Understanding How the Built Environment Around TTA Stops Affects Ridership

A Study for Triangle Transit Authority

December 2006

Department of City and Regional Planning, CB 3140 New East Building,
University of North Carolina, Chapel Hill, NC 27599, USA

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PLAN 823 Fall Workshop

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Sitting near a TTA bus in Chapel Hill

EXECUTIVE SUMMARY

This study determines the characteristics of urban development that related to Triangle Transit Authority (TTA) bus ridership levels in the Triangle region of North Carolina. While transit offers an alternative to driving, development patterns around stations must support transit use if significant ridership is desired. By analyzing the built environment – including the design, density, diversity, and destinations around bus stops – this study offers local decision makers ideas to improve the planning of these areas.

The predominately suburban form of the Triangle region raises the question of how well previous findings apply to this area. As a southern area with mostly postwar growth, the Triangle's urban form is distinct because it contains several city centers which surround a low-density research park. Furthermore, the Triangle relies on bus-based services to provide regional transit connectivity – different from previous studies that relate urban form to transit around rail service. It is relevant to examine the unique features of development and transit in the Triangle to assess their relationship more accurately, offering new information useful to municipalities, counties and transit operators in the area.

Using a proportional random sample of both 'urban' and 'not urban' stops, we collected data about the built environment around 148 bus stops in the Triangle area. In addition, we compiled secondary GIS data and transit service supply information for each stop. With this data, we used regression analysis to relate TTA boardings and alightings to the characteristics of each stop and its surroundings.

Our results suggest total boardings and alightings have a significant relationship with bus stop amenities, quantity of destinations, building and site design, and number of buses serving a stop. The pedestrian and bicycle environment was also relevant. The amount of neighborhood features and the intersection density were significant, but had an impact on ridership contrary to expectations.

While our results cannot be necessarily considered the cause of higher or lower transit use, our findings maintain the importance of a built environment that supports, and perhaps encourages, transit use. As a result, we conclude that policies which create a transit supportive environment, including provisions for bus stop shelters, mixed-use developments, and smaller setbacks, would prove fruitful strategies for developers, transportation, and land use planners in the area. Although our study focused on the Research Triangle area, these results may also be useful to similar areas relying on bus transit to provide regional public transportation connectivity.

1. INTRODUCTION

As concerns grow about pollution, global warming, congestion, and other problems related to transportation, many regions are working to enhance public transit networks to give residents more travel options. As cities expand and improve their transit systems, it is important to consider the relationship between the environment around transit stop and ridership. Much of the existing research examining the relationship between the built environment of a city and the mode of travel used by its residents have centered around several environmental characteristics that may increase transit ridership – ***density***, urban ***design,*** land use ***diversity***, *and* ***destinations***.

Figure 1.1: Transit Oriented Development (TOD), above; and Transit Adjacent Development, (TAD), below.
Source: Transit Oriented Development in the United

The built environment near transit stations varies widely across different cities and as well as different locations within the same city. Generally, development around a transit stop can be characterized as either transit-oriented or transit-adjacent. Transit Oriented Development (TOD)—development that is supportive of transit—has high quality walking environments, mixed land uses, and higher density. Transit Adjacent Development (TAD), on the other hand, is less conducive to transit ridership. TAD usually has large areas dominated by single uses, conventional parking requirements, and other characteristics that tend to favor automobile use. TAD is a less desirable form of development because it reduces and limits access from a transit stop to destinations.

This study identifies the characteristics of the built environment in the Research Triangle area that significantly affect transit ridership, using primary audit data and secondary or archival geographic information system (GIS) measures. Identifying the components of the urban landscape that affect transit use is the first step in understanding how to plan transit-supportive development. By using the results of this study, local governments, planners, transit officials, and developers can work together to create environments that are more supportive of public transit.

The Triangle Area

The Research Triangle is a rapidly growing metropolitan region located in central North Carolina. The three major cities that form the Triangle are: Raleigh in Wake Country, Durham in Durham County, and Chapel Hill in Orange County (See Figure 1.1). The Triangle region is also home to the University of North Carolina at Chapel Hill; Duke University and North Carolina Central University in Durham; and North Carolina State University in Raleigh.

The Triangle spans over 1,500 square miles, and the built environment is composed predominantly of low-density development. The area has grown rapidly over the past few decades and is expected to continue its current rate of growth into the near future. Most of its growth has occurred around principal cities, with the Research Triangle Park and the Raleigh-Durham International airport near the center of the region. Between 1970 and 2000 the area population grew from 419,000 to 967,000: a 131% growth rate over 30 years.[1] The population rose another 21% percent between 2000 and 2005, to 1.1 million people, and is projected to grow to 1.9 million by 2030.[2] This growth has been fueled primarily by job increases in the area; the number of jobs rose 30% from 1990 to 2000.[3]

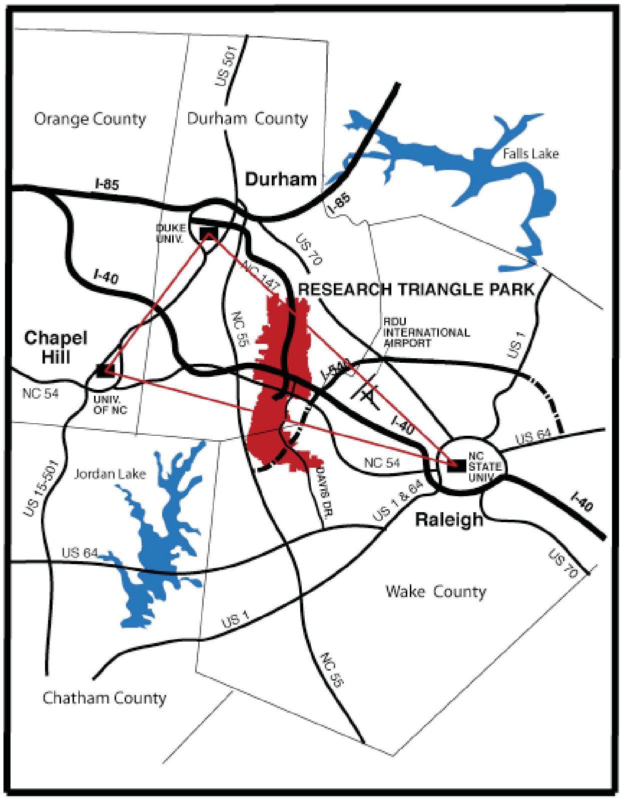


Figure 1.2: The Triangle region has three major urban areas that have shaped travel throughout the region.
Source: Research Triangle Foundation
www.rtp.org/index.cfm?fuseaction=page&filename=maps.html

Dispersed development patterns have resulted in long distances between housing, employment, and commercial areas. This low-density development was the prevailing form of development during the second half of the 20th century when much of the region's growth occurred, and its negative consequences are becoming apparent as population continues to grow. Though downtown areas in Raleigh, Durham, and Chapel Hill are currently seeing increases in dense development, density in the area as a whole remains low. Increasing congestion is occurring on major roadways, and the presence of a single interstate accident can cause significant delays for thousands of people. Due to increased pollution caused in part by automobile emissions, the Triangle counties are classified as federal non-attainment areas for ozone levels under the Clean Air Act. This means that unless ambient air pollution can be decreased and controlled, the region faces the loss of federal transportation funding and other sanctions. In addition to presenting these challenges, the low-density patterns in the Triangle are below the average densities needed to support frequent transit service, presenting local transit agencies with many challenges for providing efficient, cost-effective service.

The Triangle Transit Authority

The Triangle Transit Authority (TTA) was created in 1989 to provide regional transit services in Wake, Durham, and Orange counties. TTA provides regional bus, paratransit, and vanpool service for the Triangle. The agency also has input

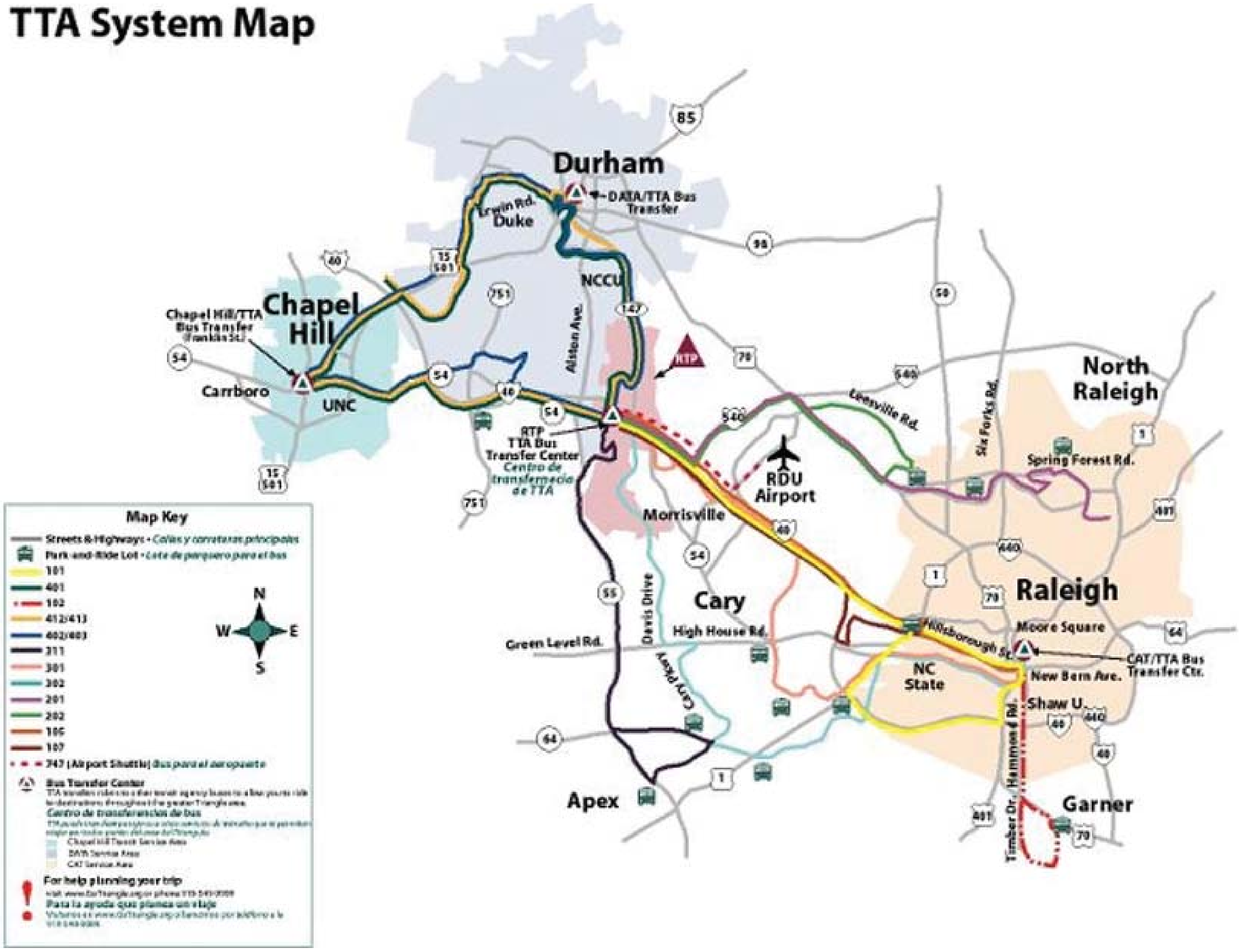


Figure 1.3: The Transit Triangle Authority System. Source: TTA, www.ridetta.org.

into plans for improving regional transportation. TTA operates sixteen routes and four shuttles Monday through Friday and three routes and one shuttle on Saturday. TTA currently focuses primarily on commuter transportation, as evidenced by its route schedules. TTA serves Raleigh, Durham, Chapel Hill, and the Raleigh-Durham International Airport six days a week. Peak service is also provided to other local municipalities including Cary, Apex, Garner, Hillsborough, and Morrisville. Service throughout Research Triangle Park is provided by a shuttle from a terminal and transfer center in RTP. The most heavily used corridors in the system are the RTP-Raleigh corridor (served by routes 105 and 107) and the downtown Durham-Chapel Hill corridor (served by routes 402, 403, 412, and413).

Service improvements and recent increases in gas prices have pushed ridership to record levels. TTA buses currently carry an average of more than 68,000 passenger trips per month, and vanpools carry an average of 33,000 passenger trips per month. Ridership in the 2006 fiscal year was 817,000, nearly an 8 percent increase over 2005 and a 15 percent increase over 2004. TTA is researching ways to expand its service and attract riders. Long-range projects include providing bus services to more outlying communities, such as Holly Springs, Fuquay-Varina, Wake Forest, Knightdale, and parts of Morrisville not currently served. Planning routes and anticipating ridership in these areas will be aided by any findings about the relationship between the built environment and boardings and alightings.

