different time periods and trip purposes. This provided a further refinement of the supply side modeling used in previous applications of this approach, though the transit needs measure remained same as noted in previous research (*Currie and Wallis 1992*).

Another adaptation of the 'Needs Gap' approach was developed by Currie (*2010*) to quantify social gaps in public transit provision for socially disadvantaged peoples. This approach involved measuring public transport supply with combined service frequency (vehicle trips per week) and access distance. The measure for social need was developed by combining the Australian Bureau of Statistics Index of Relative Socio-Economic Advantage/Disadvantage (IRSAD) and the earlier transport need index mentioned in (*Currie and Wallis 1992*).

Murray and Davis (*2001*) combined public transit need with accessibility measure for evaluating the equity of this transit service provisions. An index was developed in order to evaluate the relative public transport needs for each zone within the study area. They used a weighting approach to combine average household income, unemployment rates, and average family size. The level of access to service of an area was measured as the percentage of area suitably covered by public transit (*Murray and Davis 2001*). Hine and Mitchell (*2003*) assessed transit need and transit related social exclusion. For this purpose, they conducted a household survey to collect basic household data, socio-economic information, travel behavior, and particulars on private car ownership. This information was used by the researchers to identify transport disadvantaged peoples.

Bhat *et al.* (*2006*) described a customer-oriented, utility-based Transit Accessibility Measure (TAM) to identify the inequality between transit service provision and the level of transit need within a community. The TAM index combined the transit accessibility index (TAI) with the transit dependence index (TDI). This measure identifies the users who need the service most by comparing the level of service supply with the level of demand by the transit user.

The review of the above mentioned studies revealed that most of the research used a similar methodology to identify service gaps or to map transit equity, which estimates both transit needs and transit access, then compares them to measure service gaps or identify transit disadvantaged areas. This methodological approach is referred further in this paper as *General Approach* and the studies (as reviewed earlier) that have been used this general approach are listed as follows for ease of identification:

- Currie and Wallis (*1992*)
- Murray and Davis (*2001*)
- Currie (*2004*)
- Bhat *et al.* (*2006*)
- Currie (*2010*)

This Chapter aims to detail a methodological alternative to the ***General Approach*** that can measure the quantity and quality of transit service and represent the level of need with a single score. An accessibility-based need measure incorporating transport disadvantaged population is proposed for examining equity in service provision. The results obtained from this model-based approach are compared and contrasted for consistency with the results obtained using the General Approach and this is described in Chapter 5.

4.2 A METHOD TO IDENTIFY SERVICE GAPS

Beyond the measure of transit accessibility using composite accessibility index (as described in Chapter 3) a series of research tasks needed to be addressed in the modeling of an accessibility-based transit need measure: (*a*) Measuring transit need; (*b*) Measuring unmet transit need; and (*c*) Relating transit accessibility as a function of unmet transit need. These research tasks are discussed below prior to the description of the modeling methodology used in this research.

4.2.1 Transit Accessibility Index

The composite transit accessibility measure proposed in Chapter 3 was used to calculate the levels of access to transit services. Table 4.1 shows the composite accessibility scores and the levels of accessibility for the 17 census tracts of Meriden, CT.

4.2.2 Transit Need Index

Transit service is often considered a social service in urban areas and the provision of equitable transit service is essentially viewed as a basic right by transit planners (*Hine and Mitchell 2003*). An equitable transit service requires more concern given to serving those who need the service most. Therefore, there is a necessity to identify those people who do not have sufficient public transport service opportunities but have significant need. To do this, a transit need index was developed based on the workers who are transport disadvantaged.

Hine and Mitchell (*2001*) defined transport disadvantaged people as people whose needs are not met by public transit services. These include people with disabilities, elderly people, children, the unemployed and low-paid individuals. In another paper, Hine and Grieco (*2003*) defined the transport disadvantaged as people with low income, women, the elderly, disabled people, and children. Currie *et al.* (*2007*) identified transport disadvantaged people on the basis of car availability in households. This approach included an assessment of ‘forced car ownership’ (FCO) and ‘zero car ownership’ (ZCO) households. FCO was defined as low income households who own 3+ cars and ZCO was defined as low income households that do not own a car.

Five different transport disadvantaged classifications are considered with all data are from the Census Transportation Planning Package (CTPP) 2000 Database. The transport disadvantaged classifications are based on the number of workers belonging to the transport disadvantaged classes and are as follows:

4.2.2.1 Forced Car Ownership (FCO)

This group is comprised of workers living in low income households (annual incomes below $30,000) who own 3 or more cars. The terminology ‘forced’ car ownership has been used for low-income households in remote rural areas those ‘forced’ to own and operate cars (*Currie et al. 2007*). It is hypothesized that this classification represents households that must own a large number of vehicles to meet their mobility needs because transit service is lacking.

4.2.2.2 Zero Car Ownership (ZCO)

This group includes workers in low income households that do not own a private car. These low income households may not be able to afford a car because they would have to spend a significant portion of their total household income to operate a car (*Currie et al. 2007*).

4.2.2.3 Low Income Earners

Low income earners are workers in households with annual incomes less than $25,000. This low income constraint makes it difficult for them to have a high budget for their daily transport expense. It is assumed that this group relies on low cost public transit services more than higher income households.

4.2.2.4 People Over 65 Years Old

This group includes elderly people, who out of need or desire often change their driving behaviors and likely to use transit services for their mobility needs. As people grow older, they shorten their trips, and look for less congested and lower speed roadways and eventually stop driving (*Rosenbloom 2001*).

4.2.2.5 Disabled Individuals

This group identifies workers with any kind of disabilities (i.e., physical disability, mental illness, and other serious health impairments). This classification is considered because they generally depend on accessible and wheelchair friendly transit services for getting access to jobs and other social services.

The transit needs index uses only the transit disadvantaged workers (TDW) and the values are calculated using Equation (4-1) as shown in Table 4.1. While limiting the index to workers, the need index under-represents two classes of transit disadvantaged people (i.e., elderly people and people with disabilities). This research recognizes the limitation of this data but continues to use these data to maintain consistency in unit of measure with other data classes. Another important consideration in the development of a need index is the possible double counting of people in different transit disadvantaged groups. For example, many people in the low income group were also in the zero car ownership class, meaning they were double counted in the calculations. Therefore, the actual need index of a census tract may be lower than represented in the calculation. To prevent this situation, group data were collected and sorted as carefully as possible on the basis of cross-data between classes. Common data on different combinations of classes were collected and subtracted from the classes to avoid over counting. For example, data on workers who use a car as their mode of travel for elderly people and disabled people, and data on workers who are both elderly and disabled were collected. Then the common data were halved and subtracted from both classifications.

$$\text{Transit Need Index} = \frac{\textit{Total TDW}}{\textit{Total Tract Population}} \times 100 \tag{4-1}$$

Table 4.1: Transit Accessibility, and Transit Need Scores

Census Tract	**Accessibility Score**	**Level of Accessibility**	**Need Score** *(TDW as % of Tract Pop.)*	**Level of Need**
1701	4.29	A (Very High)	35.05	A (Very High)
1702	0.97	B (High)	36.98	A (Very High)
1703	0.04	C (Average)	26.72	D (Low)
1704	-1.25	F (Very Low)	34.76	A (Very High)
1705	-0.93	F (Very Low)	28.32	C (Average)
1706	-0.44	D (Low)	25.24	D (Low)
1707	0.05	C (Average)	29.6	C (Average)
1708	-0.03	D (Low)	30.96	B (High)
1709	1.73	A (Very high)	33.4	B (High)
1710	0.65	C (Average)	30.7	B (High)
1711	-0.69	D (Low)	32.38	B (High)
1712	-1.05	F (Very Low)	22.08	F (Very Low)
1713	-0.24	D (Low)	21.78	F (Very Low)
1714	1.78	A (Very High)	36.86	A (Very High)
1715	0.43	C (Average)	27.67	C (Average)
1716	-0.80	F (Very Low)	27.15	D (Low)
1717	-1.99	F (Very Low)	22.48	F (Very Low)

4.2.3 Unmet Transit Need

The unmet transit need index was measured as the *percentage of transit disadvantaged workers in a census tract who used private car as their mode of travel* (Equation 4-2). This research determines the unmet transit needs scores to identify service gaps between transit access and transit need scores. Journey to work data for transit disadvantaged workers were collected from the CTPP 2000 database. While defining the unmet transit need index based on car ownership indicators, this research does not consider the travelers' mode choice or lifestyle preference to own private car, which might be worth considering. Therefore, we do not presume to say that all transit disadvantaged workers would take transit service even if they have access to the service. We only intend to investigate the relationship between these unmet transit needs and accessibility measures as a means to look at the relationship between need for service and the service characteristics.

$$\text{Unmet Transit Need Index} = \frac{TDWs\ Use\ Auto\ as\ Mode\ of\ Travel}{Total\ TDW} \times 100 \qquad \textbf{(4-2)}$$

4.2.4 Transit Accessibility as a Function of Unmet Transit Need

The primary objective of this section was to develop an accessibility-based need measure to reflect the service gaps between an area's levels of transit needs and its level of transit accessibility. For this purpose, a composite accessibility index (as described in chapter 3) and an unmet transit need index were estimated in the earlier sections. A linear regression model was estimated for the composite accessibility scores and the unmet transit need scores, with unmet transit need index on the x-axis and composite transit accessibility index on the y-axis.

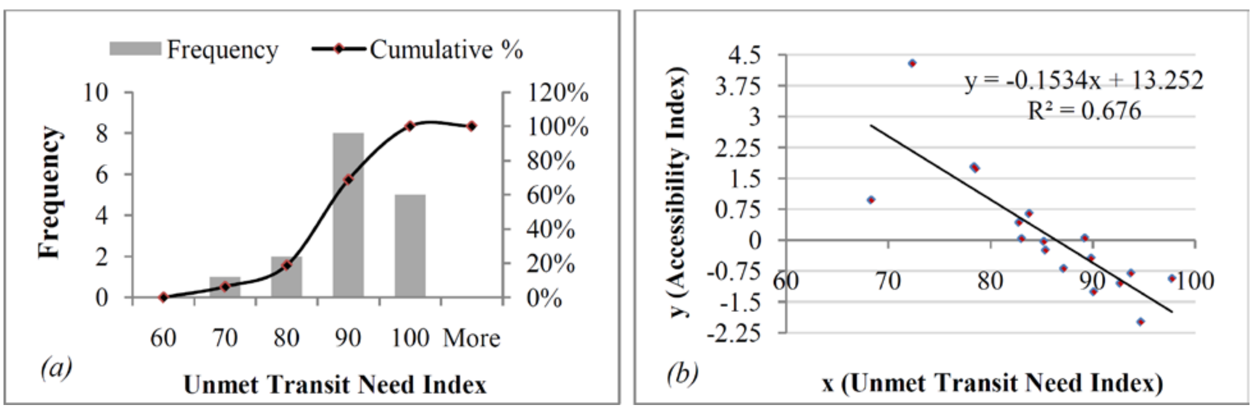

Figure 4.1: Estimation of Linear Function between Transit Accessibility and Needs: (a) Histogram of Unmet Transit Need Index, and (b) Scatter Plot to Examine Relationship

The histogram shows (Figure 4.1(*a*)) that the unmet transit need index data (Table 4.2) is normally distributed and therefore, this data can be used for developing further statistical models. A regression line (shown in Figure 4.1(b)) over the actual data points is plotted for evaluating the correlation among composite accessibility index and unmet transit need index. A hypothesis test (*t-test* at 5% significance level) was conducted to determine whether there is significant relationship between unmet transit need and composite accessibility scores and it was found that the slope of the regression line (shown in Figure 4.1(b)) differs significantly from zero. Since unmet transit need index reflects the percentage of transit disadvantaged workers that use auto, it is reasonable to expect that there is some negative correlation between the unmet transit need index and composite transit accessibility index. In this case unmet transit need index has a negative coefficient suggesting that the percentage of auto usage decreases as transit accessibility increases. The R^2 value indicates that 67.6% of variance can be accounted for by the entire regression. Most of the data points are clustered towards the lower right corner of the plot, indicating most of the tracts have high transit need and low level of accessibility and will temper any extrapolations outside of the observed data range. Ordinary Least Square (OLS) assumptions were verified for this linear model. The linear relationship indicates that higher unmet transit need *(measured as the percentage of auto use by the transport disadvantaged workers)* is correlated to poor transit service accessibility. This serves as a means of validating the supposition that transit service need is strongly correlated to the lack of accessibility.

4.2.5 Modeling Accessibility-Based Need Index

This section describes the development of service gap model as a function of service characteristics. Previous sections support the idea that unmet transit need is correlated with the lack of service accessibility as measured by service characteristics. The models described below intend to provide a simple way to estimate the impact service improvements might have on addressing the need for transit service. Furthermore, the goal of this modeling approach is to estimate service gap using only service characteristics. The response variable in the models is named as 'Accessibility-based Need Index' which estimates the unmet transit need index/service gap. The independent variables were selected to represent both spatial and temporal aspects of transit accessibility. Computational simplicity and data source availability were also taken into consideration during the selection of access variables. Independent variables were examined by investigating summary statistics, frequency distributions, raw data scatter plots and a measure of collinearity, the variance inflation factor (VIF), for agreement with model assumptions. Below is a brief description of these variables, an explanation of the required data, and the equations used to calculate the variables:

4.2.5.1 Percent of Service Area (%SERVICE_AREA)

Percent of Service Area is the percentage of a census tract served by the transit system. It is calculated by dividing the tract area covered by 0.25 mile buffers around transit stops (i.e., service area) by the total area of the tract. This variable reflects spatial accessibility to transit service.

$$\%\text{SERVICE\_AREA} = \frac{Total\ Service\ Area}{Total\ Tract\ Area} \tag{4-3}$$

4.2.5.2 Compiled Route-Miles per Square Mile of Area (BUS_ROUTE_DEN)

The total length of transit routes running through each census tract was estimated by using ArcGIS area/length calculation feature. Routes running along the edge of a tract were halved between the bordering tracts to avoid over counting the actual route length. Total tract route length (miles) is then divided by the tract area (square miles).

$$\text{BUS\_ROUTE\_DEN} = \frac{Total\ Route\ Length}{Total\ Tract\ Area} \tag{4-4}$$

4.2.5.3 Average Daily Bus Runs per Stop (DAILY_BUS)

Total number of bus stops in each tract was first determined. Bus stops falling on a tract boundary were halved between the bordering tracts. The number of bus runs for all stops were summed to get total number of daily bus runs for each census tract. A bus stop with multiple routes expands the summation over all the routes serving the stop. Finally, the total daily bus runs from each bus stop within a tract were averaged to obtain that tract's average daily bus runs per stop. The calculation of this variable requires a schedule of bus services to determine the daily vehicle runs per bus stop and a service map to get the exact location of the bus stops.

$$\text{DAILY\_BUS} = \frac{Total\ no.of\ Buses\ Run}{Total\ no.of\ Stops} \tag{4-5}$$

4.2.5.4 Daily Seat-Miles per Capita (SEAT_MILE/CAPITA)

This access variable was calculated based on three data: total daily available seats, total route-miles and total population for each census tract. Daily available seats per capita was calculated by multiplying the total daily bus runs within a tract by bus capacity and total route miles and then dividing by the total population of the tract.

$$\text{SEAT\_MILE/CAPITA} = \frac{Total\ no.of\ Buses\ Run \times Bus\ capacity}{Total\ Tract\ Population} \tag{4-6}$$

To find the best approximation of the relationship between the unmet transit need index and the independent access variables, three different models (shown in Table 4.2) were identified using backward elimination technique. In this technique, the model begins by including all variables and then the variables with the largest *p*-value removed from the model. With this backward elimination technique, Model 1 was found as the best model to predict the unmet transit need/service gap.

Table 4.2: Regression Models for Estimating Transit Needs Using Accessibility Variables

Model	Model R^2	F-value	AIC	Intercept, Independent Variable	Coefficient	t-statistic	P-value	VIF
Model 1	0.8232	32.59	8.4583	Intercept	94.2442	63.19	0.0000	-
				%SERVICE_AREA	-0.14751	-4.58	0.0004	1.23
				SEAT_MILE/CAPITA	-2.96682	-4.01	0.0013	1.23
Model 2	0.8417	37.23	8.5333	Intercept	93.9822	66.67	0.0000	-
				%SERVICE_AREA	-0.07091	-1.75	0.1026	2.18
				BUS_ROUTE_DEN	-1.79409	-4.43	0.0006	2.18
Model 3	0.7396	19.87	9.3333	Intercept	100.0435	33.32	0.0000	-
				%SERVICE_AREA	-0.17540	-4.75	0.0003	1.09
				DAILY_BUS	-0.47412	-2.53	0.0239	1.09

The resulting three models were also evaluated based on their overall utility. *Model 1* and *Model 2* proved to be better models than *Model 3* as shown by the coefficient of determination (R^2) and the *F*- values. In *Model 1*, variable *%SERVICE_AREA* has a stronger significant coefficient (higher *t*-value) than in *Model 2*. Furthermore, *Model 2* has a higher *P*-value for the *%SERVICE_AREA* variable than *Model 1*, meaning it is less useful for predicting the response variable – this is likely due to increased correlation between service area and the second independent variable, a hypothesis supported by the higher Variance Inflation Factor (VIF) values. The variance inflation factor (VIF) was calculated (shown in Table 4.2) to identify the multicollinearity of the explanatory variables. Depending on the source, upper thresholds of acceptable VIF can vary with common boundaries being a VIF of 5 or VIF of 10 (*Hine 2002, Chatterjee and Price 1991*). Against these thresholds, all three models have an acceptable level of multi-collinearity, with the preferred model, *Model 1*, having a VIF of 1.23. Furthermore, the Akaike Information Criteria (AIC) values (as shown in Table 4.2) were calculated to measure the relative goodness of fit of those non-nested competing models (*Akaike 1987*). This comparison approach favors *Model 1*among them with the smallest AIC value. Thus, it would be reasonable to conclude that overall *Model 1* is the best of the three models for estimating transit need using access indicators. The functional form for *Model 1* is as follows:

$$\text{Accessibility} - \text{Based Need Index}$$

$$= 94.2442 - 0.14752 * \%\text{SERVICE\_AREA} - 2.966682 * \text{SEAT\_MILE/CAPITA} \quad \textbf{(4-7)}$$

The model (Model 1) indicates that the accessibility-based need index reduces with the increase in service coverage and daily available seat-mile per capita of a transit service. Therefore, it states that the percentage of transit disadvantaged workers who use auto as their mode of travel reduces with the transit service improvements. The negative relationship between transit need index and the service variables suggests that an improved accessibility to transit service can reduce people's reliance on private autos. In addition, this model states that if transit disadvantaged populations can be located within accessible distance to transit services then car ownership appears to lower and public transit service will become a more feasible option.

4.3 RESULTS

Prior methods (i.e., General Approach) measured transit accessibility and the need for transit services separately and then compared them to quantify service gaps and identified transport disadvantaged areas. This chapter developed a model-based approach to identify service gaps in transit service provisions with a single accessibility-based need measure. This approach does not require the calculation of separate transit accessibility and need scores and only uses accessibility variables, which are less data intensive. Table 4.3 shows the results of the unmet transit need index (CTTP data), the values of independent variables, and the service gap results obtained from the model-based approach. The accessibility-based need index was grouped into five categories, A through F excluding E. Grade 'F' characterizes an area having "very high service gap (i.e., very low level of accessibility to transit service and very high level of transit need)" and grade 'A' represents "No Service Gap".

Table 4.3: Results of Unmet Transit Need, Values of Independent Variables, and Service Gap Results Obtained From Model-Based Approach

Census Tract	**Unmet Transit Need Score** *(% of Auto-using TDW in a Tract)*	**Independent Variables**				**Fitted Accessibility –Based Need Index**	**Service Gap**
		%SERVICE_AREA	SEAT_MILE/CAPITA	DAILY_BUS	BUS_ROUTE-DEN		
1701	72.3	76.89	4.6725	28	11.3417	69.03	A (No gap)
1702	68.29	62.36	3.8231	24.6	8.7557	73.70	B (Low)
1703	83.01	40.94	0.1253	7.33	2.2142	87.83	D (High)
1704	90.08	5.23	0.1693	19	0.4047	92.96	F (Very High)
1705	97.74	11.39	0.3660	10.6	0.7450	91.47	F (Very High)
1706	89.82	21.37	0.1812	19	1.4541	90.55	F (Very High)
1707	89.2	50.65	0.1154	11	2.0808	86.42	D (High)
1708	85.19	29.21	0.4970	14.25	2.1226	88.45	D (High)
1709	78.53	83.09	0.5775	8.8	5.6273	80.27	C (Average)
1710	83.76	69.63	0.2376	24	4.7081	83.26	C (Average)
1711	87.13	17.10	0.4388	16	1.7254	90.41	F (Very High)
1712	92.66	13.42	0.7817	11.42	0.8391	89.94	F (Very High)

1713	85.35	39.53	0.4304	14.25	2.1176	87.13	D (High)
1714	78.36	91.28	1.6148	18.4	3.8922	75.98	B (Low)
1715	82.76	83.51	0.2362	11	3.6665	81.22	C (Average)
1716	93.72	14.24	0.6629	11	0.8334	90.17	F (Very High)
1717	94.68	2.91	0.0343	11	0.1709	93.71	F (Very High)

The comparison of the service gap results between General Approach and model-based approach is described in the following chapter to evaluate consistency and completeness. The following section of this chapter presents a series of graphics for illustrating only the methodology used to identify service gaps using the accessibility-based need index.

Analysis was conducted on the 17 census tracts of Meriden, CT[1]. Calculations were carried out for three (A, B and C) public bus routes that service the city. Figure 4.2 depicts the results of composite accessibility index (see Table 4.1) that measures transit user's access existing transit services. This map can help monitor how well the transit system is serving people, revealing where transit service is most intense and where it is lacking.

[1] One of the limitations of this model is associated with the small sample size. A large sample size could provide more meaningful results, and which might be useful to conduct some other statistical diagnostic tests to justify that the correlation between transit needs and transit accessibility did not just happened by chance alone.

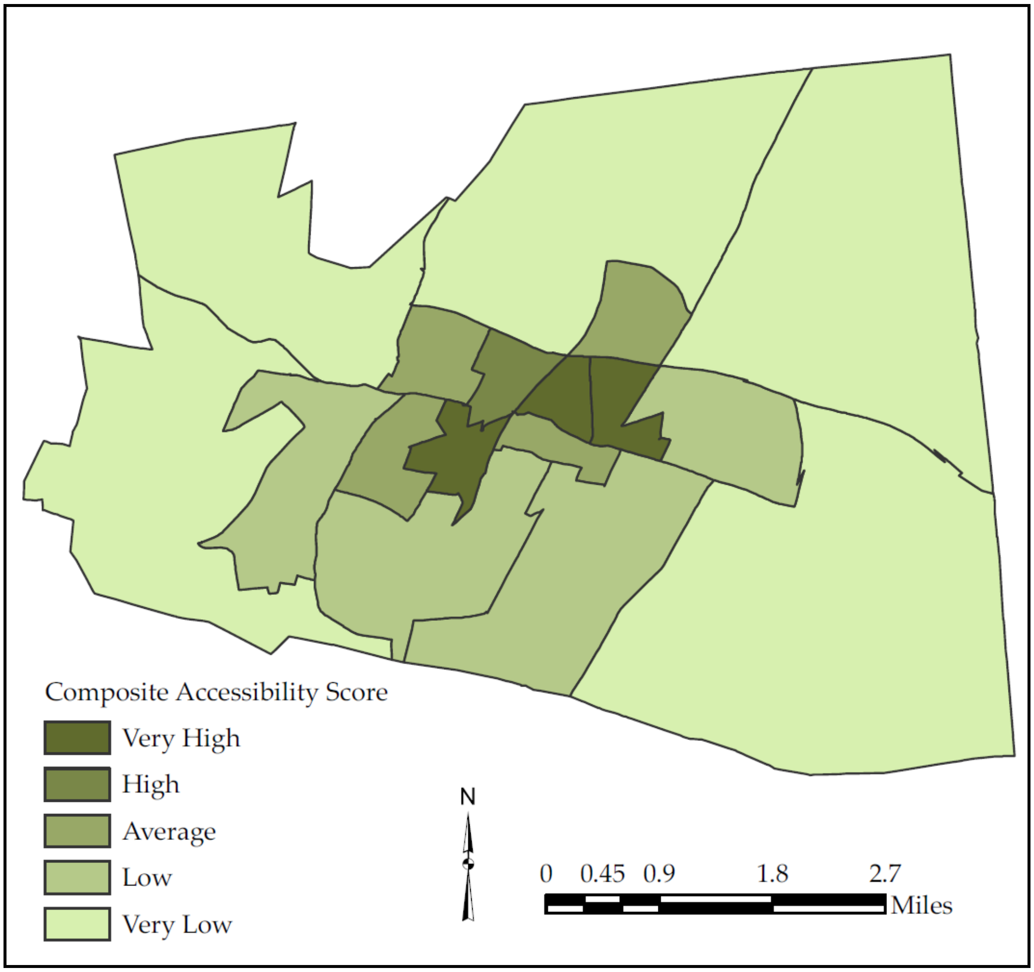

Figure 4.2: Composite Transit Accessibility Scores of Meriden, Connecticut

In Figure 4.3, the levels of transit need are mapped to identify areas with significant need for transit service. This diagram provides an overview of the concentration of transit disadvantaged workers throughout Meriden. It is assumed that the areas with the highest percentage of TDWs might have the highest need for transit service. It is expected that the areas with the highest need score (see Figure 4.3) might also have the highest level of access (see Figure 4.2). However, Figure 4.2 and Figure 4.3 showed some exceptions. For example, tract 1704 is identified as having very high transit need (Figure 4.3). Therefore, it is expected that this tract tends to have very high access. But this tract is identified as having very low access (Figure 4.2) and resulting in a very high service gap. Tract 1701 has a very high need that is coupled with very high access; therefore, there is no service gap. Tract 1717 is an example of a very low-need and very low-access resulting in a no-gap tract whereas tract 1705 is an average-need, very low-access tract resulting in an average service gap.