The demographic profile of TTA riders differs from other metropolitan areas due to the commuter focus and regional coverage of the system. The most recent data on rider characteristics comes from a ridership survey conducted in October 2003.[4] TTA riders were largely male (57 percent) and under the age of 40 (61 percent). In terms of ethnicity, the largest proportion of riders was African-American (48 percent), followed by white (34 percent), Asian (8 percent), Hispanic (5 percent), and Native American (1 percent), with 5 percent identifying themselves as Other. Riders using TTA five or six days per week were more likely to be minorities than more infrequent riders. TTA riders were relatively evenly distributed throughout a range of incomes. Notable, however, is that the largest group of riders among income groups was the lowest income group, with household income of less than $10,000 per year (17 percent). Other than this low-income group, the next largest proportions of riders came from the ranges $25,000-$34,999 (15 percent), $50,000-$74,999 (15 percent), $20,000-$24,999 (14 percent), and $35,000-$49,999 (12 percent). Though the large proportion of low-income riders is expected because these riders are unlikely to have alternatives to transit, a relatively large proportion of riders come from middle- and high-income households. The income statistics indicate that TTA buses serve people with a ride range of ages, ethnicities, and incomes.

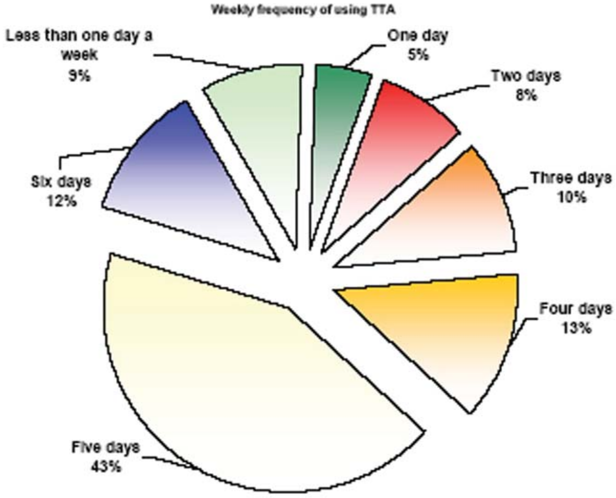
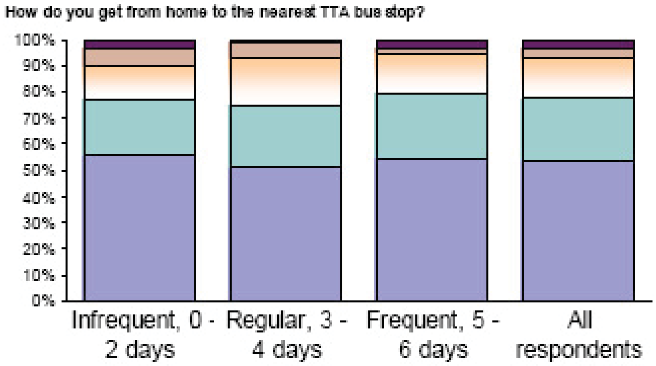


Figure 1.4: TTA Usage Pattern
Source: TTA. A Report on an Onboard Survey, 2003.

TTA's focus as a commuter service is evident in trip purposes reported by riders. Sixty-three percent of trips were for work and 15 percent for post-secondary education, meaning that seventy-eight percent of trips were commuting trips. People who rode infrequently (less than two days per week) took more trips for shopping or recreation. Sixty-eight percent of riders used TTA four or more days per week, indicating regular use. Of these, 48 percent used TTA five days per week, an indication of daily commuters during the traditional work week. Still, more than half (54 percent) of Saturday riders said they used TTA to get to work. It is evident from these figures that the majority of TTA riders are riding the bus to get to work or school, a regular commitment, regardless of day of the week. Another interesting fact is that a larger proportion of frequent users started riding TTA because of a promotion than infrequent users. This indicates that attracting users to try commuting or using TTA regularly may increase ridership more than marketing TTA for more irregular shopping or recreational trips.

Many TTA riders are choice riders, meaning in this case that they have cars or other motor vehicles available to make their trips. Fifty percent of riders had a car or other vehicle available; of these riders, 16 percent had two or more vehicles available. Though this also means that fifty percent of all riders did not have a car available, this distribution of automobile ownership is different than many transit agencies. A relatively high percentage of riders have cars available, compared to a typical transit system. This makes sense given the income characteristics reported by riders in the survey, which showed that many riders have household incomes that would support ownership of one or more motor vehicles. This is a positive statistic, showing that some Triangle residents are willing to use transit even when alternatives are available. It may also indicate that some residents are frustrated with congestion and other problems of automobile use in the area.

All TTA riders have to travel to access bus stops, and the mode used to reach the stop is important. More than half (53 percent) of riders walk to access bus stops, while 27 percent connect from local bus services. Sixteen percent of riders drive to the bus stop, which is notable for transit services in general but not unexpected in a largely suburban region. The percentage of people walking to the stop is lower than local bus systems such as Raleigh’s Capital Area Transit, where 89 percent of riders surveyed walk to the stop. The regional nature of TTA service means that many of its riders travel long distances, with an average bus trip duration of 44 minutes. In addition, many riders have to transfer, with 76 percent of riders reporting one or more transfers. People may be more likely to connect from local services, other TTA buses or their cars (through park and ride services) on a system such as TTA because the percentage of time spent in transfer between modes is low in proportion to the total trip time from origin to destination.



	Infrequent, 0 - 2 days	Regular, 3 - 4 days	Frequent, 5 - 6 days	All respondents
■ Other	3%	1%	3%	3%
■ bike	7%	6%	2%	4%
□ car	13%	18%	15%	15%
■ local bus other than TTA	22%	24%	25%	24%
■ walk	56%	51%	54%	54%

Figure 1.5: Mode of Travel to TTA Bus Stops (categorized by frequency of riding TTA)

Source: TTA. A Report on an Onboard Survey, 2003.

Almost half of TTA riders reported using the service for less than one year (48 percent). A total of 73 percent of riders reported using TTA for two years or less. This indicates that many riders are new riders. This may reflect the fact that TTA has added service to new areas in recent years. Indeed, an even higher proportion of riders would be expected to be new riders at present because of the role of increasing gas prices in increasing ridership. However, 26 percent of riders reported using TTA for three or more years, indicating that they system has a regular base of riders. The exact reasons why long-term riders have continued using TTA service are unknown, but one possible reason is that other modes of travel are not available.

In the survey, TTA asked riders to rate several aspects of service, including some that pertain to the bus stop environment. When asked to rate comfort while waiting for the bus on a scale between 1(very poor) and 7(excellent), only 18 percent of respondents gave TTA an “excellent” score, with frequent riders giving lower scores than infrequent riders. Twenty-two percent of riders rated comfort as a 3, 2, or 1, indicating negative perceptions. The scores given by different riders probably relates to the stops which they commonly use, but more detailed information of this sort was not collected. Despite some negative perceptions, the priority which riders would give to such improvements is not known, as TTA did not include stop-area improvements to determine rider desire for various improvements.

The relationship between of the built environment and ridership analyzed in this study does not take into account the demographics of riders boarding and alighting at individual stops. However, the entire demographic profile of TTA riders can supplement the results of this study in several ways. For example, providing bus stop amenities that appeal to commuters and regular passengers can have an effect on a large proportion of existing riders. This could mean improving shelters and waiting areas rather than focusing on schedule information, since regular riders are already likely to have schedule information. For riders who have to transfer between local or other TTA buses, having an attractive and safe waiting location would be beneficial. In addition, because a majority of riders walk or connect from local bus services, improving pedestrian facilities around bus stops could increase the attractiveness of TTA service to many users. Implementing visible changes in the surrounding areas around stops can leave a positive impression on new riders as well as showing existing riders that TTA is working to improve the bus riding experience.

2. PREVIOUS STUDIES

Many research studies have found that people in traditional neighborhoods travel more by transit and by foot than do people in typical suburban neighborhoods.[5] For this study, 'traditional neighborhoods' are defined as neighborhoods located close to an urban area on streets that connect well to others and have some commercial or retail services within walking distance. 'Conventional neighborhoods' are typically those with lot sizes of one-half to one acre or larger. They are single-use neighborhoods with few or no services within walking distance and little connectivity between streets. In analyzing key components that are associated with higher transit use, the four D's – density, diversity, design, and destinations – have been found to be important factors in many studies. Research has found density to be the best predictor of increased transit use; land use diversity and design are of lesser importance. Recent evidence has indicated the effect of destinations as well as other factors that may also play a role, including level of service.

Figure 2.1: Traditional Neighborhoods, above; and Conventional Neighborhoods, below.

Compact, diverse, and pedestrian-oriented neighborhoods are generally found to have lower trip rates and higher rates of use of alternative modes of travel than conventional contemporary neighborhoods. Research on the relationship between land use and public transit has increased in recent years. In 1993, researcher Robert Cervero found that "micro-scale design elements are too 'micro' to exert any fundamental influences on travel-behavior; more macro-factors, like density and the comparative cost of transit vs. automobile travel, are the principal determinants of commuting choices."[6] In 2001, a comprehensive assessment of existing studies by Ewing and Cervero found that people in traditional neighborhoods travel more by transit and foot than do people in typical suburban neighborhoods.[7] A 2006 study of California light rail lines by Cervero found that residents of transit oriented developments are more likely to use transit than residents in surrounding cities, implying that housing density and urban design do indeed influence transit use.[8]

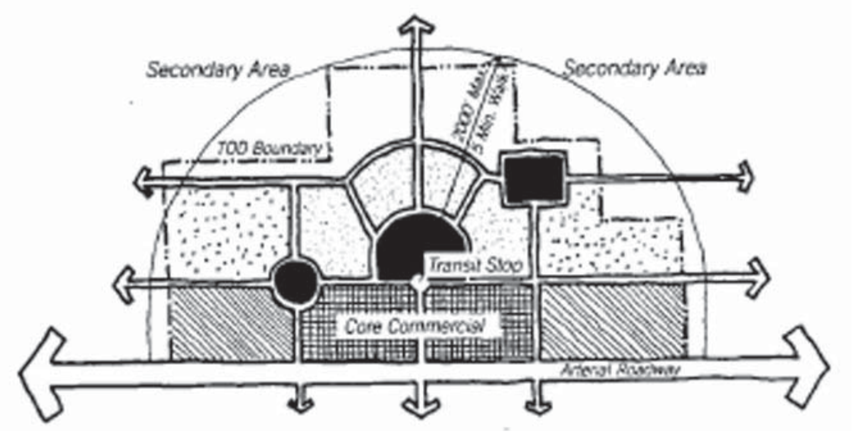


Figure 2.2: Illustration of Transit Oriented Development

Source: Urban Design, Transportation, Environment and Urban Growth

Additional research provides evidence that land use characteristics also influence travel behavior. A 2004 study found that the pedestrian environment, accessibility, interaction with other modes of transportation, and competition from other stops are all significant in determining transit ridership.[9] A study of neighborhoods in Chapel Hill found that residents were more likely to substitute walking for driving for some trips in a New Urbanist neighborhood than they were in a conventional neighborhood.[10] Similarly, urban form is an influential factor in whether or not children walk to school.[11] [12]

While these studies offer more information about the connection between land use and transportation, the variables differed between studies. This makes it difficult to understand which elements are the most significant. Areas were often categorized as urban or suburban for study purposes; however categorization often results in the loss of more nuanced information.[13] Some other limitations in previous studies have included a lack of a strong theoretical base, the omission of travel time, cost and socioeconomic variables. Few have addressed the magnitude of travel changes to understand the extent of transit use.

This study attempts to identify and define the land use characteristics that have the greatest influence on bus travel. These land use characteristics differentiate traditional, New Urbanist, and transit oriented development from conventional development, as the former creates a more hospitable environment for transit than the latter. Key differences in density, diversity, design, and destinations are explained below.

Density

Density, measured as both residential population density and employment density, is important because it determines the number of people in a particular area who can walk to a transit station. Density has been found to be the most significant factor in predicting the level of transit ridership. Research relating density to ridership has historically been more prevalent than diversity or design, perhaps due to the relative ease of calculating density. The relationship between density

Table 2.1: Minimum Densities for Supporting Transit

	Local Bus, Intermediate Service (a)	Local Bus, Frequent Service (b)
Dwelling Units per acre	7	15
Residents per acre	18	38
Employees per acre	20	75

Note: The density of the employment destination is more important in influencing trips than the density of the residential areas where the trips originate.

(a) Average density; varies as a function of downtown size and distance to downtown.
(b) Average density over a two-square mile tributary area.