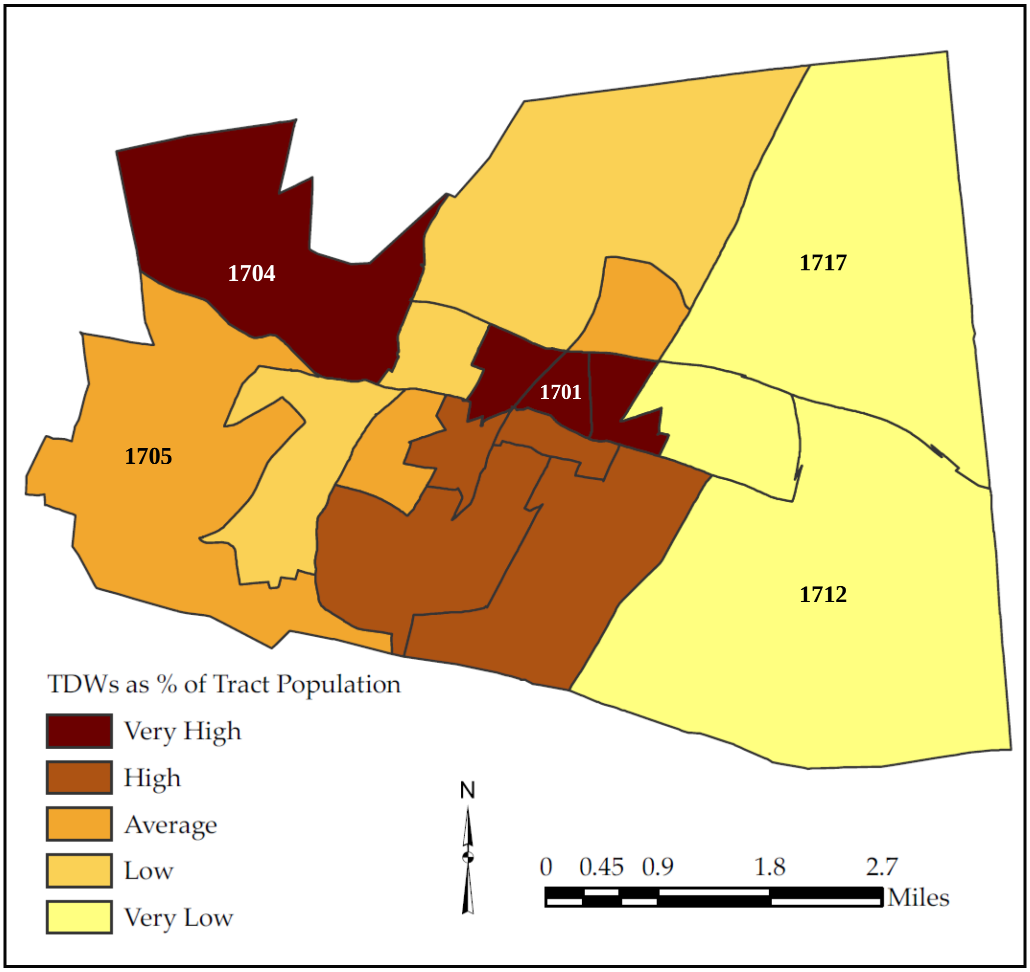

Figure 4.3: Transit Need Scores of Meriden, Connecticut

Identification of transit disadvantaged areas can be an important tool for helping prioritize service improvements or expansions. The "Unmet Transit Need" measure was used as the baseline service gap measure (dependent variable) in this model-based approach (values in Table 4.3). Figure 4.4 depicts the distribution of unmet transit need scores. The results are as expected – unmet need follows a lack of service. While intuitive this is useful as a validation in this simple application and a baseline for more extensive applications.

Figure 4.4 shows that tract 1704 has very high service gap and tract 1701 displays no service gap with unmet transit need score. However, this unmet transit need score tends to rate some tracts as higher service gap than they are expected. For example, tracts 1712 and 1717 have very low need (as defined by TDW %) and coupled with very low access (Figure 4.3 and Figure 4.2) therefore these are "No Gap" tracts. But the unmet transit need index (Figure 4.4) rates these tracts as "Very High" service gap tracts as those tracts have high percentage of auto using transit disadvantaged workers. Therefore, in addition to the expected transit disadvantaged areas, the unmet transit need index identified the tracts as the disadvantaged areas those who might have low need for transit service but have high potential reduction in auto usage with the provision of improved transit access.

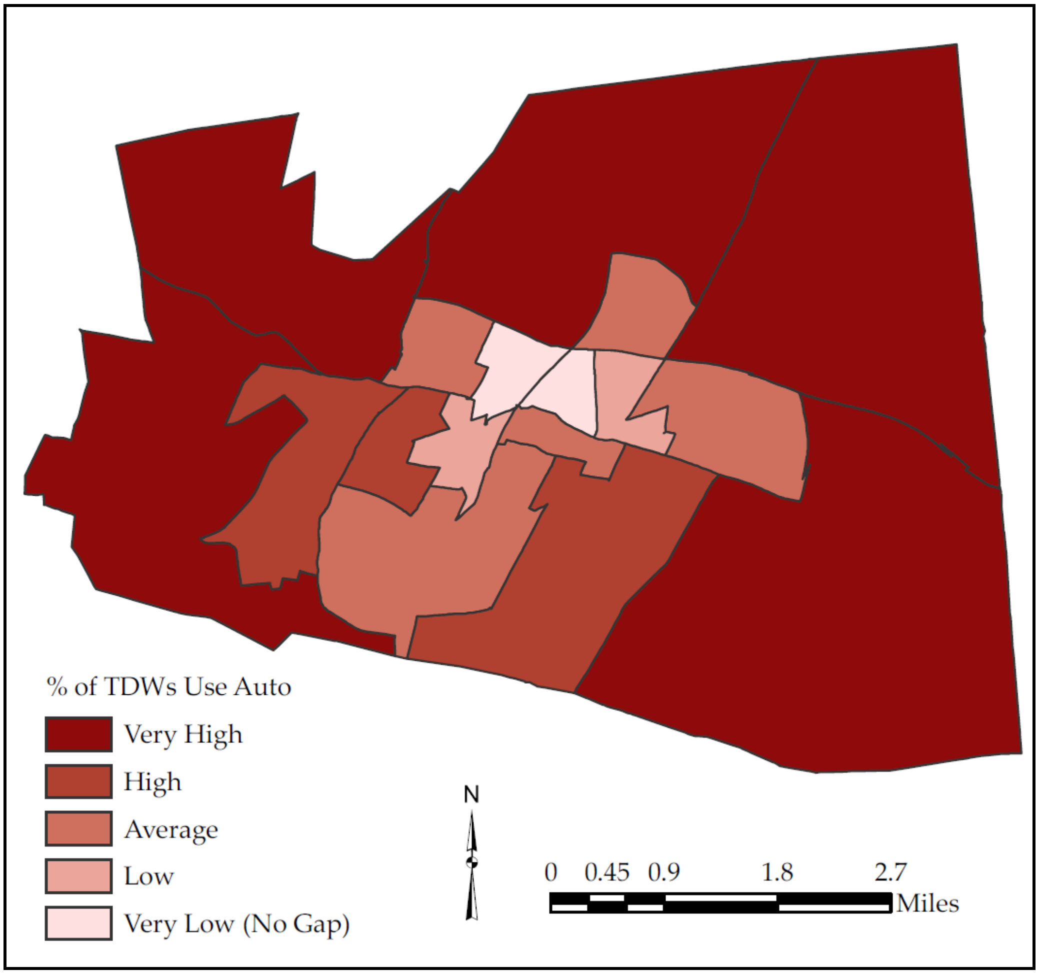

Figure 4.4: Unmet Transit Need Scores of Meriden, Connecticut

Results of the model-based service gap score (i.e., Fitted Accessibility-based Need Index) using different service characteristics shown in Table 4.3. The purpose of this modeling approach was to estimate the need impact of different hypothetical improvement options (i.e., building new bus stops, building new transit lines, increasing service span or service frequency, etc.) on transit accessibility. The following sections describe the model results and applications.

4.3.1 Assessing Service Gaps/Transit Disadvantaged Areas

Figure 4.5 shows the spatial distribution of the combined transit accessibility and transit need scores for the census tracts; the darkest shades are areas with very low accessibility and very high transit needs (i.e., very high service gap) and the lightest shades indicate very high accessibility with very low transit needs (i.e., no gap). Using this single index for each tract, one can easily identify the transport disadvantaged areas. The low level of public transport and consistently high transit need for transit services areas suggests that significant expenditure on public transport services and infrastructure should be prioritized for this region. These areas should be of great interest to transit providers because they contain the most needy transit users, which should be a concern to increase the efficiency of this service and it will help transit planners in government agencies ensure an equitable use of public resources

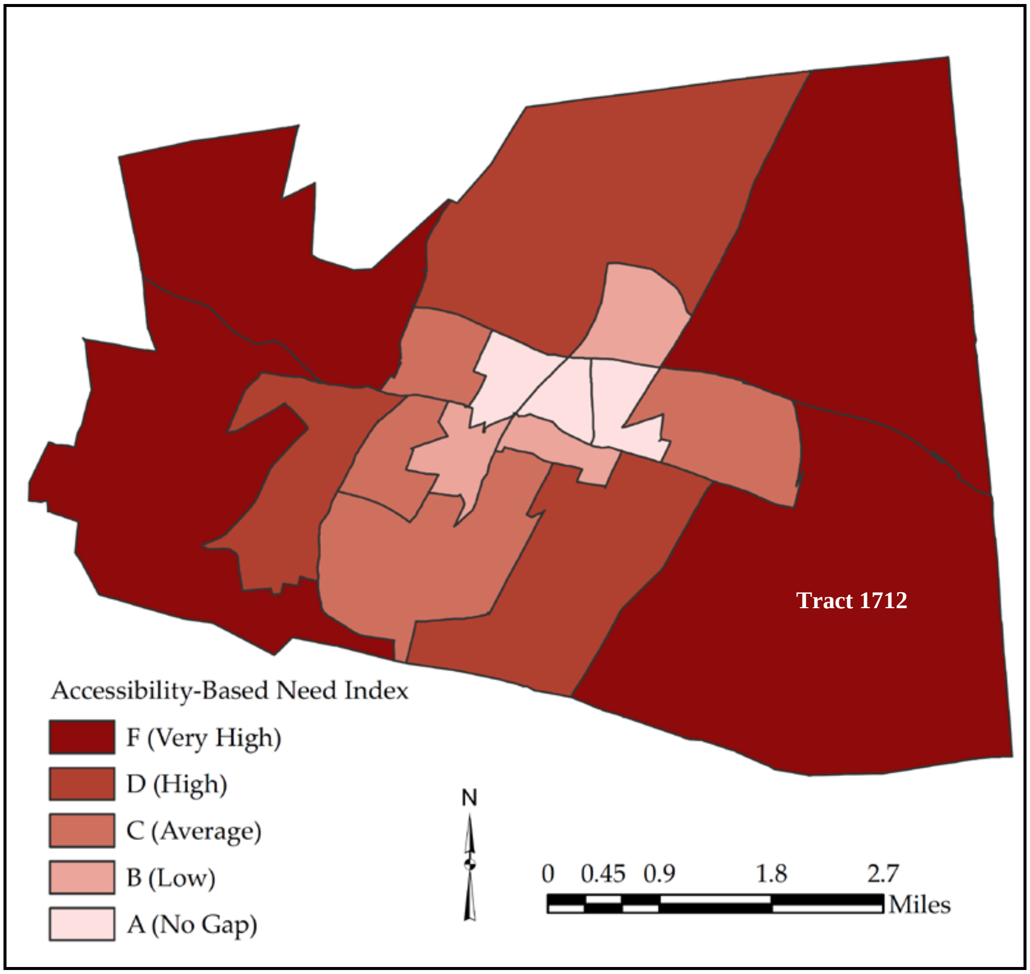

Figure 4.5: Levels of Service Gaps between Transit Access and Transit Need of Meriden, Connecticut

4.3.2 Determining Service Improvement Options

This paper developed a model that can be used to examine service changes and their estimated impact on unmet transit need. This model provides a basis for assessing various policies to ameliorate the lack of transit accessibility. This model requires relatively little data and yet is designed to assist transit providers to identify best possible new facilities or re-allocation schemes in order to optimally utilize resources from a transit accessibility and need perspective. Following is a brief example of how such a method could be applied.

Transit disadvantaged areas can be analyzed to determine potential locations for new and expanded facilities or services. An assessment of service improvement options were investigated for census tract 1712. Figure 4.5 shows that tract 1712 is a transit disadvantaged area with a very high unmet transit need for service but a very low transit accessibility level.

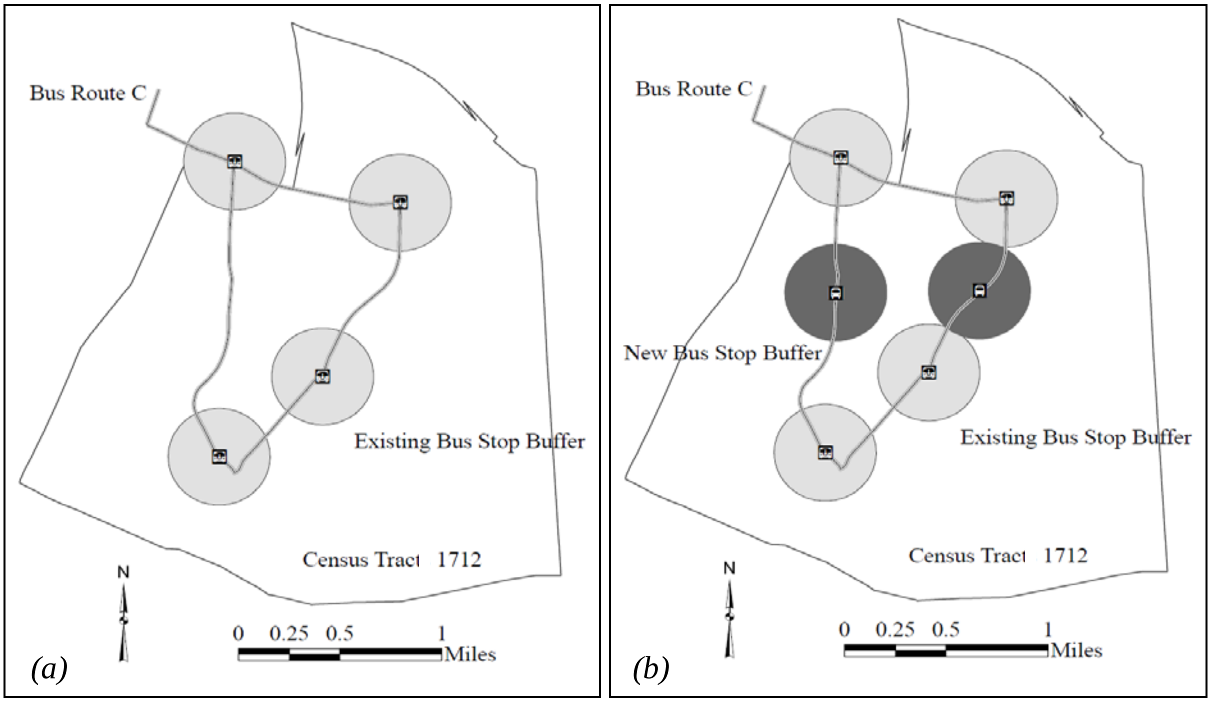

Figure 4.6: Assessing Accessibility Improvement Options for Tract 1712: (a) #1 Existing Locations of Bus Stops and Route Alignment, and (b) #2 Proposed New Bus Stops

Figure 4.6(*a*) shows the existing locations of bus stops and route alignment in census tract 1712. Connecticut transit (CTTransit) provides bus service to this tract with bus route C. This tract had a population of 7,565 in the year 2000 and a land area of 5.034 square miles (US Census). A total of 40 vehicles runs are made at these four bus stops daily. The average service span for this route is eleven hours (from 6:30 am to 5:30 pm) and the average headway for each stop is approximately one hour. This low frequency bus service results in poor accessibility and according to the model developed in this paper, represents highest transit need for this tract. With this simple model, improvement policies can be inspected to measure the changes in transit need resulting from of service improvements. Two hypothetical options for this census tract are considered in this paper.

In Option 1, the bus service frequency and the hours of service were increased for the existing bus stops and route alignments (Figure 4.6(*a*)). The service span was increased to 13 hours from 11 hours and the bus service frequency was changed to 40 minutes, which only caused changes to one of the independent variables, SEAT_MILE/CAPITA. Using the model equation, this option improves the accessibility-based need grade from F to D (i.e., from 'very high need with very low accessibility' to 'high need with low accessibility').

The second option considers the placing of two new transit stops (Figure 4.6(*b*)) within this tract. Locations of these stops were chosen so that the 0.25 mile buffer areas around the transit stops would not overlap, increasing service coverage. It was also assumed that the number of buses run from the new stops is the same as the buses running from the adjacent stops. The addition of these two stops affected both of the independent accessibility variables (%SERVICE_AREA and SEAT_MILE/CAPITA) which also found to offer little improvement (from grade F to grade D) in the accessibility-based need index.

Changes in level of unmet transit need with the provision of transit service attributes may be predicted using this model result by calculating the changes in the percentage of transit disadvantaged workers using auto as their mode of travel (i.e., the need index). Results show that the accessibility-based transit need index value lowers from 90.0 to 88.3 in Option 1 and 87.4 for Option 2, meaning that more disadvantaged workers may possibly be covered by the transit service if there are frequent bus stops rather than increased service span or more frequent bus service. Intuitively, it seems that the cost for building two new transit stops may be much less than the cost for increasing service span by two hours and increasing the service frequency of transit service. A detailed benefit/cost analysis would be needed to make the final determination, however, the derived accessibility-based need improvements clearly favor Option 2.

This chapter has presented a model-based approach for measuring service gap to address the need for a single, straightforward and user-friendly tool for evaluating public transit accessibility and transit needs simultaneously. The design of the accessibility-based need index model is intended to support the idea that the service gap can be measured using different spatial and temporal characteristics of public transit service only. Development of this methodology for measuring service gap used a relatively small area (Meriden, CT) for providing maximum flexibility in calculation of access and need scores and straightforward verification of the results. The usefulness of the accessibility-based need index for measuring service gaps is next tested by means of a case study conducted in the City of New Haven, Connecticut. The following chapter describes the step-by-step process used to develop the model-based service gap measuring tool for New Haven.

5.0 NEW HAVEN CITY CASE STUDY

This chapter summarizes the framework for measuring service gap in transit service based on the research described in Chapter 3 and Chapter 4 and compares the results obtained from the model-based approach with the results obtained using the General Approach for consistency. The first application of the service gap measuring model was applied to the city of Meriden, CT. This area was selected due to its manageable size (only 17 census tracts) and its relatively isolated, small transit system with only 3 transit lines and 27 bus stops. This chapter aims to validate the methodology for a city having a large-scale transit system compared to that in Meriden. The transit accessibility and transit need-based approaches for measuring service gaps was applied to the city of New Haven bus service for representing the validation of the methodology and illustrating the potential for the methodology to be used as a planning tool.

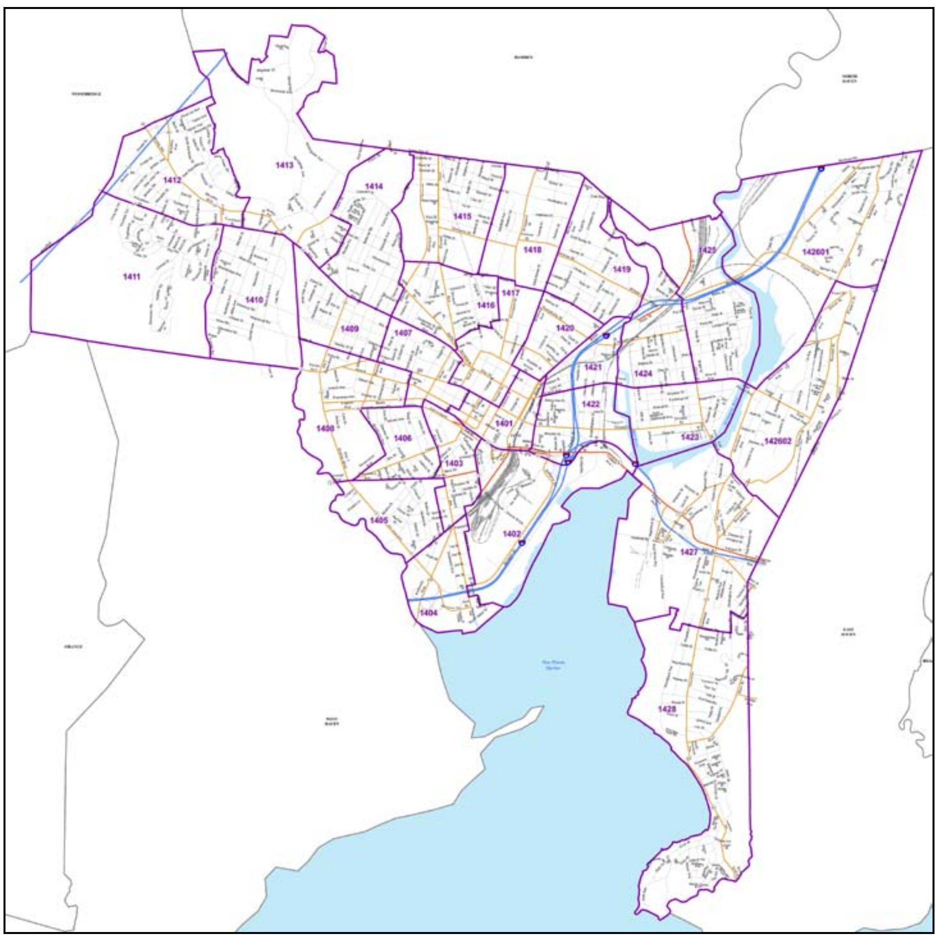

Figure 5.1: City of New Haven, Connecticut
(Source: http://www.cityofnewhaven.com/cityplan/pdfs/Maps/CensusTracts_streets_34x42.pdf)

5.1 STUDY AREA

The city of New Haven (Figure 5.1) had a 2000 population[2] of 123,626 and a land area of 19.22 square miles. The 2000 Census counted 49,358 workers in the study area, giving an overall employment density of 4.01 workers per acre. Transit bus service in the New Haven metropolitan area is provided by Connecticut Transit (CTTransit). CTTransit operates a fleet of 110 passenger vehicles on 20 fixed routes serving 981 transit stops (see Figure 5.2) for this study area. The regular routes provide service every 15 to 20 minutes throughout the usual service span of 5 am to 12 am, which represents frequent transit service compared to that in Meriden.

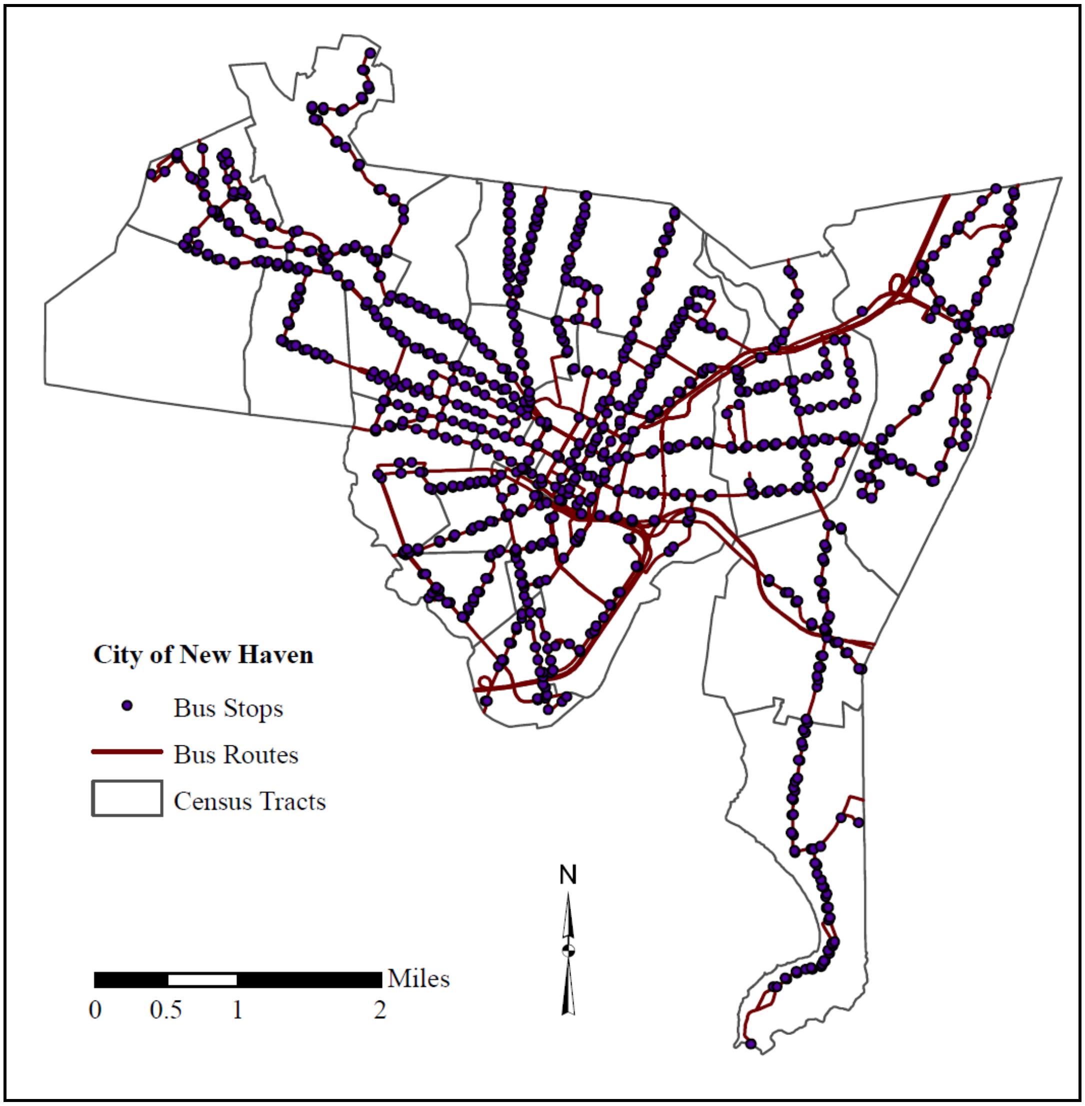

Figure 5.2: Bus Routes and Bus Stops Provided by CTTransit in New Haven, Connecticut

[2] This research used US Census 2000 data for analysis. Census Tract level socioeconomic and demographic data for this study area was not yet available from US Census 2010.