Sources: For residential densities, Boris Pushkorov and Jeffrey Zupan (1977). For employment densities, Reid Ewing (1996) and L.D. Frank and Gary Pivo (1994). Urban Land Institute. Ten Principles for Successful Development Around Transit (p. 9).

and ridership has been widely known since a 1977 study by Pushkarev and Zupan was published. Numerous studies have all found that higher densities – both population and employment – lead to higher ridership levels.[14]

Table 2.1 illustrates common density thresholds for different service levels.

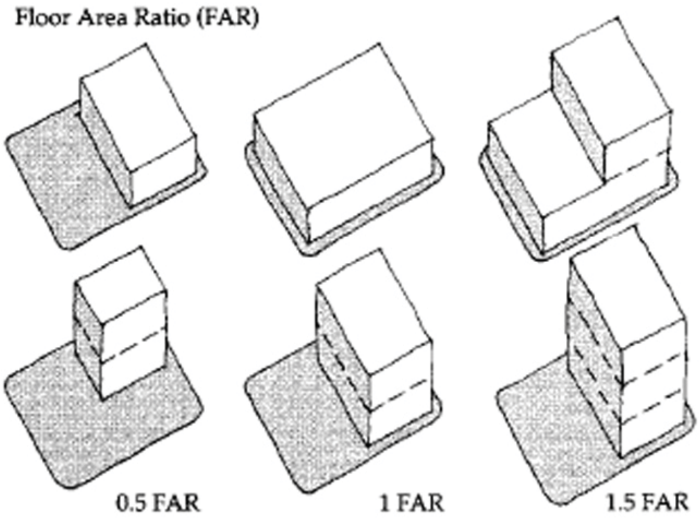


Figure 2.3: Floor Area Ratio (FAR) Illustrations
Source: Urban Design, Transportation, Environment and Urban Growth

Employment Density

Transit use for work trips appears to be more dependent on higher employment densities at destinations than on residential densities at origins.[15] For frequent bus service, the employment density threshold is 50 employees per net employment acre, although 75 employees per acre is a more common minimum. At more than 75 employees per acre, there is a significant shift from driving to transit and walking.[16] Transit-supportive development can reach these density levels through floor to area ratios (FAR) that are close to 1.0 or greater (see Figure 2.1). Development under a 1.0 FAR usually has surface parking, while development over 1.0 typically has structured parking. In a 1991 study of suburban activity centers, the most significant relationship was the number of stories in office buildings, which was highly correlated with the percent of work trips made by mass transit.[17]

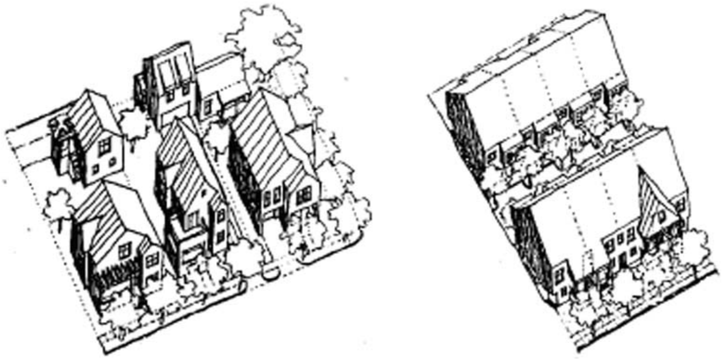


Figure 2.4: Higher Density with Attractive Design
Residential densities, 7-15 units/acre (left) supportive of bus service and 20-35 units/acre (right) supportive of frequent bus service
Source: Urban Design, Transportation, Environment and Urban Growth

Residential Density

A 1977 study by Pushkarev and Zupan found that transit ridership increased sharply at residential densities above 7 dwellings per acre.[18] This standard is still widely cited as a minimum for transit service. The level of bus service recommended by transportation organizations and policy guides is often based on density. These include basic levels of bus service (20-40 buses per day) for 4-7 dwelling units per acre[19] and 15 dwelling units per acre for frequent bus service.[20] For comparison, the Triangle averages only about 3 units per acre. The region's relatively low density for transit use means that it is important to focus service in areas with density that can support transit.

Limitations and Assumptions on Density Studies

The studies of density from around the country recognize that density is often accompanied by limitations to auto use. The greatest transit use was found in areas where automobiles are not convenient, typically older cities that were built before the automobile was invented.[21] These areas often have limited or user-paid parking or traffic congestion that discourages auto travel and makes transit an attractive alternative. As density increases, transit use, walking, and cycling are assumed to increase. The impact on transit use is also influenced by the quality of the transit service and the site design features in areas immediately surrounding transit stops.[22] Areas of higher density are often accompanied by a combination of an increased mix of uses, more walking, and greater transit use.

Measuring the impact of density on transit use has become mandatory for many programs that require ridership projections, such as the Federal New Starts program. The importance of density cannot be overstated: it appears essential to higher levels of transit ridership. However, there are other factors that influence transit ridership. Density by itself does not always have a major impact on travel decisions.[23] Density only has an impact when combined with other elements, such as accessibility of destinations within walking distance and attractive design. Furthermore, how density is measured in research studies may have an impact on the results. Gross density, typically measured by dividing census population figures by area, is often too broad to capture the density of the 'micro' environment where it is the most essential. By contrast, density measures that account for land devoted to water bodies, utilities, and open space, may provide a better depiction of the compactness of development.

Diversity

Land use diversity typically refers to development patterns that include a combination of office, retail, and residential uses in close proximity to one another. There is a high correlation between mixed land uses and higher transit use in many studies.[24] Research on the effect of land use diversity on transit ridership is not as clear as density, which may be because land use diversity is more difficult to analyze. Land use diversity has been measured at several different scales, ranging from the jobs-housing balance on a census tract level to mixed-use development at a site level.

Different studies provide insight into different elements of land use diversity and their effects on transit use. One study measured diversity as the jobs-population balance and found that the built environment can decrease vehicle miles traveled.[25] When land use mix at the census tract level was compared to transit use, the relationship was found to be relatively weak. However, land use mix was found to be more significant at a more detailed level at the origins and destinations, especially for work trips.[26] The mixing of uses was found to reduce travel demand at employment destinations.[27] Similar to findings about density, the impact of land use mix on transit use was found to be greater at employment destinations than at residential origins.[28] Having a mix of uses in close proximity to employment destination is important because many people who use transit to commute may want to walk to lunch or to run errands. At higher densities, the addition of retail to a neighborhood was associated with greater transit use than in areas with similar density.[29] Local land use mix has been found to be less statistically significant than residential densities[30] or regional accessibility.[31]

Macro vs. Micro Level Land Use Mix

The highest standard for "mixed-use" is a densely populated neighborhood where jobs and services are within walking distance of residences. Understanding this relationship requires an analysis at a micro level of a ¼ mile radius, which is a five-minute walk for a typical person. One study defined a truly mixed-use area as one in which the majority of residents can fulfill their weekly shopping needs within walking distance.[32] Another study found a correlation between mixed-use neighborhoods and commuting by foot.[33]

Transit oriented developments are typically designed at a micro-scale so that they are truly mixed-use. Although some master planned communities do have a mix of uses, they are often separated into individual development zones by major arterial streets and property lines, with pedestrians isolated from the street.[34] These compare negatively to a transit oriented development, in which the mix of uses occurs within immediate proximity: on the same block, lot, or building. This represents a very fine grain of multiple uses. Housing and offices in transit oriented developments are often located above retail within a five minute walk of a transit stop.

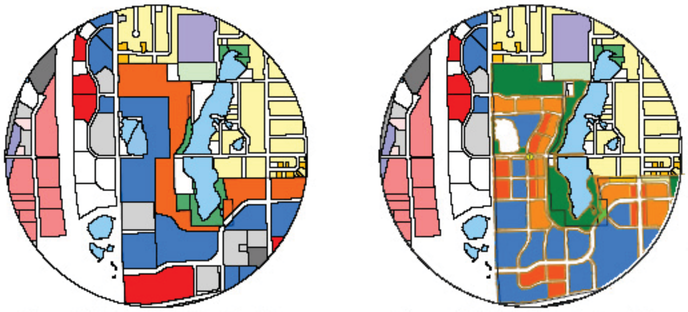


Figure 2.5: The land use pattern, left can be more transit supportive by mixing uses at a finer grain.
Source: Urban Design, Transportation, Environment and Urban Growth

Clustering

Clustering is a means of increasing the diversity of land uses in a small area through the deliberate placement of buildings. Instead of different uses or different buildings separated at an even distance, structures are "clustered" together, which creates a common destination and makes them more accessible to pedestrians (see Figure 2.2). Even in areas of low density, common destinations can be clustered together, such as in a village or town. This creates a transportation node in which multiple uses are accessed more quickly, allowing residents to complete multiple errands in one trip.

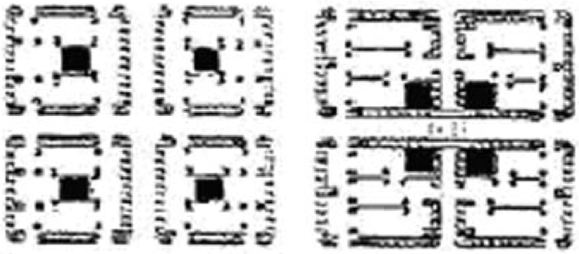


Figure 2.6: Illustration of Clustering
Source: Land Use Density and Clustering. TDM Encyclopedia. Victoria Transportation Policy Institute

Design

Urban design concerns the arrangement, appearance, and function of cities, focusing on the public space located between buildings. Design of public space depends on a combination of several factors: site design considerations (building and parking lot locations, as well as street design elements), sidewalks, road widths, and crosswalks. Design is important because it shapes the quality of the walking environment and configuration of the street network, which can lengthen or shorten the distance between places.

An urban design concern for transit is the design of the bus stop, which is the factor primarily considered by TTA. Bus stop facilities such as benches, shelters, and schedules make a positive contribution to the overall transit experience and add to the pedestrian environment. However, most research on design and transit focuses on walkable and accessible streets. Research on urban design is relatively new, with much of it conducted in the past five years. Most of the existing research focuses on rail transit, but transit supportive environments are also important for bus transit.

In studies of urban design, researchers Ewing and Cervero theorize that urban design is likely to have only a marginal impact on primary trips – the trips taken to go to a specific destination (typically work trips). They note that urban design will have a more important impact on secondary trips, i.e. whether people feel compelled to walk or drive after they reach their destination.[35] Robert Cervero has identified statistically significant transit supportive design features in some of his research. They include high numbers of four-way intersections, a limited quantity of on-street parking,[36] and high levels of sidewalk provision.[37] Because individual urban design features do not always prove statistically significant by themselves, effects on travel are likely to occur only with a composite of multiple variables.[38]

Design factors also appear to have a greater effect when analyzed at a more detailed level. In an analysis for the Federal Highway Administration, Parsons Brinckerhoff et al. looked at the impact of micro-scale design elements on travel behavior. The design elements they considered include sidewalks, pedestrian-oriented street systems with protected intersection crossings, buildings located relatively close to sidewalks, parking controls, and locations that foster or support walking and transit use. These elements are typically found in environments built at a smaller, human scale and are associated with individual building sites.[39]

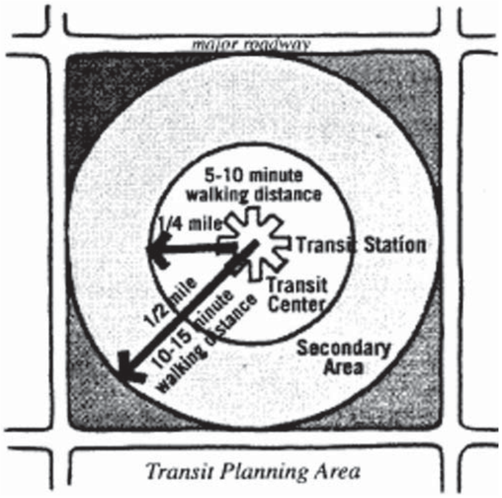


Figure 2.7: A 1/4 mile walk and 1/2 mile walk from a transit stop.
Source: Land Use Density and Clustering. TDM Encyclopedia.

Walkability

Walkability refers to the quality of the walking environment, including the existence of sidewalks or paths and the degree of walking safety, comfort, and convenience. Because most transit trips begin and end with either a walking or biking trip, the ability to walk or bicycle easily should be considered. To be transit supportive, a place should have an easily accessible bus stop that is supported not just by sidewalks but also by the surrounding roadway, building, and parking designs.

To create transit supportive development, it is important to understand the primary areas likely to be used by transit riders. The area calculated identifies the primary walkable catchment of a transit stop. The primary area is defined as the space within ¼ of a mile, while the secondary area is that within ½ of a mile.[40] To encourage more transit use, it is important to focus on land use changes within half a mile of a transit stop, or conversely, to identify walkable areas that may be good locations for transit expansion.

Roadway Design

Roadway design can have a significant impact on the degree to which an area is walking and transit friendly. A road with many lanes and wider lane widths takes longer to cross than one with fewer and narrower lanes. Traffic speed is also critical to walking and safety: at faster speeds a pedestrian is more likely to be seriously harmed if hit by an automobile, and the perception of safety is low.

The Federal Highway Administration recognizes the importance of pedestrian access. The US Department of Transportation’s policy on integrating bicycling and walking into transportation infrastructure states that “bicycling and walking facilities will be incorporated into all transportation projects unless exceptional circumstances exist.”[41] However, the construction of walking and cycling facilities may accompany large roads that detract from the walking experience or may not connect to the adjacent land uses.

Figure 2.8: The walkable section of Colonial Drive (left) had fewer accidents than the non-walkable section (right) in an Orlando study.

Source: Safe Streets, Livable Streets (p.289)

Figure 2.9: A walkable street, Edenton Avenue, in downtown Raleigh (left) and an non-walkable street, Hwy 54 in Chapel Hill (right).

The presence of trees and on-street parking are important characteristics of walkable streets because they buffer potentially dangerous traffic from the pedestrian realm and provide spatial definition to the public right-of-way.[42] A study of Colonial Drive in Orlando over a five year period (1999-

2003) compared two sections: a walkable section with sidewalks, trees, and on-street parking and a section with a 20-foot clear zone on either side of the road and the wider lane widths typically required by arterial engineering standards (see Figure 2.3). The study found that the walkable street was much safer by every measure than the clear zone street. The walkable street had fewer auto accidents and zero pedestrian or bicycle injuries. This contrasts with five pedestrian and bicycle injuries on the clear zone street, three of which were fatal.[43]

Elements such as marked crosswalks, pedestrian crossing signals, and curb bulb-outs at intersections can improve the pedestrian experience by making streets safer. Another form of speed control is the sense of enclosure created by some built environments, a narrowing measure that causes the driver to go more slowly.[44] This sense of enclosure can also be created by a tree canopy over the street or by placing taller buildings close to the street.

Figure 2.10: Buildings next to the street are accessible to pedestrians

Building Design

Building type and orientation are integral to transit-supportive development. Within a core pedestrian-oriented area, buildings should achieve a minimum transparency of 40 percent (made up of windows, glass doors, etc.) and setbacks of no more than 1 to 10 feet.[45] This creates a sense of safety for the pedestrian by providing a set of "eyes on the street" as defined by urban writer and critic Jane Jacobs. Building orientation is also important: when buildings face the street, they are more accessible to pedestrians and transit riders because there is a direct, well-defined connection to their destination.[46]

Higher densities are often associated with less attractive building designs. Consequently, proponents of higher density environments argue that attractive building design can reduce opposition to denser residential areas. Higher densities can be provided along with the some of the most appealing factors of urban or suburban areas - namely trees and human-scaled buildings. Human scale is defined as building designs that are two to four stories tall, are located close to the street, have a number of windows to create visual interest for the pedestrian, and have multiple entrances.[47]

Figure 2.11: A parking lot separates the sidewalk and the building, above; and a building located next to the sidewalk with parking located behind a screen, below.

Parking Design

Parking design plays an important role in the development of environments that support transit. On-street parking is important for mixed-use areas because it buffers pedestrians from traffic and offers convenient short-term parking for customers. It also reduces the space needed for large parking lots. Parking lots located between the street and buildings create dead space and displace active land uses along the street, making the walking environment less hospitable and connections to buildings much longer. A walk from the street through a large parking lot is often feels uninteresting and uninviting as this ‘dead space’ has little activity or visual interest. Placing buildings behind parking lots also makes the sidewalk environment less inviting to pedestrians because it reduces human interaction, natural surveillance, and shelter from sun and rain.[48]

Transit-supportive design, on the other hand, includes human-scaled buildings located near the street, parking areas located behind buildings, and a clear pedestrian circulation system through any parking lot.[49] The Urban Land Institute, a leading organization of real estate developers, also recognizes the importance of appropriate site design around transit. Their best practice standards note the best location for parking is a 5 minute walk from a transit stop with the building located next to the stop. Shared parking, structured parking, and parking behind buildings are all appropriate ways of accommodating automobiles near transit.[50]

Connectivity

Connectivity refers to the ease with which destinations may be reached because their locations are linked. This element is important because it can reduce the amount of walking necessary to get from one place to another. High levels of connectivity are typically the result of grid pattern networks that reduce the distance between two places.[51] In areas with high accessibility, residents have more options for walking, which may reduce the desire or need to drive for some trips.

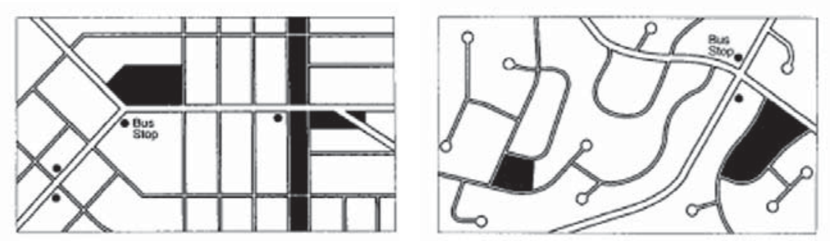


Figure 2.12 A connected grid pattern, left, is associated with greater connectivity than a loop and cul-de-sac pattern, right.

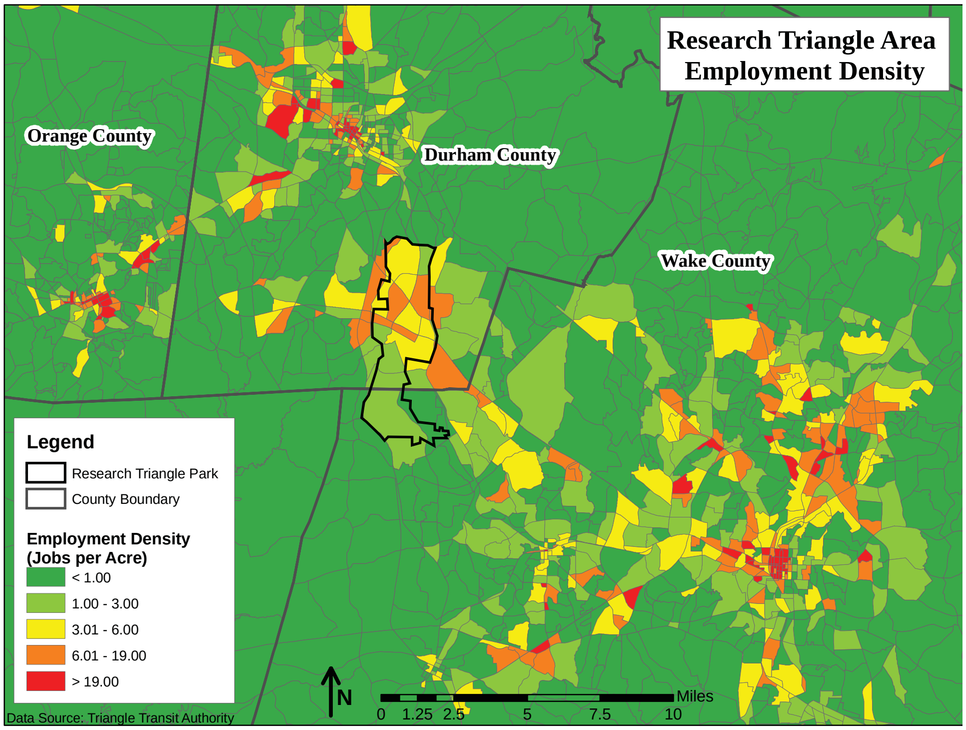
Source: Safe Streets, Livable Streets (p.289)

Smaller block sizes also help provide connectivity,- important to a transit user since it Shortens the distance between one location and another. Hence, one guideline for suburban transit supportive development defines a maximum block length of 500 feet and maximum block size of seven acres to encourage transit use in a suburban environment.[52] Smaller block sizes improve the connectivity for pedestrians, thus increasing their access to potential destinations.

The design factor of connectivity (created by the road pattern) and the destination factor of accessibility (referring to travel time to a place many people visit) are closely linked. Depending on how two sites are connected, access can be provided with a direct route or with a long, circuitous route. Naturally, a longer route results in less access.

Destinations

The fourth factor affecting transit use identified in more recent evaluations of the built environment is Destinations. It is defined as accessibility to activity concentrations, expressed as the average travel time to all other destinations within the region. For example, a location within the regional core will ordinarily have a higher 'destinations' rating than a location on the fringe of the urban area because the central location offers greater accessibility to a higher percentage of the region's employment.[53]



Data Source: Triangle Transit Authority

Figure 2.13: Employment density in the Triangle is relatively dispersed, with higher concentrations in the downtown areas of Raleigh, Durham and Chapel Hill.

Accessibility to a job destination has been found to be a significant predictor of transit use along with good street connectivity at the employment destination.[54] Employer incentives also play a role in the decision to use transit or to drive. A study in California found that when employees were offered free parking or subsidized auto commute costs, they were more likely to drive, but those who were offered flexible work hours and subsidized transit commute costs increased their transit use.[55]

The Triangle's residential growth pattern is very dispersed, and because of this it is likely to rank lower on accessibility to activity concentrations than other regions. Employment destinations, on the other hand, are relatively dispersed throughout the Triangle region, with numerous nodes of job concentrations and no clear "center." Despite the absence of a single employment center, the presence of employment concentrations may correlate with transit use in the Triangle since commuters comprise most of TTA's ridership.

Transit Supportive Policies

If planners and policy-makers are interested in encouraging transit supportive development, there are many options they can consider. Changing suburban-oriented zoning and roadway standards along transit routes can help foster greater transit use, as typical suburban standards for parking and road access are excessive for development around transit and can reduce the site's pedestrian orientation and sense of place.[56]

While bus stops have not traditionally been regarded as hubs for development, interest in them is growing. Routes with frequent bus service can create opportunities for transit supportive development.[57] Zoning that allows higher densities, reduced parking supplies, and shared parking options may encourage more transit supportive development.[58] Streetscape and design improvements may have less effect on transit use, but these neighborhood amenities do make living in high-density neighborhoods more attractive.

A Southern California study of municipal zoning codes found a widespread exclusion of transit-oriented development.[59] Another study of consumer preferences for housing in Atlanta and Boston found that people in Boston who preferred a transit and pedestrian friendly neighborhood were far more likely to live in one than were people in Atlanta.[60] This suggests that there is unmet demand for pedestrian neighborhoods in the Atlanta region—where most development is auto oriented—as compared to Boston, where there are more pedestrian-oriented neighborhoods.   For transit supportive design to occur, local regulations need to permit mixed-use, walkable places with smaller building setbacks and lower parking requirements.

The Urban Land Institute (ULI) also offers advice about development around transit, noting that higher-density development should be planned near high-service bus corridors.[61] ULI specifies that development around transit should promote compact development, multiple uses, pedestrian orientation, and attention to civic uses.

Figure 2.14: TTA users appear to be using a shopping cart as a bus stop bench along Hwy 54 in Durham.

3. TRANSIT IN THE TRIANGLE

Applicability of Previous Studies

Previous studies offer important information about land use and transportation relationships; however their applicability to the Triangle may vary. However, most studies of the built environment to date have been performed outside the South, and in cities with very different built environments than the Triangle cities. Few studies have been performed to examine transit ridership in predominantly suburban areas. In addition, studies relating the built environment to transit use have been almost exclusively performed around rail stations rather than bus stations. These factors may limit the applicability of past studies in the Triangle area and in other primarily suburban metropolitan regions. Our study seeks to fill in these gaps in the literature by investigating the relationship between the built environment and transit use in a predominantly suburban environment.