5.2 FRAMEWORK FOR MEASURING SERVICE GAP

The framework for determining the level of service gap for bus service in a study area, in this case, census tracts, consists of several steps. The steps are described as follows:

Step 1: Measure the level of accessibility to transit service using a composite transit accessibility index *(as described in Chapter 3).*

Step 2: Identify the total need for bus transit service, using transit disadvantaged worker characteristics.

Step 3: Determine the gap between current service provision and total need by comparing the two scores determined in **Step 1** and **Step 2**. This approach is identified as ***General Approach*** in this research.

Step 4: Determine service gap using a model-based approach, which requires service characteristics only. This step comprises sub-steps as follows:

- **Step 4.1:** Identify transit disadvantaged workers who use auto as their mode of travel to work which is hereafter defined as the unmet need for bus transit service.
- **Step 4.2:** Examine the relationship between unmet transit need *(Step 4.1)* and transit accessibility measure *(Step 1)* to explore the relationship between the need for service and service characteristics.
- **Step 4.3:** Model the accessibility-based service gap measure using the unmet need for transit service as the dependent variable and service characteristics as the independent variables.

The model-based service gap results *(Step 4)* have been compared with the ***General Approach*** results *(Step 3)* for consistency and effectiveness. Results of the above mentioned steps for New Haven bus service system are described in the following sections.

5.2.1 Transit Accessibility

Figure 5.3 depicts the calculated accessibility scores as measured by the composite accessibility measure for the city of New Haven. The accessibility scores (Table 5.1) quantify three important aspects of public transit accessibility: spatial coverage, temporal coverage, and comfort. This tool is designed to provide a snapshot of the transit accessibility of a town, city, or region. This map provides an answer to the question "Which areas of a town/city/region have good, bad or average access to transit service?"

In this map (Figure 5.3), scores are shown by standard deviation classification, generated with the GIS mapping functions. The areas with very high access to transit service (highest accessibility scores) are shown in the darkest shading, the high scores are in the next darkest, and so on. As shown in Figure 5.3, accessibility scores were highest in the central portion of service area in tracts with high amounts of transit service. The central tracts (i.e., Tracts 1401, 1417, etc.) have high accessible scores due to having frequent (temporal coverage) bus service to and from the tracts (trip coverage). The bus stops in tracts 1401 and 1417 serve most of the New Haven bus routes and have high spatial coverage due to bus stop density.

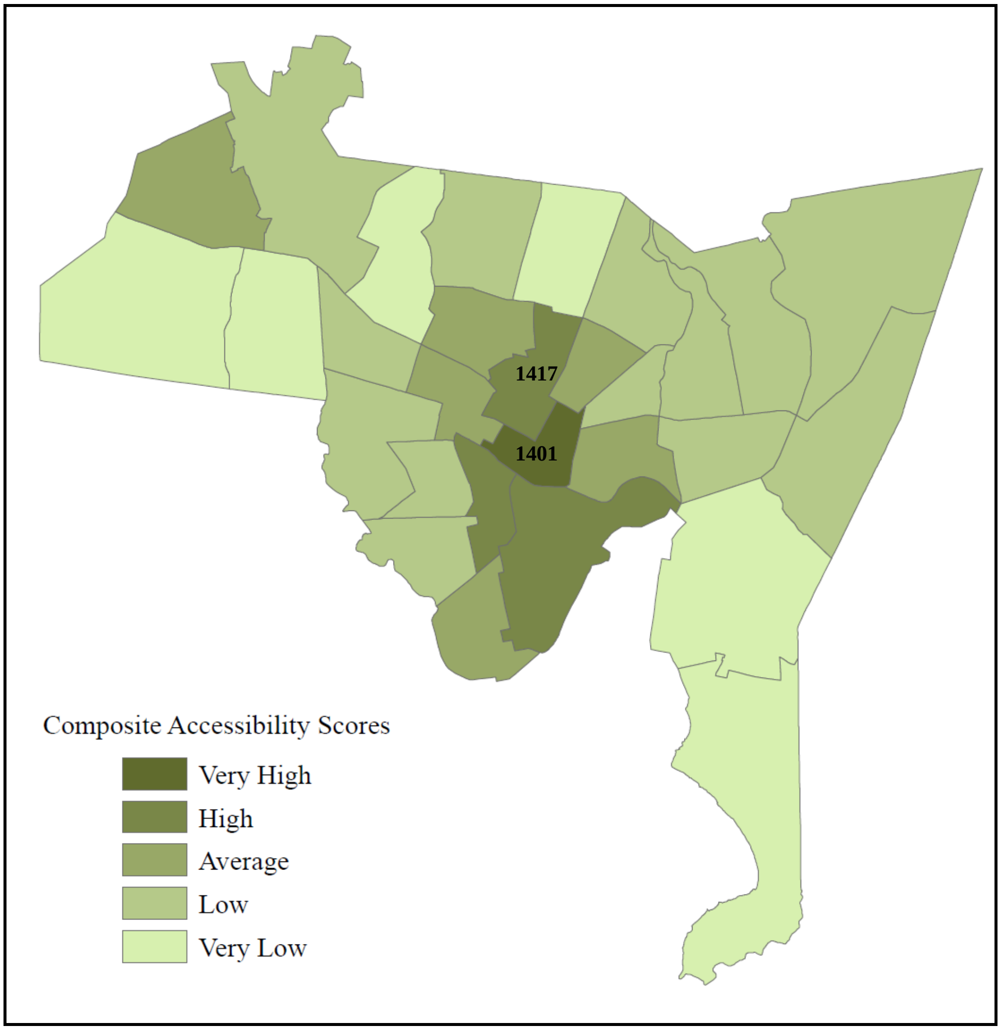

Figure 5.3: Composite Transit Accessibility Scores of New Haven, Connecticut

5.2.2 Transit Need Level

Need for transit service was calculated using the segments of the population who experience barriers to transit services such as the elderly, disabled, and low-income households. In much literature, these segments are often aggregately referred as "Transit Dependent". This research utilizes a metric called "Transit Disadvantaged Workers (TDW)" to identify regions with substantial need for transit service and it is reported as "% of tract population" (Table 5.1).
Census Transportation Planning Products (CTPP) data from the 2000 Census was used to tabulate the percentage of a tract's population that is TDW. TDW are defined as those meeting one or more of the following criteria (classifications are explained in detail in Chapter 4):

1. Low Income Earners: Workers in households with annual income < $30,000
2. Workers over 65 years of age
3. Disabled workers

4. Workers in “Forced” Car Ownership (FCO) households.
5. Workers in Zero car households (ZCO)

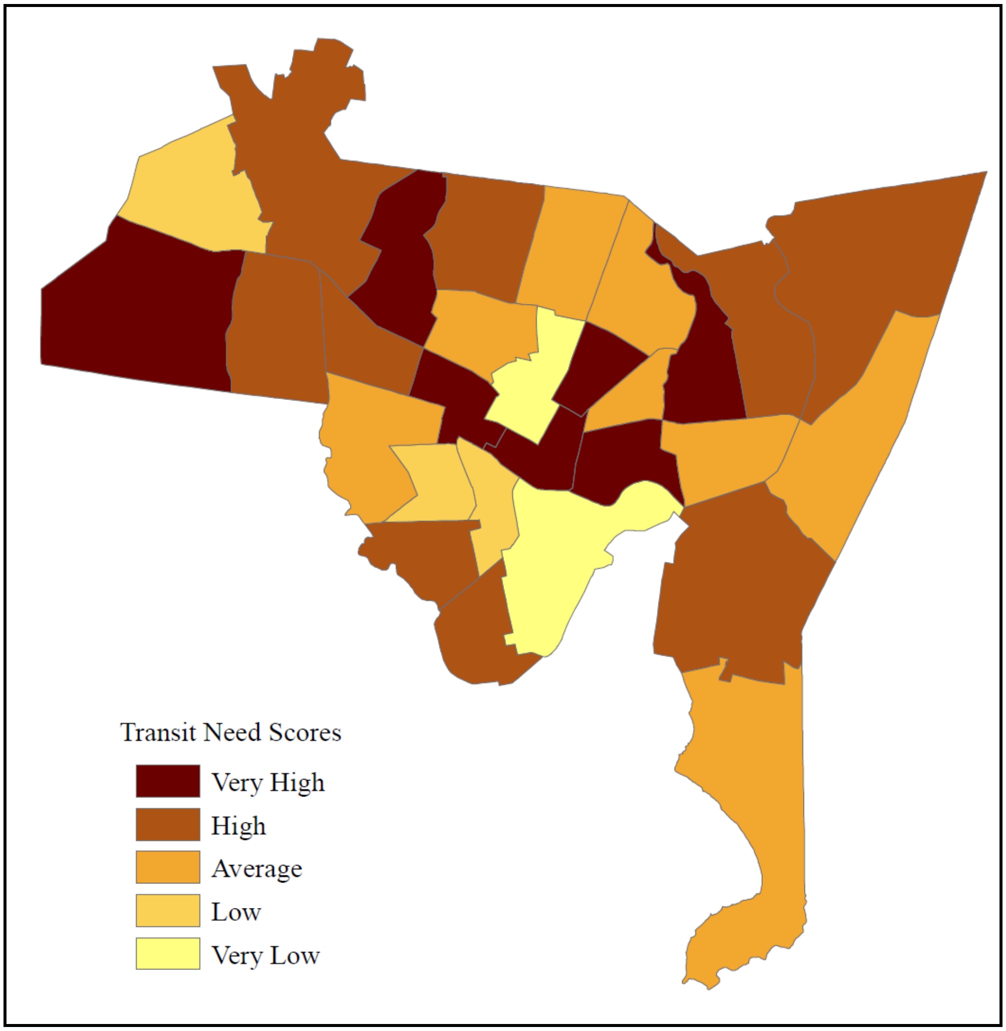

Figure 5.4: TDW as % of Tract Population of New Haven, Connecticut

Figure 5.4 depicts an overview of the need scores throughout New Haven. This distribution of TDW is provided to inform the other side of the accessibility question: “Which areas in a city or town have the greatest need for transit service?” It is worth noting that the distribution of TDW gives a different result that is expected. As one would usually expect that the areas with the highest percentage of TDWs would tend to have the highest degree of access as well (See Figure 5.3). However, there are exceptions for some tracts, and therefore it is required to evaluate the level of service gaps for the identification of priority areas for future investments in transportation infrastructure.

Table 5.1: Service Gap Results From General Approach and Unmet Transit Need Scores

Census Tract	Accessibility Score	Level of Accessibility	Need Score *(TDW as % of Tract Pop.)*	Level of Need	Service Gap *(General Approach)*	Unmet Transit Need Score *(% of Auto-using TDW in a Tract)*
1401	6.01	A (Very High)	28.40	A (Very High)	No Gap	26.37
1402	0.92	B (High)	14.16	F (Very Low)	No Gap	32.79
1403	0.71	B (High)	16.39	D (Low)	No Gap	39.97
1404	0.83	C (Average)	21.62	B (High)	Low	65.85
1405	-0.68	D (Low)	21.72	B (High)	Average	63.93
1406	-0.22	D (Low)	17.24	F (Very Low)	No Gap	46.51
1407	0.63	C (Average)	28.03	A (Very High)	Average	32.16
1408	-0.55	D (Low)	19.50	C (Average)	Low	65.03
1409	-0.24	D (Low)	23.51	B (High)	Average	71.72
1410	-1.30	F (Very Low)	21.67	B (High)	High	70.56
1411	-1.92	F (Very Low)	25.48	A (Very High)	Very High	83.63
1412	0.06	B (High)	16.68	D (Low)	No Gap	52.57
1413	-0.71	D (Low)	24.09	B (High)	Average	52.67
1414	-0.93	F (Very Low)	21.67	A (Very High)	Very High	65.97
1415	-0.29	D (Low)	22.15	B (High)	Average	68.59
1416	0.42	C (Average)	20.65	C (Average)	No Gap	51.92
1417	3.99	B (High)	11.51	F (Very Low)	No Gap	40.00
1418	-0.92	F (Very Low)	20.98	C (Average)	Average	35.36
1419	-0.51	D (Low)	18.25	C (Average)	Low	64.10
1420	0.09	C (Average)	25.39	A (Very High)	Average	50.44
1421	-0.28	D (Low)	21.23	C (Average)	Low	57.71
1422	0.42	C (Average)	24.78	A (Very High)	Average	57.39
1423	-0.78	D (Low)	17.65	C (Average)	Low	65.68
1424	-0.30	D (Low)	25.05	A (Very High)	High	65.91
1425	-0.57	D (Low)	22.01	B (High)	Average	42.52
142601	-0.73	D (Low)	21.78	B (High)	Average	69.58
142602	-0.66	D (Low)	17.85	C (Average)	Low	76.81
1427	-1.22	F (Very Low)	23.58	B (High)	High	72.59
1428	-1.26	F (Very Low)	17.64	C (Average)	Average	93.44

5.2.3 Service Gap: General Approach

The General Approach for measuring service gaps in transit service requires measuring transit need and transit access separately, and then comparing the two scores to measure service gaps or identify transit disadvantaged areas (details in Chapter 4). Here, service gap is defined as the difference between need rating (Figure 5.4) and access rating (Figure 5.3).

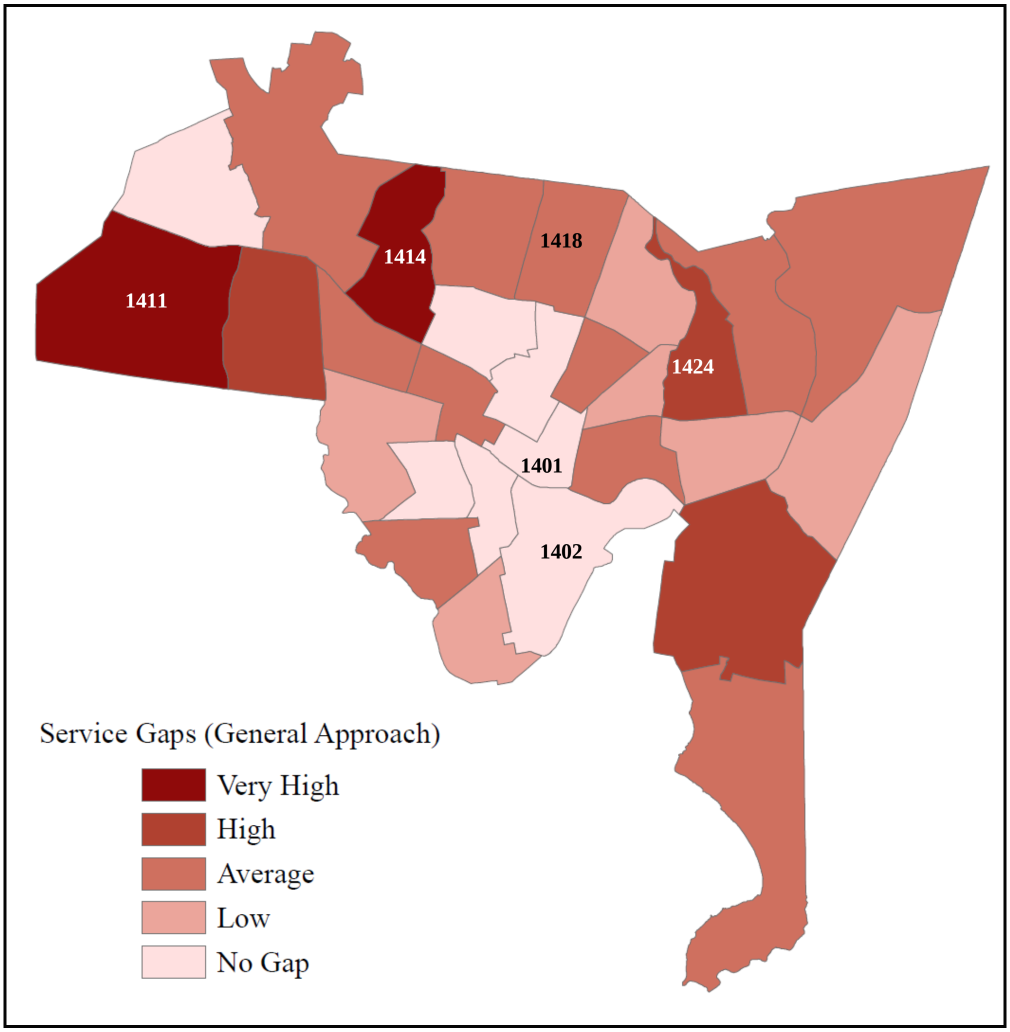

Figure 5.5: Transit Service Gaps *(General Approach)* of New Haven, Connecticut

Figure 5.5 shows service gaps between accessibility and need in a particular tract, with the highest service gap in the darkest shading and no gap in the lightest shading. For example, tract 1411 and 1414 are identified as having a relatively very high transit need (as defined by TDW %). These tracts have very low access and result in a very high "Service Gap" (Figure 5.5). Tract 1424 has very high transit need and low access level, representing high service gaps whereas tract 1418 is an example of average-need, very low-access tract resulting in an average service gap. Tract 1401 has a very high need that is coupled with very high access, resulting in no gap. Tract 1402 is an example of a very low-need, high access and therefore no gap tract. In addition, this tract can be identified as a high development potential tract as it has high access but very low need for this service. The comparison of transit access and transit need scores, and the resulting service gaps are summarized in Table 5.1 for ease of interpretation.

5.2.4 Unmet Transit Need: CTTP Data

A primary objective of this research is to develop a model-based method that can predict the service gap with a single score by using different accessibility attributes. This research determines a measure called "unmet need for transit service" to identify service gaps between transit access and transit need. Unmet transit need was defined as the percentage of auto-using transit disadvantaged workers. Journey to work data for transit disadvantaged workers were collected from the CTPP 2000 database. Figure 5.6 shows the distribution of unmet transit need for each tract in New Haven.

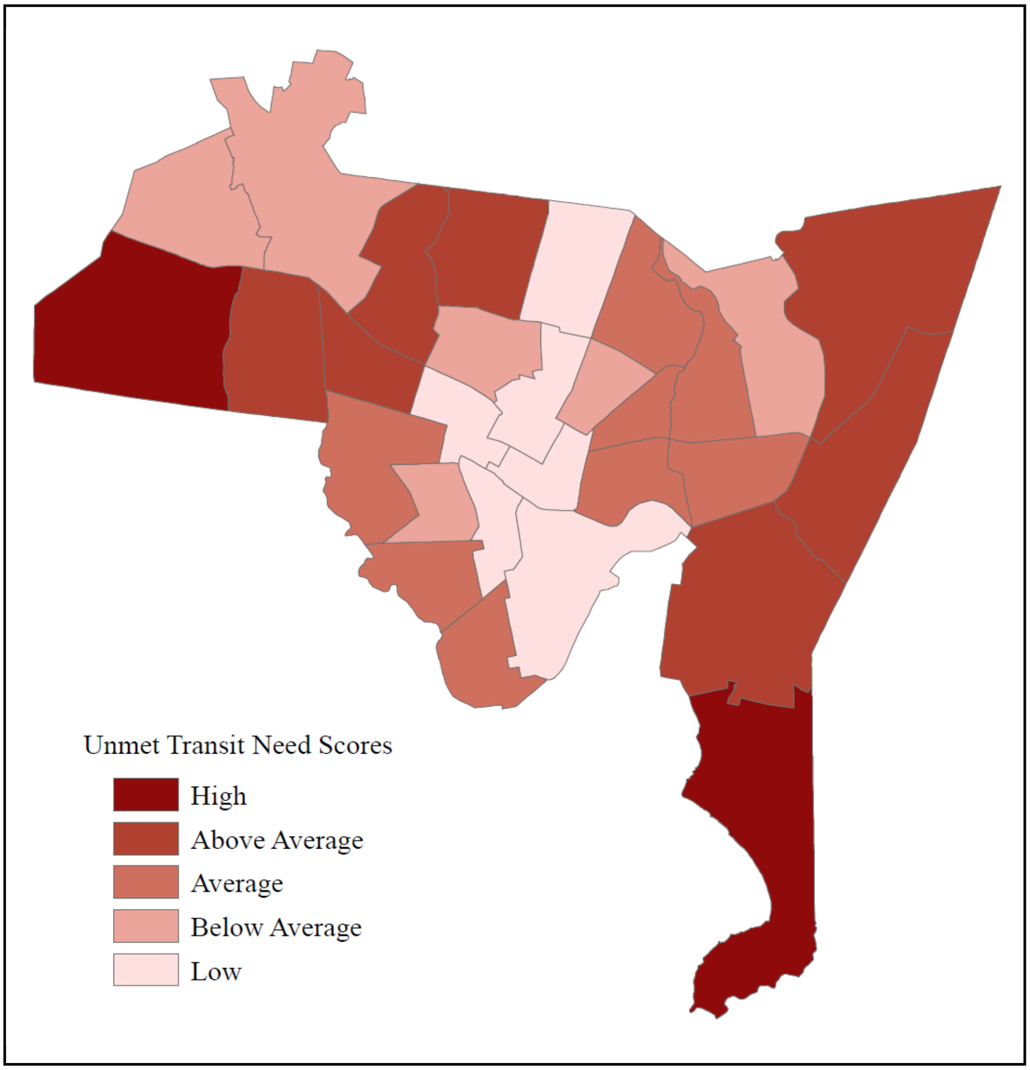

Figure 5.6: % of TDW who Used Auto as Mode of Travel of New Haven, Connecticut

5.2.5 Transit Accessibility as a Function of Unmet Transit Need

The relationship between unmet transit needs (CTPP data) and accessibility scores forms the basis of modeling need as a function of service characteristics. It has been found that unmet transit need is strongly correlated to the lack of transit accessibility for city of

Meriden (Chapter 4). This section provides the validation of this supposition for New Haven. The histogram shows (Figure 5.7(a)) that the unmet transit need scores are normally distributed and can be used for developing statistical models. A hypothesis test (*t-test* at 5% significance level) was conducted to determine whether there is significant relationship between unmet transit need and accessibility scores and it was found that the slope of the regression line (shown in Figure 5.7(b)) differs significantly from zero, which suggests that the unmet transit need is in fact correlated with the lack of service accessibility.

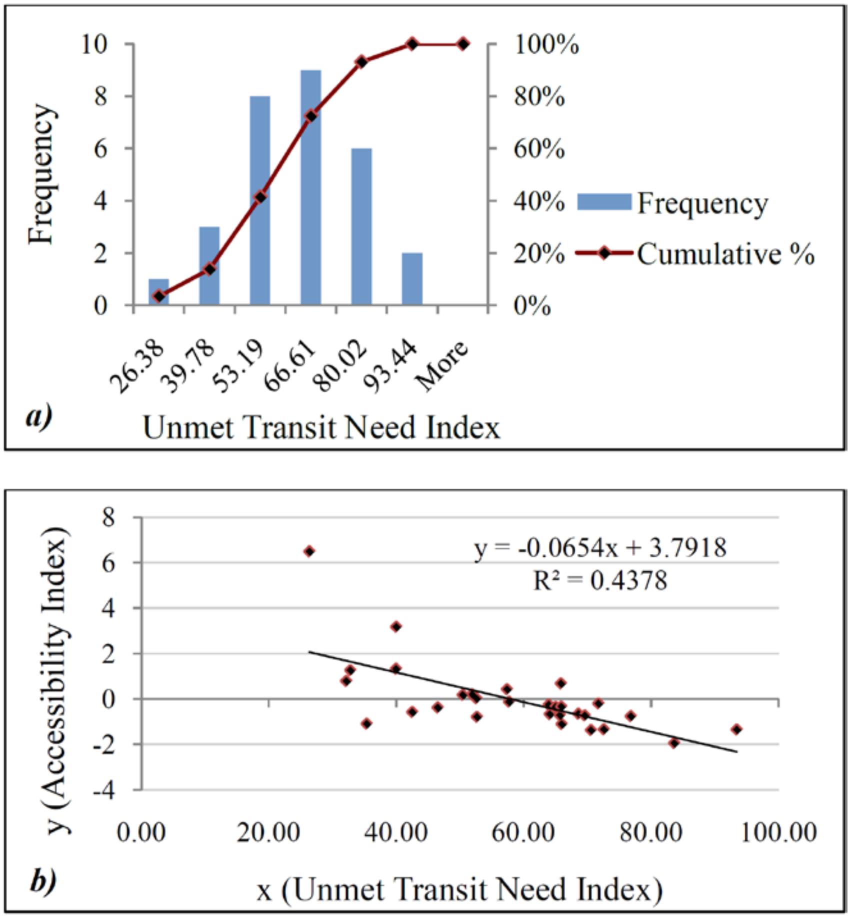

Figure 5.7: Estimation of Linear Function between Transit Accessibility and Unmet Needs (New Haven): (a) Histogram of Unmet Transit Need Index, and (b) Scatter Plot to Examine Relationship

5.2.6 Service Gap: Model-Based Approach

A goal of this portion of the study is to establish a model that estimates service gap based solely on service characteristics that do not require extensive data processing or complicated calculations. Modeling transit need measure as the function of service attributes followed the same methodology described in Chapter 4, and used similar service characteristics as independent variables for New Haven. This research recognizes that the model parameters (Model 1 in Chapter 3) used for Meriden cannot be used for New Haven as service characteristics are completely different (i.e., New Haven has 20 bus routes, 7 times higher than that of Meriden). Hence, a new model equation (Model 2) was formulated for New Haven. The regression analysis results for Model 2 is summarized in Table 5.2 and the functional form for this model is as follows:

Model 2: (for New Haven)

$$\text{Accessibility} - \text{Based Need Index}$$

$$= 98.62696 - 0.42229 * \%\text{SERVICE\_AREA} - 0.04542 * \text{SEAT\_MILE/CAPITA} \quad \textbf{(5-1)}$$

Table 5.2: Accessibility-Based Service Gap Measure Regression Analysis Results

Regression Statistics	
Multiple R	0.66414
R Square	0.441082
Adjusted R Square	0.398089
Standard Error	12.63775
Observations	29

ANOVA

	df	*SS*	*MS*	*F*
Regression	2	3277.060931	1638.530465	10.2592389
Residual	26	4152.529483	159.7126724	
Total	28	7429.590414		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	98.62696	12.43313194	7.932591393	2.0723E-08
%SERVICE_AREA	-0.42229	0.137366985	-3.074194723	0.00491166
SEAT_MILE/CAPITA	-0.04542	0.016625619	-2.732213808	0.01115679

Figure 5.8 depicts the spatial distribution of service gaps obtained from the accessibility-based need index. Service gap results obtained from this model were compared to those from *General Approach* (Figure 5.5) for examining consistency. For ease of interpretation the service gap results obtained from two approaches were assigned a service gap score of 5 for ‘very high service gap” and a score 1, indicating “no service gap” for both measures (shown in Table 5.3).