The Built Environment and Resident Preferences

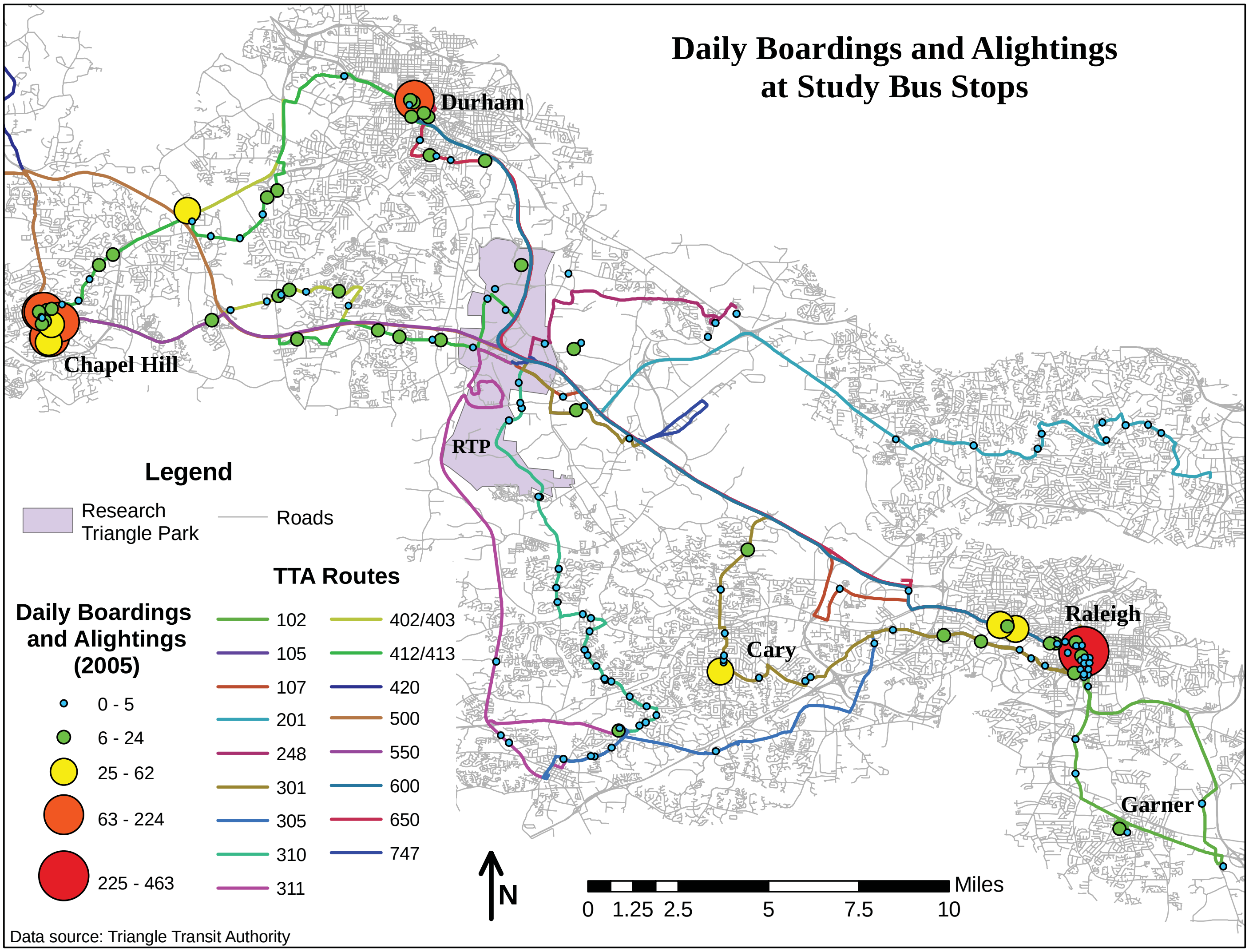
It is important to focus on the characteristics of the built environment in the Triangle when considering the implications of previous research findings. The Triangle is characterized by low-density development and a separation of land uses. However, the existing patterns of development should not be taken as an unchangeable model for the future. While there are only a few areas of the Triangle that can be characterized as such, that does not mean that higher-density, mixed-use neighborhoods are not desirable here and cannot be built.

Many urban planners and researchers contend that residential environments currently being built do not offer a variety of housing situations to satisfy the preferences of all people. There is a divergence, termed “neighborhood type dissonance,” between the physical structure of some people’s residences and their preferences for land use types near their homes.[62] This means that these people are living in areas that do not conform to their preference for environmental surroundings. People cannot consider existing location choices as a true reflection of consumer preferences. If they do so, they are ignoring important factors, including the narrow range of housing options in the market.[63] These housing options don’t often provide a full selection of tradeoffs between housing preferences and neighborhood preferences. Simply put, the market has failed to provide the type of development appealing to people who prefer transit- and pedestrian-friendly environments.[64]

There is evidence that such traditional neighborhoods are in high demand, as many high-density, mixed-use areas in the Triangle command extremely high rents compared to typical suburban neighborhoods. A comparison of conventional and New Urbanist neighborhoods throughout the country finds that residents are willing to pay more to live in a New Urbanist neighborhood.[65] There is an opportunity in the Triangle for developers to create environments that allow all residents to live in areas that meet their individual preferences. Determining the factors that contribute to transit ridership will help municipalities and developers create environments that support transit. Providing transit supportive environments can offer Triangle residents a greater variety of places to live and work and more choices to get from one place to another.

Understanding Land Use and Transit in the Triangle

This study aims to determine what characteristics of the built environment affect bus ridership in the Triangle Region – a more suburban, low-density area. Many cities around the country are attempting to implement transit systems without a detailed understanding of how suburban environments interact with transit systems. In areas where rail systems do not exist, as in most suburban areas, providing regional bus transit may be the only way to provide short-term transportation options to residents. This study will determine what factors can be expected to affect ridership in this predominately suburban region.



Data source: Triangle Transit Authority

Figure 3.1: Daily Boardings and Alightings at bus stops in this study show which stops have high ridership.

4. METHODOLOGY

The data collected for this study was initially comprised of all 600 TTA bus stops as of 2005. Boarding and alighting counts were gathered from a TTA ridership survey in 2005. An arbitrary sample size of 160 was set to allow for detailed analysis and ensure a representative sample while ensuring that auditing was feasible in the time frame of the study. We then followed a stratified-random sampling approach, defining two strata (proportional groups) based on the degree of urbanization around each stop. Given the prevailing development patterns in the Triangle, this effectively oversamples stops belonging to the highly urbanized strata, which we hypothesize would exhibit many of the built environment attributes relevant to transit ridership, and thus would allow for detailed identification of these attributes.

Bus Stop Sampling Process

Stops were classified into one of two strata using the average of three urban scores: gross population density, gross employment density, and intersection density, all calculated at the Transportation Analysis Zone (TAZ) level. Each stop was given a score for each measure: low (0), medium (1), or high (2). These scores were determined roughly by the 50th, 90th, and over 90th percentiles for the variables (see Table 4.1).

Table 4.1: Bus Stop Sampling Process

Persons per Square Mile (Acre)		Classification	% of Observations
Min	Max		
6,400 (10)	16,067 (25)	High	7.5%
2,560 (4)	6,399 (9.9)	Medium	37.0%
0	2,559 (3.9)	Low	55.5%
Jobs per Square Mile		**Classification**	**% of Observations**
Min	Max		
10,000	81,017	High	11.3%
2,000	9,999	Medium	38.2%
0	1,999	Low	50.5%
4+ way intersections per square mile (acre)		**Classification**	**% of Observations**
Min	Max		
53 (0.083)	143 (0.223)	High	7.5%
15 (0.024)	52 (0.081)	Medium	37.0%
0	14 (0.022)	Low	55.5%
Average of Urban Measures		**Classification**	**% of Observations**
Min	Max		
1.50	2.00	High	5.7%
0.50	1.49	Medium	42.1%
0.00	0.49	Low	52.2%

We then sampled all stops in the highly urban strata (n=35). The remaining 125 stops were randomly sampled from among the “medium” and “low” stops, with 21.9% chosen from the total set of stops in those two groups. Stops were then removed from the sample for a variety of reasons. First, stops were buffered at a distance of 75’ in every direction. This was done to eliminate stops that were too close to each other because their stop attributes and segments would be extremely similar. This resulted in the removal of seven stops. Second, from each pair of stops within a 75’ radius, the stop to be removed was randomly selected. One other stop was removed because, although it fell outside the 75’ radius, it served as a partner stop for a different stop in the sample. Third, three park-and-ride bus stops were eliminated because they are functionally different from other stops: large amounts of people access them by automobile. When a stop was eliminated, a replacement was randomly selected from among the remaining stops in the “low” and “medium” groups. Additional stops were removed due to uncertainty in their boarding and alighting data; their location; or the auditors inability to access them . The final sample of stops was 148, including 32 highly urban strata stops (91.4%) and 116 “medium” and “low” urbanization stops (20.3%).

Segment Sampling Process

For most stops, three road segments in the area surrounding each bus stop were selected based on the road location displayed in GIS. By design, one segment had to be where the stop was located. The other two segments chosen were those located closest to the stop. This non-random sampling of segments is suitable because the segments closest to the stop were deemed to have the most influence on whether the stop was accessible or not.

Most segments were between 200 and 400 feet in length. No segments were duplicated in audits of nearby stops. Both sides of a street were considered to be one segment if the road had fewer than four lanes. However, auditors could select an opposite side of such a street for separate auditing if the two sides were substantially different. For some stops, fewer than three segments were audited because auditors determined that additional segments were functionally the same as the first segment audited. Where multiple stops were located in close proximity, no segments were selected for use with multiple stops.

Bus Stop Surroundings

To determine the bus stop built environment, a buffer of ¼ mile was created around each stop. This is generally deemed the distance that a person will walk to use transit, and thus the environment in this area is most pertinent in determining which built environment characteristics affect ridership. Due to the fact that ridership is the dependent variable in our study, we are concerned with the area from which a stop is likely to draw riders. The quarter-mile buffers were used to measure socio-economic and built environment factors. Secondary data included population, employment, and intersection density, in addition to bus stop level of service. Variables were also created for proportion of office and proportion of residential uses in the stop buffer. A land use entropy measure was computed which measured the mixture of residential, office and industrial uses. The highest possible entropy score was achieved when the three uses were perfectly balanced, while a buffer with a single use received a score of zero. Service supply was calculated in a variety of ways, including the number of routes and buses serving a stop per day, broken down into categories of regional, regional express, local, local express, and peak buses. Secondary data was gathered from the U.S. Census and from local governments in the TTA service area. Primary data was gathered using an audit of road segments adjacent to each bus stop.

Auditing Process

Audits are a means of collecting built environmental attribute data that are not available or quantified in other sources. Audits can also be used to collect more detailed information than is available from secondary data sources. The audit used in this study combined questions from a number of existing audits with some new questions. Questions were grouped into categories based on the built environment characteristics which they were aimed at capturing. Six overall categories were used: Bus Stop Environment, Destinations, Pedestrian and Bicycle Environment, Road Design, Neighborhood Features, and Architecture Design. Bus Stop Environment was measured once for each stop, while the other five attributes were measured for each segment audited. Appendix A includes a copy of the audit form as well as a manual that explains auditing procedures in detail.

The questions used in this audit came from a variety of sources (See Table 4.2). Questions about the bus stop environment were drawn from Bus Stop Safety Audit (BSS)[66], Easter Seals[67], and other sources. These questions were expected to have high reliability due to the ease of assessing the presence of physical

Table 4.2: Question Sources for Audit Indices

Index	Source	Question Number
Bus Stop Environment	Multiple	1
	BSS	2, 3
	EasterSeals	4
Destinations	New (no source)	5, 6, 7, 8, 9, 10
Pedestrian/Bicycle Environment	PEDS	11,12,13,14,15,16
Road Design	PEDS	17,18,19,20
	New (no source)	21,22
Neighborhood Features	Irvine-MinnesotaInventory	23,25
	New (no source)	24,28
	PEDS	26,29
Architecture Design	Irvine-MinnesotaInventory	31
	PEDS	32
	CaryCommunityAppearanceManual	35
	New (no source)	36

attributes of a stop. Questions about destinations were all new. In many past audits, questions about presence of types and numbers of destinations have not been included in part because of the difficulty in ensuring reliability of these questions, since they are more subjective and difficult to measure than other features of an area. Questions about the pedestrian and bicycle environment and road attributes were drawn primarily from the Pedestrian Environment Data Scan (PEDS), with two new questions about road design.[68] Questions about neighborhood features and architecture were predominantly drawn from multiple sources, as these categories have not been as extensively tested as other areas. Neighborhood features questions included new questions as well as some from PEDS, Irvine-Minnesota Inventory,[69] and Urban Design Qualities Related to Walkability.[70] Architecture design questions also came from the same sources, with the addition of the Cary Community Appearance Manual.[71]

The accuracy and reliability of questions from existing audits such as PEDS and BSS is high; these audits have been tested repeatedly and reviewed by numerous groups. The accuracy and reliability of new questions, however, is unknown. Though new and untested questions have not had multiple tests to ensure reliability, questions added to this audit were refined several times to ensure maximum reliability. Pilot-testing was performed to ensure that auditors were consistent in interpretation of questions with uncertain reliability. This pilot-testing, as well as continuous opportunities for comment and review of the audit throughout the process, helped ensure consistently in procedures and data recording. Overall, the questions which have been tested in previous studies are known to be reliable, while there is uncertainty about reliability of new questions.