The difference between service gap results (shown in Table 5.3) shows that majority of census tracts (18 out of 29 tracts) have identical service gap results between two approaches. Only 3 tracts (i.e., 1407, 1420, and 1422) rated lower service gap results in the model-based method. All the three tracts rated as ‘Low’ service gap in modeling approach rather than ‘Average’ service gaps in general approach. For the other 8 census tracts (e.g., 1408, 1428, etc.), the model-based approach rated higher service gap results but did not alter service gap result by more than one level. For example, tract 1428 has an ‘Average’ service gap in the general approach, however it shows ‘High’ service gap in the model-based approach. Therefore, it can be said that the accessibility-based modeling approach tends to rate the tract service gap as higher than the general approach. Furthermore, a chi-square test of goodness-of-fit was performed to determine whether there is significant difference between the model-based frequencies and the general approach frequencies in different service gap categories. The chi-square critical value (*df* $= 4, \alpha = 0.05$) is 9.488, which is greater than the calculated chi-square value of 2.435. Therefore, we failed to reject the null hypothesis and the evidence did not suggest that the distributions are significantly different.

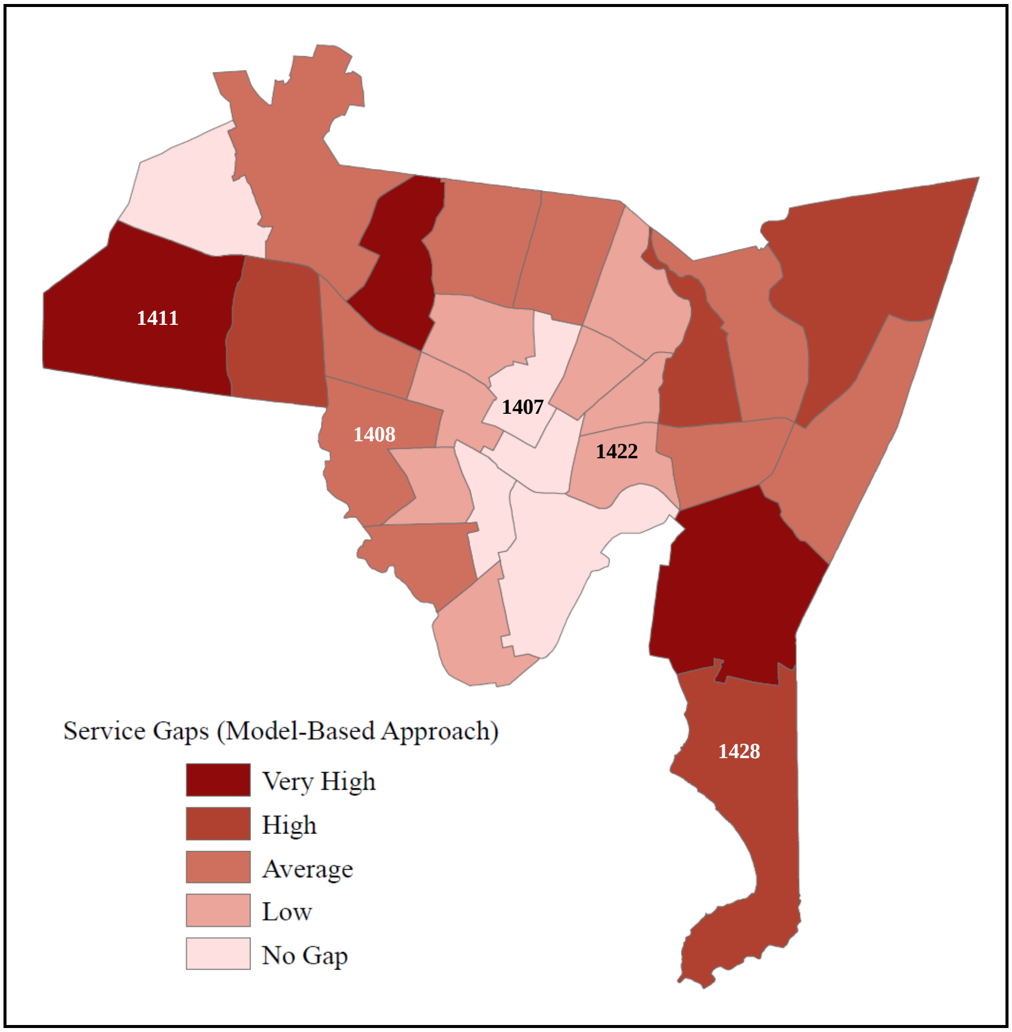

Figure 5.8: Service Gaps *(Model-Based Approach)* of New Haven, Connecticut

The basic idea is that the model-based service gap score, measured with different service characteristics can be used to increase transit accessibility by placing priorities on service improvements. At this point it is difficult to demonstrate the correctness of using service characteristics to estimate unmet need/service gap in census tracts. The model is certainly not transferable to other cities; this is because each city will have different service characteristics in different scales. However, it did accomplish the goal of estimating service gap using only service characteristics.

Table 5.3: Comparison of Service Gap Results Obtained from General Approach and Model-Based Approach

Census Tract	Service Gap		Service Gap Score		
	General Approach	Model-Based Approach	General Approach	Model-Based Approach	Difference
1401	No Gap	No Gap	1	1	0
1402	No Gap	No Gap	1	1	0
1403	No Gap	No Gap	1	1	0
1404	Low	Low	2	2	0
1405	Average	Average	3	3	0
1406	No Gap	Low	1	2	1
1407	Average	Low	3	2	-1
1408	Low	Average	2	3	1
1409	Average	Average	3	3	0
1410	High	High	4	4	0
1411	Very High	Very High	5	5	0
1412	No Gap	No Gap	1	1	0
1413	Average	Average	3	3	0
1414	Very High	Very High	5	5	0
1415	Average	Average	3	3	0
1416	No Gap	Low	1	2	1
1417	No Gap	No Gap	1	1	0
1418	Average	Average	3	3	0
1419	Low	Low	2	2	0
1420	Average	Low	3	2	-1
1421	Low	Low	2	2	0
1422	Average	Low	3	2	-1
1423	Low	Average	2	3	1
1424	High	High	4	4	0
1425	Average	Average	3	3	0
142601	Average	High	3	4	1
142602	Low	Average	2	3	1
1427	High	Very high	4	5	1
1428	Average	High	3	4	1

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This research creates a method for evaluating existing transit services to identify areas with access to transit service and where it is lacking. The survey results provided the current state of practice of measuring overall quality of transit service and identify the important access measures in evaluating quality of transit service. This research examined the benefit of a consistent grading scale across different stakeholder groups and formulated a composite accessibility measure. The 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 covers three important accessibility coverage aspects (i.e., spatial coverage, temporal coverage and comfort). The methodology used for developing composite accessibility measure helps transit planners to 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 composite accessibility scores provides a relative accessibility measure of the degree to which transit is reasonably available and it might be taken as reliable and defendable measure by 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 the certainty is likely to be that the area truly is highly accessible). From policy makers' perspective, assessment of transit accessibility should consider different user viewpoints (i.e., transit planner, provider, property developer, etc.). The composite measure combines three simple methods that encompass several user perspectives.

This research effort further seeks to measure unmet transit need for a clearer picture of accessibility – one that is sensitive to the transit needs of the transit disadvantaged population. The method for evaluating transit need presented in this research was intended to aggregate the volume of transport disadvantaged workers who might be faced with limited mobility options in their community. It was shown that the lack of transit service is highly correlated with large transit disadvantaged populations, suggesting that a relationship exists between these services and demographic characteristics.

A regression model was then estimated for measuring transit service gap based on simple service characteristics. This model was found to provide useful insight into the relationship between unmet transit need and service provision. This research examined the consistency of the model's results with the results of the more data-intensive general approach. The comparison showed that the model was able to identify service gaps in transit service provision in a reliable and defendable quantitative manner.

The model-based service gap scores (i.e., accessibility-based need scores) provide a solid basis for identifying shortcomings in service coverage and examining equity in transit service provision. The accessibility-based transit need distribution can help professionals and policy makers make more informed decisions regarding the design and equitable allocation of transit services. Making equitable allocation of investments in transit service can increase access to community events and jobs for all people, particularly those who have limited transport options. This model-based accessibility measuring tool reflecting the service gaps can also be used as a means to prioritize service improvement options by predicting their effects on service gap scores.

6.2 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

The limiting feature of this research is that this method cannot be directly generalized to everywhere or to those areas 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 socioeconomic and demographic characteristics (i.e., car ownership, income level, etc.) of transit users. In addition, the composite accessibility index can have different meaning 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.

Future research is needed to develop a more accurate measure for estimating service gaps by incorporating more accessibility indicators, such as travel time, pedestrian route connectivity to transit stops, or network connectivity. Improvements are needed in the indices developed if they are to truly capture the passenger's perspective in an accessibility metric. The composite index and need-based index include many aspects important to passengers' perception of access, however, a full understanding and model of the perception of access was beyond the scope of this project and deserves investigation in future work. Addition of network connectivity as an accessibility indicator to this work would add another important coverage aspect (i.e., origin-destination *(O-D)* trip coverage) for transit service. An implication of conducting transit accessibility analysis for the rail service alongside the bus service might be a potential future research option for representing actual level of access to transit services. Further modifications in calculation of current accessibility indicators could be useful in measuring transit accessibility. For example, using a polygon area measure, other than the buffer area based on straight-line distance, could be appended with the improved service area calculation for a transit stop.

Transit disadvantaged population data, other than the transit disadvantaged worker, might provide a strong measure for estimating neediest populations with mobility problems. As an improvement upon this work, the current analysis technique could be enriched by using updated available socioeconomic and demographic data from Census 2010.

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APPENDIX A

A.1 SURVEY QUESTIONNAIRE

1. What type of agency are you?

- ❑ Public transit system
- ❑ Government human services agency
- ❑ Regional Planning organization/ Association
- ❑ Private nonprofit human services agency
- ❑ Private nonprofit transportation provider
- ❑ Private for-profit transportation provider
- ❑ Other (Please specify): ____

2. What types of service does your agency provide?

- ❑ Fixed-Route City Bus (FR)
- ❑ Demand-Response Small Vehicle (DR)
- ❑ Both Fixed-Route City Bus (FR) and Demand-Response Small Vehicle (DR)
- ❑ Deviated Fixed-Route
- ❑ Express Service- Commuter-oriented Express Bus Service
- ❑ ADA Paratransit
- ❑ Accessible Taxi
- ❑ Shuttle Service
- ❑ Rail
- ❑ Other (Please specify): ____

If you are a Transit Provider please complete **Part 1** and **Part 3**
If you are a Transit Planner please complete **Part 2** and **Part 3**

Part 1: Transit Provider (Q. 3 – Q. 9)

3. Please provide your agency's regular service times for the periods listed. *(Or please attach schedule brochures or provide website address regarding service schedule)*

Monday to Friday: ____ to ____

Saturday: ____ to ____

Sunday: ____ to ____

Website: ____

Please provide a list of total number of vehicles and their capacity that your agency operates for transportation service.