Audit Indices

Data gathered from the audit was combined to create six indices representing distinct aspects of the built environment. The six indices corresponded roughly with the categories outlined in the audit, with a few exceptions for questions which were examined and deemed to represent a different built environment category better than the category in which the question was placed originally (See Table 4.3). The indices were attempts to quantify the bus stop environment, destinations, pedestrian and bicycle facilities, road design, neighborhood features, and architecture design. Each index combined several audit questions to create an overall score for each stop.

Table 4.3: Audit Questions Originally Included in Each Index

Index	Question Number
Bus Stop	1,2,3,4
Land Use	5,6,7,8,9
Ped/Bike Facilities	11,12,13,14,15,16,20
Road Design	17,18,19
Neighborhood Features	10,21,22,23,24,25,26,28,29,30
Architecture Design	31,32,33,34,35,36

The Bus Stop Index included audit questions 1, 2, 3, and 4. The questions in the Bus Stop Index examined various features of the TTA bus stop area that were expected to encourage ridership. Amenities such as signs and schedules provide information, while others like seating and lighting provide comfort and a feeling of safety. Sidewalks and paved landing areas make the bus stop more accessible. Finally, a companion bus stop indicates that a convenient return route is available. Each of these elements was expected to make riding the bus a more practical and attractive mode of transportation.

Figure 4.1 HIGH SCORE: A bus stop on Hillsborough St at NCSU, with a TTA sign, a sidewalk, a bus shelter, a bench, and newstands.

Figure 4.2: LOW SCORE: A bus stop along Hwy 54 in Durham is unpaved, and marked only by a sign.

The Destinations Index included audit questions 5, 6, 7, 8, and 9. Density and diversity of uses are widely viewed as major contributing factors for bus ridership. The Destinations Index sought to capture the intensity of use and a breakdown that is more precise than dividing uses into simplified residential and commercial categories. Certain nonresidential establishments are more compatible with riding the bus because they offer more activities to occupy one's time. Big box stores, meanwhile, may discourage public transit because customers have a lot to carry. The presence of jobs and housing near bus stops may also increase ridership. Overall, more businesses and residences in the area surrounding a stop mean that more people are likely to come to that area who could potentially ride the bus.

Figure 4.3: HIGH SCORE: Downtown Durham is a denstination center due to the high amount of employment.

Figure 4.4: LOW SCORE: This residential neighborhood in Cary is not likely to be a major destination.

Figure 4.5: HIGH SCORE: Franklin Street in downtown Chapel Hill has a continuous sidewalk with street trees that separate pedestrians from traffic.

Figure 4.6: LOW SCORE: Western Blvd by NCSC lacks a sidewalk or place to walk along the street without entering traffic.

The Pedestrian and Bicycle Index included audit questions 11, 12, 13, 14, 15, 16, and 20. Since travel by foot or by bike goes hand-in-hand with travel by bus, it is important that stops are served by good pedestrian and bicycle facilities. A quality pedestrian experience depends on many details. Continuous sidewalks on both sides of a street which connect to other sidewalks create a complete network. Flat street segments, signalized crosswalks, lighting, buffers that separate pedestrians from traffic, and sidewalks without bumps and cracks all make walking easier, safer, and more comfortable. Bicycle lanes and greenways complement the pedestrian network and provide more modes of travel. Pedestrian and bicycle facilities are necessary for a rider to get to and from a bus and remain important as the rider travels among the destinations accessible from the stop.


Figure 4.7: HIGH SCORE: Academy Drive in Cary has few lanes to cross, a stop light, a pedestrian crosswalk and slower traffic.


Figure 4.8: LOW SCORE: The intersection of Hwys 54 and 55 in Durham is more difficult due to additional turning lanes and faster traffic.

The Road Design Index included audit questions 17, 18, and 19. This index measures the assumption that pedestrian-friendly road design has a positive effect on bus ridership. If people feel safe and comfortable crossing the road and waiting for the bus, their likelihood of riding the bus increases. A six-lane road generally has faster traffic and a higher traffic volume than a two-lane road, making for a more unpleasant environment. Roads with multiple turning lanes also increase pedestrian difficulty in crossing safely and conveniently. The presence of traffic control devices, such as stop lights, stop signs, and other traffic calming devices, improve the pedestrian environment by slowing traffic and offering opportunities for pedestrians to safely cross.


Figure 4.9: HIGH SCORE: Outdoor dining and trees lining the street creates a pedestrian-friendly neighborhood in Cary.


Figure 4.10: LOW SCORE: This parking lot in Cary creates a large separation from the sidewalk and the building.

The Neighborhood Features Index included questions 10, 21, 22, 23, 24, 25, 26, 27, 28, 29, and 30. It measures the assumption that a high-quality neighborhood has a positive effect on bus the belief that a neighborhood with these qualities will encourage bus ridership. This index includes aspects of the environment such as attractive landscaping, outdoor dining, and pedestrian facilities. Having these features in a neighborhood would theoretically make it more attractive to people walking to a bus stop.

Figure 4.11: HIGH SCORE: A residential building with small setbacks and first floor windows can define the street,as found on Blount Street in Raleigh.

Figure 4.12: LOW SCORE: Large blank walls are negative features next to the sidewalk, such as this wall along Hwy 54 in Durham.

The Architectural Design Index included questions 31, 32, 33, 34, 35, and 36. It measures the assumption that high-quality architectural design encourages bus ridership. This type of design includes several aspects. First, buildings heights are such that the street becomes an "outdoor room." The ideal building height on a two-lane street would be between two to four stories, because these dimensions create a human-scaled streetscape. Buildings should also have small setbacks from the street because this creating an inviting pedestrian environment. Ample window coverage on the ground level of buildings allows for transparency to pedestrians and increased perception of safety. In addition, buildings architecture should be broken into sections. Doing so allows design at a human scale, creates visual interest, and gives identity to separate portions of a building. Finally, buildings should have distinguishing features that create identity and a sense of place. At the same time, buildings should avoid negatively distinguishing features in the public realm. Dumpsters, loading docks, and vents should be placed in the rear of buildings. The Architectural Design index reflects the belief that buildings designed with these features in mind will encourage bus ridership.

Analysis Methods

Preparation of the audit data was required prior to beginning analysis. Five of six sections of the audit gathered data by segment. Thus, each stop had multiple segments associated with it. To measure the built environment at the stop level, the segment attributes were aggregated to the stop level. Due to proximity of many stops, especially in urban areas, some segments audited for use with one stop were also located within a short distance or adjacent to other stops. The data for segments proximate to multiple stops was included in the aggregation for each of the stops. The number of segments per stop ranged from one to seven segments. For each stop, we aggregated the audit scores and divided by the number of segments to get an average stop score for each question. The variables calculated at a stop level were ready for analysis without any aggregation. Analysis was performed using only those stops for which all variables were complete.

Each question was given a score to allow questions to be combined into an index. Scores were given such that features that would improve ridership were given positive scores. Features that would be expected to decrease ridership were given negative scores. Features that were found in previous studies to have

Table 4.4: Audit Scoring

Bus Stop ID ________________________
Segment ID ________________________
Auditor ________________________

Segment audited:

One side only	
Both sides	

BUS STOP ENVIRONMENT

1 Bus Stop Amenities checklist:

TTA Bus stop sign	1
Shelter	3
Bench or seating wall	3
Schedule	2
Map	1
Real-time information display	1
Trash can	1
Lighting	2
Bike racks	1
None	0

2 Is the landing area paved?

Yes	1
No	0

3 Is there a sidewalk leading to the stop?

Yes, from one direction only	1
Yes, from two or more directions	2
No sidewalks leading to stop	0

4 Is there a companion bus stop across

Yes	1
No	0

DESTINATIONS

5 # of non-residential places where people tend to stay for a considerable period of time?

>2	2
1-2	1
0	0

6 # of non-residential, service-oriented places where people get something relatively quickly, then leave?

>3	2
0-3	0

7 Generally, what amount of employees work this segment?

Large (i.e. IBM office site)	3
Medium (30 plus employees)	2
Small (fewer than 30 employees)	1
No visible employment	0

8 Are there residential uses present?

Yes	1
No	0

9 Are there any BB or grocery stores?

Yes	0
No	1

10 Are there vacant lots present?

Yes	0
No	1

BIKE/PEDESTRIAN FACILITIES

11 Pedestrian facilities (check all that apply)

Unpaved footpath	0.5
Sidewalk	1
Bike/Greenway/Ped path	1
None	0

12 Rate the steepest part of segment

Level to Moderate	1
Steep	0

13 Buffer between road and pedestrian

Yes	2
No	0
N/A	0

If no sidewalk, skip to question 15

14 Sidewalk Location

All sides	1
1/2 sides	0

Sidewalk completeness

All sides complete	2
1/2 side complete	1
None complete	0

Sidewalk Connectivity to other sidewalks

Sidewalks connect to others	1
Sidewalks do not connect to others	0

Sidewalk condition:

Poor (many cracks, bumps, holes)	0
Fair (some cracks, bumps, holes)	1
Good (few cracks, bumps, holes)	2

15 Lighting present along segment?

Yes	1
No	0

16 Bicycle lane present?

Yes	1
No	0

ROAD ATTRIBUTES

17 Number of vehicle travel lanes	
18 Number of lanes to cross	
If 17 and 18 both < 4	2
If 17 or 18 > 4	0

19 Traffic control Devices (all that apply)

Traffic Light	2
Stop Sign	1
Traffic calming	1
None	0

20 Crossing Aids in segment (all that apply)

Pavement markings	1
Pedestrian Signal	1
Overpass/Underpass	1
Flashing Warning (for cars)	1
Ped/Bike street signs	1
None	0

21 Amount of segment fronted by off-street parking

More than half	-1
Less than half	0
None	1

If answer is "None" in Q21, skip Q22

22 Off-street parking on the segment is located (check all that apply):

In Front of Buildings	-1
To the side of buildings (w/street frontage)	-0.5
In standalone lots	-1

NEIGHBORHOOD FEATURES

23 Are there any outdoor dining areas?

Yes	1
No	0

24 Pedestrian amenities in public realm (e.g. garbage cans, benches, mailboxes, bike racks, etc.)

Many (3+)	2
Few (1-2)	1
None	0

25 Is the ped facility shaded by trees?

Yes/Somewhat	1
No	0
N/A	0

26 Relationship between built and natural env.

Landscaping in isolated patches	0
Natural environment more prominent	0.5
Landscaping/Veg. complement buildings	1

27 Are there buildings on the segment?

Yes	0
No	0

If no buildings present, skip Q28 - Q36

28 Walk through parking lot to get to most buildings?

Yes	0
No	2

29 Connections between building entrances and streets? (Check all that apply)

Defined path	1
Undefined path	0.5
Inhibited Connection	0

30 If no sidewalk is present OR buildings are set back >40 ft, are there connections between adjacent sites

Yes	0
No	-1
N/A	0

ARCHITECTURE DESIGN

31 Building Height (SEE TABLE X FOR SCORING)
(in stories)

5 or more	
3-4	
1-2	
Heights vary	

32 Average Building Setback from Street

At edge of sidewalk (or curb if no sidewalk)	4
Within 40 feet of curb	2
More than 40 feet from curb	0

33 Amount of buildings oriented towards a street?

More than half	-1
Less than half	0
None	1

34 Typical window coverage at ground level?

More windows than wall	1
Some windows	0.5
Few windows	0
Blank wall	0

35 Amount of buildings with architecture broken into sections?

More than half	1
Less than half	0.5
None	0

36 Are buildings designed with distinguishing

Yes, most buildings	1
Few/no buildings	0
Negatively distinguishing features	-1

effects on ridership were given higher weight. Tables 4.4 and 4.5 illustrate the scores given to each question. Given this scoring, all of the indices were expected to have positive associations with ridership.

Table 4.5 Heights Question Scoring

Number of Lanes (Question 17)	Building Setback (Question 32)	Building Height (Question 31)			
		1-2 stories	3-4 stories	5+ stories	Heights vary
2	No setback	5	4	3	4
	0-40 ft	4	5	4	5
	> 40 ft	3	4	5	4
3 or 4	No setback	4	5	4	5
	0-40 ft	3	4	5	4
	> 40 ft	2	3	4	3
5 or 6	No setback	3	4	5	4
	0-40 ft	2	3	4	3
	> 40 ft	1	2	3	2
More than 6	No setback	2	3	4	3
	0-40 ft	1	2	3	2
	> 40 ft	0	1	2	1

To analyze the data, negative binomial regression was used to test the relationship between transit ridership and built environment characteristics. The dependant variable for this model was the total boardings and alightings from a 2005 survey conducted by TTA. The independent variables were the audit indices, three secondary measures of land use, and level of service or service supply. Secondary variables included the proportion of land area used for residential uses, intersections per square mile, and land use mix. The last independent variable, total buses, is a measure of the total number of local, local express, regional, and regional express buses that serve a stop. When analyzing count data, as in our study, ordinary least squares regression is inappropriate. In addition, the negative binomial distribution is more appropriate than Poisson regression because of overdispersion in the data. The negative binomial distribution, unlike Poisson, allows the variance to be greater than the mean.