Vehicle Type		Seating Capacity	Number of Vehicles
Bus	Passenger Van		
	Mini Bus		
	Midsize Bus		
	Standard City Bus		
	Suburban Service Bus		
	Double-Decker Bus		
	Articulated Bus		
	Tractor-Trailer Bus		
	Trolley Bus		
	Other		

Vehicle Type		Number of Vehicles
Rail	Heavy Rail/Metro	
	Commuter/Regional Rail	
	Light Rail/Tram	
	Streetcar/Trolley	
	Other	

5. At what spatial level is transit service data collected? *(Please check all that apply)*

- ❑ Parcel
- ❑ Census Block
- ❑ Traffic Analysis Zone (TAZ)
- ❑ Census Tract
- ❑ Regional
- ❑ Other (Please specify): __________
- ❑ Not Applicable

6. What type of area are you serving?

- ❑ Urban
- ❑ Suburban
- ❑ Rural
- ❑ Other (Please specify): __________

7. What is the method(s) used at your agency to collect transit data? *(Please check all that apply)*

- ❑ O/D studies
- ❑ Ride checking by transit staff
- ❑ Electronic Registering Fare boxes (ERFs)
- ❑ Smart cards
- ❑ Mobile Data Terminals (MDTs)
- ❑ Automatic Passenger Counters (APCs)
- ❑ Automated Vehicle Location (AVL)
- ❑ Other (Please specify): ______________________
- ❑ Not Applicable

8. Please specify the service area size of your transportation service. *(Please provide as much detail as possible)*

No. of Counties: __________

No. of Towns: __________

Square Mileage: __________

Other (Please specify): ______________________

9. Listed below are a number of possible coordination activities with mobility planners/co-operative agencies you undertake or wish to undertake to improve access to public transit. Please indicate your agency's current status in these coordination activities by checking the appropriate box and listing the coordinating agency(s).

Coordination Activity 1: *Providing transportation services, or more transportation services, under contract to another agency.*

- ❑ Activity currently exists
- ❑ Interested to undertake
- ❑ Not interested
- ❑ Unavailable

Name of the Agency(s):

Barriers:

Part 2: Transit Planner (Q. 10 – Q. 11)

10. Do you use any Origin-Destination (O-D) data in your planning model?

- ❑ Yes
- ❑ No

If **"Yes"**, Please answer the following questions.

What is the geographic extent of your Planning model?

Counties: [ ]

Towns: [ ]

Mileage: [ ]

When the O-D data was last updated? [ ]

What is the source of this O-D data?

[ ]

How does O-D data contribute to your planning activities?

[ ]

What are the sources of travel demand/census data that you used in your planning model?

[ ]

11. What type of travel demand modeling information do you use in your planning activities? *(Please check all that apply)*

- ❑ No. of Cars Available
- ❑ Household Income
- ❑ Population Density
- ❑ Employment Density
- ❑ Total Land Area
- ❑ No. of Drivers in Household
- ❑ No. of Adults in household
- ❑ Land Use
- ❑ Race
- ❑ Age
- ❑ Education
- ❑ Other (Please specify): [ ]

If you use *Cars available* data, please explain how car ownership/cars available data does assist your planning activities.

If *Household income* is considered, please specify the threshold value for low income:

- ❑ Annual Income Less than $15,000
- ❑ Less than $20,000
- ❑ Less than $30,000
- ❑ Less than $40,000
- ❑ Other (Please specify):

Part 3: Transit Provider & Planner (Q. 12 – Q. 17)

12. Please rank each of the following measures on a scale of 1 to 10 indicating the measure's importance in maintaining and improving access to public transportation services in your service area, where 1 is the most important and 10 is the least important. *(Please use each number only once)*

Accessibility Measures	Rank
More Bus Routes and Stops and More Areas Served	
More Frequent Service and Better Service Span	
Stop Area Development Density	
Trip Coverage	
Better On-time Performance	
More Parking Availability	
Safer Environment at Stops and Shelters	
Better Pedestrian Access to/from Stops	
Encouraging Interaction Across Modes (i.e. Bike Racks)	
Better Serving Disadvantaged Population (i.e. Limited Income, Poor English Proficiency)	

13. From your perspective, what are the most critical gaps/unmet needs (in service or other areas) in your provided public transportation/transit service?

14. What are the top challenges/barriers facing passenger transportation/transit in your service area?

15. What are the opportunities in your community/county/service area for expanding, improving, and enhancing passenger transportation/transit?

16. What strategies do you employ to increase the efficiency/level of service of your transportation operations?

17. Do you have any additional comments or insights you'd like to share?

APPENDIX B

B.1 SUMMARY OF RESPONSES

There were 13 agency responses to the survey. Among them eight (8) agencies were Transit Providers, five (5) agencies were Transit Planner.

Q.1: AGENCY TYPE

Seven (7) of the eight (8) Transit Provider agencies were public transit system agency and one (1) was both the public transit system and private for-profit transportation provider. All the five (5) Transit Planner agencies were regional planning organization.

Q.2: SERVICE TYPE

A majority of Transit Provider agencies reported providing ADA Paratransit and both FR and DR service, followed by shuttle service, fixed route, and express service. (Respondents were checked all that apply).

Service Type Provided								
Service Type	Fixed Route (FR)	Demand-Response (DR)	Both FR and DR	ADA Paratransit	Shuttle Service	Express service	Deviated Fixed Route	Other
# of responses	**2**	**1**	**5**	**5**	**4**	**2**	**1**	**2**

Transit planning agencies reported their service types as transportation planning, coordination with providers, funding, and providing technical assistance in planning.

<u>Transit Provider Response (Q3 – Q9)</u>

Q.3: SERVICE HOURS

Of the agencies responding, most provide transit service Monday thru Friday and Saturday each week. Only two out of eight agencies indicated Sunday service is not available.

Hours and Days Transportation Services are Provided	
Days of the Week	**Hours Range**
Monday to Friday	6:00 am – 10:30 pm
Saturday	8:00 am – 10:30 pm
Sunday	9:00 am – 7:00 pm

Q.4: VEHICLE CAPACITY

All the responding transit providers operated bus system with different bus types. Majority of respondent agencies used Mini Bus, Midsize Bus and Standard city Bus to serve the passengers.

Vehicle Capacity					
Vehicle Type (capacity)	Mini Bus (8-16)	Midsize Bus (14-30)	Standard city Bus (27-46)	Suburban Service Bus (57)	other (38)
# of responses	**7**	**5**	**7**	**1**	**1**

Q.5: DATA COLLECTION LEVEL (SPATIAL)

Of the eight (8) responses, three (3) indicated they collect data at service route level and two (2) responded they collect data at census tract and regional level.

Q.6: SERVICE AREA TYPE

Most of the responding transit providers are serving urban and suburban area. (Respondents were checked all that apply).

Service Area				
Area Type	Urban	Suburban	Both Urban and Suburban	Rural
# of responses	**1**	**1**	**6**	**2**

Q.7: METHOD OF TRANSIT DATA COLLECTION

A majority of Transit Provider agencies reported they collect transit data using ride checking by transit staff, followed by electronic registering fare boxes. (Respondents were checked all that apply).

Collection Method(s)	**No. of Responses**
Ride checking by transit staff	7
Electronic registering fare boxes	6
O/D studies	2*
Automatic passenger counters	2
Passenger surveys	2
Mobile data terminals	1
Automated vehicle location	1
Other	2

**Norwalk Transit District*

Q.8: SERVICE AREA SIZE

The most frequent size of transit service area for the responded transit providers are summarized as follows:

Area Type	Range	Mode	Mean
No. of Counties	1 – 4	2	N/A
No. of Towns	6 – 17	9	N/A
Square Mileage	124 - 625	N/A	-

Q.9: COORDINATION ACTIVITY

Coordination Activity 1: *Providing transportation services, or more transportation services, under contract to another agency.*

Current Status	No. of Response
Activity currently exists	8
Interested to undertake	0
Not interested	0
Unavailable	0

Barriers:

- FTA charter bus regulations
- School bus regulations
- Funding limitations

Coordination Activity 2: *Joining together with another agency or municipality to consolidate the operation of transportation services.*

Current Status	No. of Response
Activity currently exists	5
Interested to undertake	1
Not interested	2
Unavailable	0

Barriers:

- Consolidation of operation with other transit agencies is a ConnDOT decision.

Coordination Activity 3: *Purchasing transportation services from another organization, assuming that the price and quality of service met your needs.*

Current Status	No. of Response
Activity currently exists	1
Interested to undertake	0

Not interested	7
Unavailable	0

Barriers:

- Purchase of service is a ConnDOT decision.
- Would lead to organized labor issues
- Service quality and control

Coordination Activity 4: *Coordinating schedules and vehicle operation with nearby paratransit providers so that riders can transfer from one service to another.*

Current Status	No. of Response
Activity currently exists	5
Interested to undertake	2
Not interested	0
Unavailable	1

Barriers:

- Interstate operating issues.
- Lack of coordination and cooperation among different type of services in different districts.

Coordination Activity 5: *Highlighting connections to other fixed-route or demand-responsive services on your schedules or other information materials.*

Current Status	No. of Response
Activity currently exists	8
Interested to undertake	0
Not interested	0
Unavailable	0

Barriers:

- Frequent change of schedule for MTA transit service.

Coordination Activity 6: *Adjusting service hours or frequency of service.*

Current Status	No. of Response
Activity currently exists	6
Interested to undertake	2
Not interested	0
Unavailable	0

Barriers:

- Inconsistent holiday (year to year) schedule for MTA transit service.

Other Coordination Activity:

Current Status	No. of Response
Activity currently exists	Shared office space, Jobs Access Human service transportation
Interested to undertake	Workforce connection

Transit Planner Response (Q.10 – Q.11)

Q.10: USE OF O-D DATA IN PLANNING MODEL

Of the five (5) Transit Planner agency responses, only one replied they use O-D data in their planning model. The geographic extent of their planning model is counties and source of this O-D data is TBD (Transportation Benefit District). This use the O-D data to forecast travel demand.

Q.11: TYPE OF TRAVEL DEMAND MODELING INFORMATION

Only one transit planning agency of the five responding agencies uses travel demand modeling information in their planning activities. It uses number of cars available data, household income, land use data and mode of transportation sector data in operational transit planning.

Transit Provider/Planner Response (Q.12 – Q.17)

Q.12: RANKING OF ACCESSIBILITY MEASURES

Accessibility measures	Average Ranking	Ranking
More Bus Routes and Stops and More Areas Served	2.5	**2**
More Frequent Service and Better Service Span	1.9	**1**
Stop Area Development Density	7.7	**9**
Trip Coverage	6.9	**8**
Better On-time Performance	5	**4**
More Parking Availability	8.4	**10**
Safer Environment at Stops and Shelters	5.7	**5**
Better Pedestrian Access to/from Stops	4.8	**3**
Encouraging Interaction Across Modes (i.e. Bike Racks)	6	**7**
Better Serving Disadvantaged Population (i.e. Limited Income, Poor English Proficiency)	5.8	**6**

Q.13: UNMET TRANSPORTATION NEEDS

- Increased services, improved reliability, expanded service hours, increased capacity on existing routes
- Simplified routing, increased frequency, additional and improved shelters
- More service to commuters during the midday and later in the evening
- Integrated statewide fare policy/ fare collection technology
- Funding for additional service to overcrowding and improve on-time performance
- Poor bus route connection to the job centers, enhanced inter-district connections
- More cross-town service, additional interregional services
- Real time travel information- delays, location, next arrival (for commuter rail)
- Adjusted frequency of local service to enable service to interface with rail and other bus service
- Increased/enhanced elderly & disabled service
- Increased consideration of transit in new developments (access between developments and transit)
- Planning for steady investment in transit operations
- Ability to transfer to other agencies from one agency
- Increased headways, dedicated transit stops and corresponding schedules
- Increased parking, Transit oriented development and provision of ITS where opportunities exist

Q.14: TOP CHALLENGES/BARRIERS

- Lack of Funding to allow expansion of bus service – additional operating subsidies not available
- Delays in completing projects
- Lack of capacity
- Aging infrastructure
- Determination of long term viability of routes and location of stops based on passenger boarding in formation
- Lack of funding to recruit full-time employer, for ADA transit services
- Larger travel time, shorter hours of service
- Increased fuel and operating costs
- Inconsistent operating funding and public awareness of services
- Rider parking and bus size (too small) is a major concern on shuttle routes
- Lack of compatible fare collection equipment

Q.15: EXPECTED OPPORTUNITIES

- Extended Evening service
- Potential for more integration of fixed-route and paratransit service
- Provision of joint local bus service
- Coordination of land use and public transportation
- Access of shuttle transit to the rail station
- Improved on-time performance, Increasing headways on key bus routes

- Providing expanded rail parking
- Implementing ITS at transit facilities

Q.16: STRATEGIES TO INCREASE EFFICIENCY

- Use of scheduling software, efficient scheduling and run-cutting (operator assignment)
- Dedicated funding source
- Interlining fixed routes to maximize schedule maintenance, adding deviated trips to address specific needs
- Continuing evaluation of existing and new origins and destinations
- Surveying customers to determine their needs
- Monitoring of driver performance
- Periodic reviews of route performance (ridership, revenue, productivity)
- Marketing of transit services
- Operational analyses of different services
- AVL and camera system on buses