The data was first analyzed using all the audit questions except those that had uncertain theoretical basis or ambiguous expectations for effects on ridership (See Table 4.6). Lack of existing empirical support was not sufficient for removal of a question, but if clear expectations about the effect of a variable could not be formulated, questions were dropped. For example, it was unclear whether having “big box” stores would increase or decrease ridership. These stores could increase ridership if employees ride the bus, as hourly employees are likely to be low-income and therefore less likely to have a car. However, these stores could decrease ridership because customers are likely to purchase bulky items or large quantities of items, which cannot be easily transported by hand.

After removing the questions without theoretical support, questions remained in the indices that, when tested, had little effect on ridership or were highly collinear with one another (See Table 4.7). To further refine the audit indices, the variables composing each index were tested for collinearity and significance. (See Appendix for details of regressions for each index). For variables exhibiting high collinearity, only one of the collinear variables was included in the final index. For example, in the Pedestrian/Bike index, many of the sidewalk questions were highly correlated with one another, since the answers for these questions were dependent on having such a facility in the first place. Therefore, only one part of question 14, which detailed sidewalk characteristics, was used in the refined index. In addition to removing collinear variables, those with a significance greater than 0.4 were removed. A final negative binomial regression was repeated for the new audit indices, land use variables, and total buses. A variable inflation factor (VIF) test was performed to ensure that none of the final variables were collinear (Questions that had a VIF greater 4.0 were removed from the final index).

Table 4.6: Questions Dropped from Analyses for Theoretical Reasons

Index	Question Number
Bus Stop	4
Land Use	8,9
Ped/Bike Facilities	none
Road Design	none
Neighborhood Features	26,30
Architecture Design	35

Table 4.7: Questions Dropped from Analyses due to Statistical Insignificance or Collinearity

Index	Question Number
Bus Stop	1c,1e,1f,1h,3
Land Use	none
Ped/Bike Facilities	11a,11c,11d,13,14a,14b,14c,15,16,20b,20c
Road Design	19c
Neighborhood Features	10,22b,25,28,29c
Architecture Design	31,34,36b

Table 4.8: Questions Included in Each Index in Final Analyses

Index	Question Number
Bus Stop	1a,1b,1d,1g,2
Land Use	5,6,7
Ped/Bike Facilities	11a, 12, 14d, 20a, 20d,20e
Road Design	17, 18, 19a, 19b
Neighborhood Features	21, 22a, 22c, 23, 24, 25, 26, 29a,29b
Architecture Design	32,33,36a,36b

The Research Triangle Park area has a unique built environment, with large office buildings located away from roads, often behind vegetation and large buffers.To examine the effects of the built environment characteristics of the RTP area, we performed separate analyzes for the full set of stops and for the set of stops excluding those in RTP. Seven stops in the final sample were located in RTP. This analysis allowed comparison with the full sample to determine if the RTP stops significantly affected the indices or any of the outcome variables.

5. ANALYSIS

Summary Statistics

Table 5.1 shows the summary statistics for the ten variables used in the quantitative analysis. The number of boardings and alightings for the bus stops audited ranged from 0 to 463, with a mean of 14. The number of total buses (local and regional) that served stops ranged from 0 to 21, with a mean of 2.8. The mean for the land use mix variable (lu_mix,), is 0.44, indicating that land uses within a quarter mile of bus stops are not perfectly mixed, but they are also not characterized by one land use. The mean proportion of residential land area is 27 percent, with the range being from 0 percent to 80 percent residential. The mean intersection density was 32.3 intersections per square mile.

Summary statistics of the audit data for the seven municipalities served by TTA as well as RTP are shown in Table 5.1. Bus stop amenities were lacking at most stops audited. Signs, the most basic amenity, were only present at 75 percent of stops. If signs are not present, people may not even be aware of the possibility of taking transit in a certain area. Shelters were only present at 14percent of stops, and schedules were only present at 7percent.

Table 5.1 Descriptive Statistics for Variables used in the Intial and Final Models

Initial Model	**N**	**Mean**	**Std. Dev.**	**Min**	**Max**
TOT_BA_2005	148	13.86	47.69	0	463
Int_Den	148	32.30	35.19	0	142.72
lu_mix	148	0.44	0.16	0.07	0.77
res_prop	148	0.27	0.22	0	0.80
Total_Routes	148	2.84	3.60	0	21
StopIndex	148	4.49	3.47	0	15
DestinIndex	148	1.61	1.23	0	4.60
PedIndex	148	7.96	2.59	0.50	12
RoadIndex	148	5.57	1.63	2.50	10.67
NeighborhoodIndex	148	3.59	1.78	-0.17	8.33
ArchitectureIndex	148	4.38	2.19	0	9.50
Final Model	**N**	**Mean**	**Std. Dev.**	**Min**	**Max**
TOT_BA_2005	148	13.86	47.69	0	463
Int_Den	148	32.30	35.19	0	142.72
lu_mix	148	0.44	0.16	0.07	0.77
res_prop	148	0.27	0.22	0	0.80
Total_Routes	148	2.84	3.60	0	21
StopIndex2	148	2.38	1.87	0	8
DestinIndex2	148	1.61	1.23	0	4.60
PedIndex2	148	3.48	1.24	0.50	6
RoadIndex2	148	2.42	0.95	0.67	4.67
NeighborhoodIndex2	148	1.75	1.36	-0.67	5.67
ArchitectureIndex2	148	1.42	1.43	-0.17	5.67

The characteristics of bus stops varied by municipality (See Table 5.2), as did other characteristics. Suburban locations generally had fewer destinations within a short distance of a stop. However, the pattern is not absolute, less than 2/3 of the segments audited in Morrisville had such destinations. Similarly, people traveling to work are likely to have

Table 5.2 Bus stop characteristics by city for all Triangle Cities

		Apex	Cary	Chapel Hill	Durham	Garner	Morris-ville	RTP	Raleigh	Total
Number of stops		**6**	**29**	**19**	**40**	**3**	**1**	**7**	**43**	**148**
Sign?	Yes	50.0%	86.2%	79.0%	69.6%	66.7%	100.0%	57.1%	72.1%	74.3%
	No	50.0%	13.8%	21.1%	27.5%	33.3%	0.0%	42.9%	27.9%	25.7%
Shelter?	Yes	0.0%	3.5%	42.1%	17.5%	0.0%	0.0%	28.6%	9.3%	14.9%
	No	100.0%	96.6%	57.9%	82.5%	100.0%	100.0%	71.4%	90.7%	85.1%
Schedule?	Yes	0.0%	3.5%	21.1%	10.0%	0.0%	0.0%	0.0%	4.7%	7.4%
	No	100.0%	96.6%	79.0%	90.0%	100.0%	100.0%	100.0%	95.4%	92.6%
Lighting?	Yes	0.0%	51.7%	36.8%	5.0%	0.0%	0.0%	28.6%	4.7%	18.9%
	No	100.0%	48.3%	63.2%	95.0%	100.0%	100.0%	71.4%	95.4%	81.1%
Paved Landing?	Yes	83.3%	72.4%	89.5%	65.0%	66.7%	100.0%	57.1%	76.8%	73.7%
	No	6.3%	27.6%	10.5%	35.0%	33.3%	0.0%	42.9%	23.3%	26.4%
Trash Can?	Yes	0.0%	0.0%	52.6%	7.5%	0.0%	0.0%	28.6%	16.0%	14.7%
	No	100.0%	100.0%	47.4%	92.5%	100.0%	100.0%	71.4%	84.0%	85.4%
Bike Rack?	Yes	0.0%	0.0%	10.5%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%
	No	100.0%	100.0%	89.5%	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%
Seating?	Yes	0.0%	3.5%	57.9%	15.0%	0.0%	0.0%	42.9%	10.0%	16.5%
	No	100.0%	96.6%	42.1%	85.0%	100.0%	100.0%	57.1%	90.0%	83.5%
Map?	Yes	0.0%	0.0%	15.8%	2.5%	0.0%	0.0%	0.0%	2.0%	3.2%
	No	100.0%	100.0%	84.2%	97.5%	100.0%	100.0%	100.0%	98.0%	96.8%
Companion Stop?	Yes	66.7%	72.4%	73.7%	57.5%	50.0%	100.0%	42.9%	34.0%	54.4%
	No	33.3%	27.6%	26.3%	42.5%	50.0%	0.0%	57.1%	66.0%	45.6%
Sidewalk to stop?	Yes	83.3%	75.9%	89.5%	65.0%	66.7%	100.0%	28.6%	78.0%	73.4%
	No	16.7%	24.1%	10.5%	35.0%	33.3%	0.0%	71.4%	22.0%	26.6%

a predictable schedule such that they can plan to use bus service even with long headways. While the presence or absence of a sidewalk was related to the relative urban/suburban character of a location (1/3 of segments in Morrisville had sidewalks, whereas 95 percent of those in Chapel Hill did), sidewalk completeness was poor throughout the Triangle. Overall, only 24 percent of segments audited in the Triangle had complete sidewalks. While there were relatively few buildings judged to be a negative influence on the bus stop environment, buildings set back greater than 40 feet from the street were the norm in suburban environments (82 percent of segments in Garner, 100 percent in Apex). Setbacks were somewhat smaller in urban areas (43 percent with large setbacks in Chapel Hill, 50 percent in Raleigh). Additional tables that summarize each of the audit questions can be found in the Appendix.

Results

Table 5.3 shows the results of the negative binomial regression models predicting Triangle Transit Authority bus ridership using ten independent measures of environment, bus service, and land use as predictors. The initial shown was

Table 5.3 Binomial Regression Models predicting total boardings and alightings for 2005 for all stops

			Initial Model		
TOT_BA_2005	B	Std. Err.	exp(B)	% change *	P>z
Constant	-0.37	0.61	0.69	-31.00	0.54
Int_Den	-0.01	0	0.99	-0.96	0.04
lu_mix	-0.08	0.85	0.92	-8.06	0.92
res_prop	-1.32	0.64	0.27	-73.21	0.04
Total_Routes	0.09	0.04	1.10	9.59	0.01
StopIndex	0.15	0.04	1.16	15.62	0.00
DestinIndex	0.39	0.11	1.47	47.17	0.00
PedIndex	0.09	0.05	1.09	9.11	0.11
RoadIndex	-0.03	0.07	0.97	-3.08	0.66
NeighborhoodIndex	-0.15	0.08	0.86	-14.08	0.05
ArchitectureIndex	0.24	0.07	1.27	27.20	0.00
/lnalpha	0.14	0.15			
alpha	1.15	0.17			
Likelihood-ratio test of alpha=0: chibar2(01) = 1400.33 Prob>=chibar2 = 0.000					
Summary Statistics					
	N	148		Log likelihood	-393.06
	LR chi2(10)	143.26		Pseudo R2	0.15

			Final Model		
TOT_BA_2005	B	Std. Err.	exp(B)	% change *	P>z
Constant	-0.49	0.54	0.61	-38.75	0.37
Int_Den	-0.01	0	0.99	-1.20	0.01
lu_mix	-0.05	0.80	0.95	-5.22	0.95
res_prop	-1.42	0.61	0.24	-75.87	0.02
Total_Routes	0.09	0.04	1.10	9.94	0.01
StopIndex2	0.25	0.07	1.28	28.07	0.00
DestinIndex2	0.35	0.10	1.41	41.35	0.00
PedIndex2	0.25	0.11	1.28	28.35	0.02
RoadIndex2	0.11	0.11	1.12	11.96	0.31
NeighborhoodIndex2	-0.21	0.09	0.81	-19.06	0.03
ArchitectureIndex2	0.41	0.11	1.50	50.34	0.00
/lnalpha	0.13	0.15			
alpha	1.13	0.17			
Likelihood-ratio test of alpha=0: chibar2(01) = 1034.95 Prob>=chibar2 = 0.000					
Summary Statistics					
	N	148		Log likelihood	-392.32
	LR chi2(10)	144.73		Pseudo R2	0.16

* Percent change in ridership associated with unit increase in variable

statistically significant (chi-squared = 143.26, df = 10; p < 0.001). In the initial model all of the variables except PedIndex, RoadIndex and lu_mix have a significance of at least 95 percent. In the final model, obtained by removing audit questions that were either insignificant or highly collinear from the audit indices, the results are also statistically significant (chi-squared = 144.73, df = 10; p < 0.001). All of the independent variables except RoadIndex, and lu_mix have a significance of 95%.

The Bus Stop Index was highly significant (>99 percent) and positively related to bus ridership. A unit increase in the bus stop index was associated with a 31 percent increase in ridership. Of the possible bus stop amenities, having signs, shelters, schedules, lighting, and paved landing areas were significant and correlated with increased ridership. In the final model, the mean score for the stop index was only 2.38 out of 8 possible points, as the majority of stops did not have shelters and many did not even have TTA signs. An increase of one unit system-wide would mean raising the mean to 3.38. At this level, an “average” stop might have a sign, a paved landing area, and either a shelter, schedule information, or lighting. Without a sign it may be difficult for people to even know that a stop is there, while other aspects that were significant make waiting more comfortable and secure. Figure 5.1 displays the relationship between the Bus Stop Index and ridership.

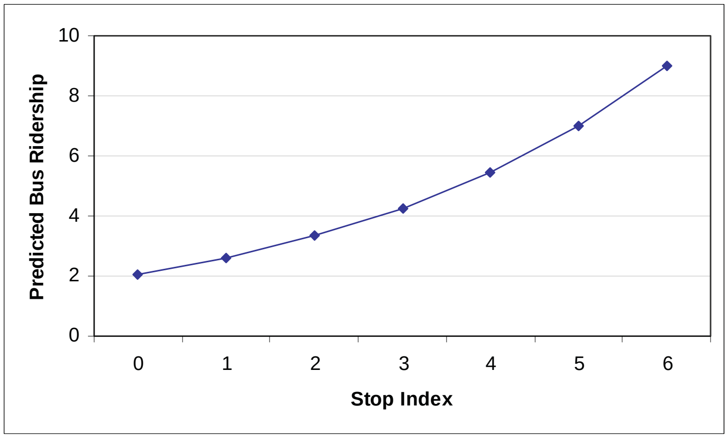


Figure 5.1: Bus Stop Index versus Ridership

Like the Bus Stop Index, the Destinations Index variable was also highly significant (>99 percent) and positively related to bus ridership. A unit increase in the destination index (DestinIndex) was associated with 42 percent more bus riders. When we ran the individual destination questions against the dependant variable, we found that having a lot of places that people can visit for a long time, and having high employment were positively associated with ridership. Having a lot of places that people visit for a short time, however, was associated with lower ridership, but its explanatory power and significance were poor. The mean score on the destinations index was 1.61 out of 7 possible points, which indicates that there are many stops located near few destinations. An increase of one unit systemwide would mean raising the mean to 2.61 and at this level, an “average” stop might be located in an area with

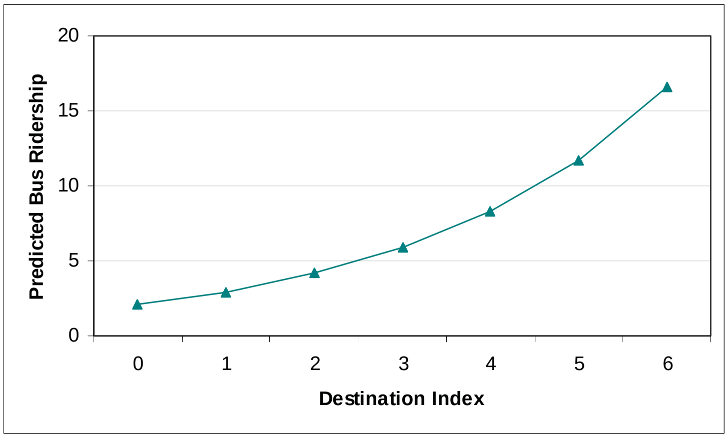


Figure 5.2: Destinations Index versus Ridership

Case Study: NC-54 at Falconbridge, Chapel Hill, NC

This stop is located on the south side of NC Highway 54, a four-lane divided highway, just north of the NC-54 and I-40 interchange. At the location of the bus stop, the road is four travel lanes and five lanes to cross. The road width is about 200 feet and has a speed limit of 45 miles per hour. The bus stop is located along the side of the road with an unpaved landing area in a ditch. For years people have requested a shelter at that stop because the area gets muddy when it rains. They have also complained that the stop has no paved area for people to stand away from the road.

NCDOT is currently reconfiguring the intersection to restrict left turns from Falconbridge to 54. It is adding a lane on the ramp from I-40 West to 54 West and adding a right turn lane at Falconbridge. NCDOT has told TTA not to pick up passengers at that intersection, although people continue to stand in the work area to catch the bus. Once construction is over, the TTA stop may be moved.

The population and employment density are relatively low here – about 760 persons and 200 jobs within a quarter mile of the stop. The ridership level may be due to the Falconbridge Shopping Center, which offers essential services to people who depend on transit.

Aerial Source: Google, 2006

Despite inhospitable conditions, ridership at the Falconbridge stop is closer to average. This also may be due to the high number of buses that stop at Falconbridge, which has one of the highest levels of service provided by TTA.

NC-54 at Falconbridge (Stop #134)		
Employment Density	197	Jobs/Square Mile
Population Density	765	People/Square Mile
4-way Intersection Density	36	Intersections/Square Mile
Boardings & Alightings	7	Riders/Day
Regional Buses	58	Buses/Day
Peak Service Regional Buses	28	Peak Buses/Day

a small number of employees and one to two destinations where people stay for a long time, or a large number of employees. Figure 5.2 displays the relationship between the Destinations Index and ridership.

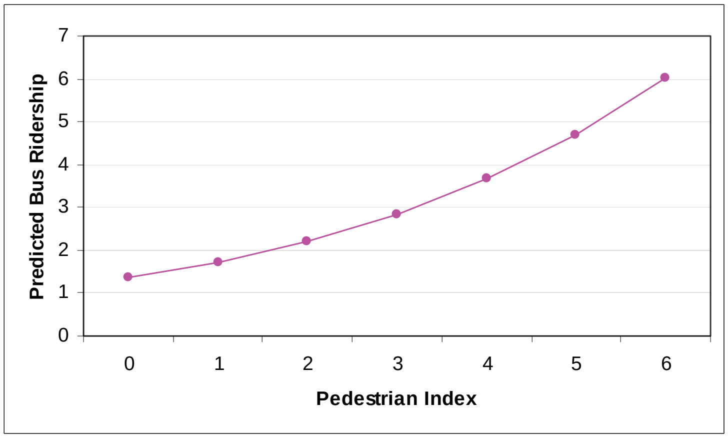


Figure 5.3: Pedestrian/Bicycle Index versus Ridership

The Pedestrian/Bicycle Index variable was significant (>95 percent) and positively related to bus ridership. A unit increase in the Pedestrian/Bicycle Index was related to a 23 percent increase in ridership. The initial model did not show this index to be significant, but when we mined the index (i.e. removed individual audit questions that were not significant), we found that many of the variables were highly collinear with each other and therefore decreased the overall significance of the Pedestrian/Bicycle Index. When we removed the questions with high collinearity from the final model (see Table 2), the audit index became significant and positively correlated with bus ridership. The mean score on the ped/bike index was 3.48 out of 6.5 possible points. An increase of one unit system-wide would mean raising the mean to 4.48. At this level, the area around an “average” stop might have complete, well-maintained sidewalks that connect to others, as well as some pedestrian amenity such as a pedestrian signal and markings nearby to help people access the stop. Figure 5.3 displays the relationship between the Pedestrian/Bicycle index and ridership.

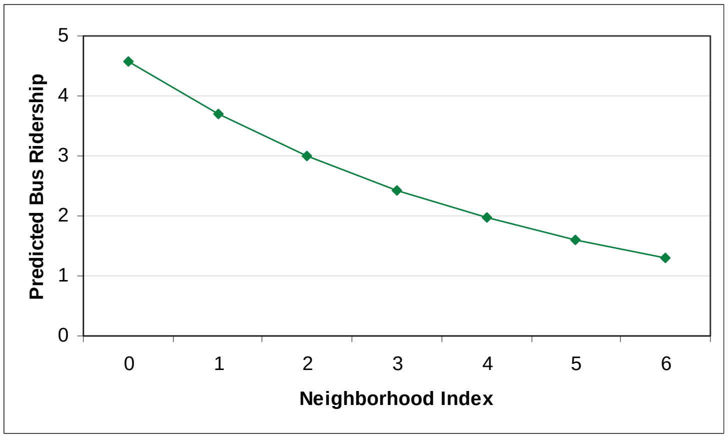
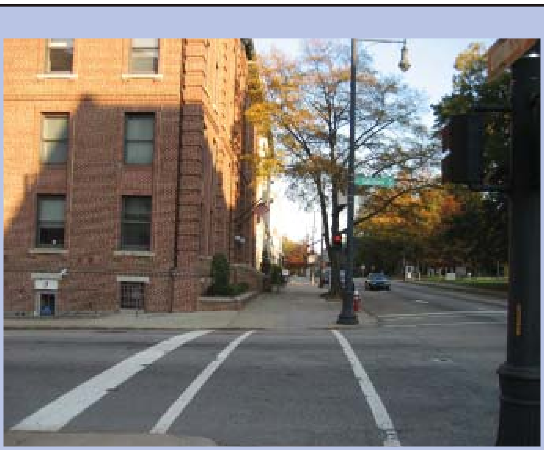


Figure 5.4: Neighborhood Features Index versus Ridership

The Neighborhood Features Index variable was significant (>95 percent) and negatively related to bus ridership. A unit increase in the Neighborhood Features Index was associated with 19 percent fewer riders. The negative relationship of this index is contrary to our expectations. The mean score on the neighborhood index was 1.75 out of 6.5 possible points. One aspect to note is that this relationship between neighborhood features and ridership is calculated given that all other variables are equal. Many positive neighborhood features are more likely to be present accompanied by other features such as good pedestrian environments, which may have an offsetting, larger effect on ridership. Figure 5.4 displays the relationship between the Neighborhood Features Index and ridership.

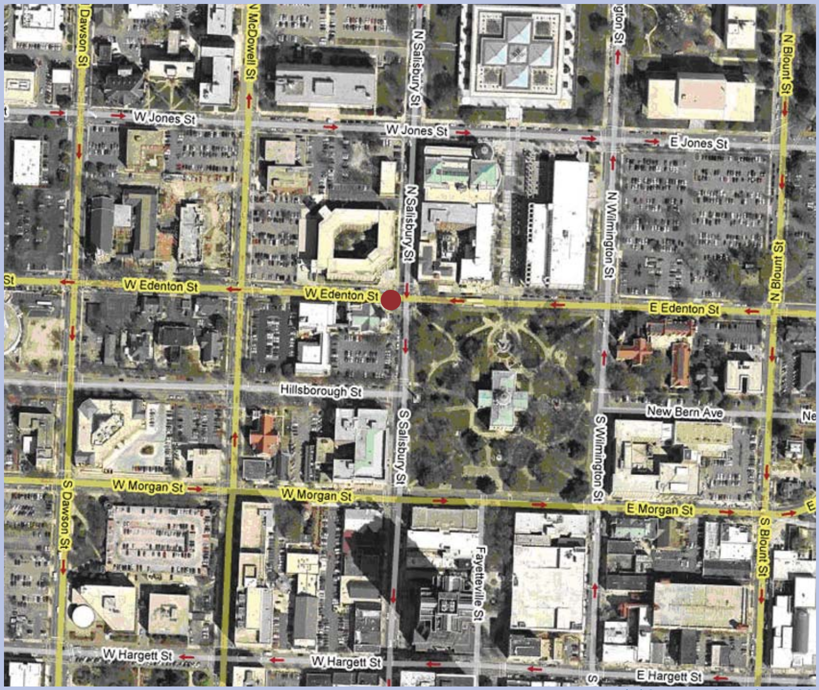
Case Study: Downtown Raleigh, NC



This stop is located at Edenton Street and Salisbury Avenue, along the north side of downtown Raleigh adjacent to the capital. The bus stop is located on a corner with sidewalks, pedestrian crossing signals, a speed limit of 30 miles per hour, and a short crossing distance of 3 lanes (50 feet total). The presence of short blocks that create many four-way intersections makes it easier to walk from one place to another by reducing distance between them. Also, buildings have little or no setback from the street and there are sidewalks on all sides of the street. All of these elements create an overall environment that is transit supportive.

There is high employment in the area as downtown Raleigh has the highest concentration of jobs in the region. However, the population density is much lower since very few people live downtown.

This stop has 38 regional buses and 15 peak service buses, although ridership is lower than average. The ridership may be low because the majority of downtown Raleigh riders get off at the Moore Square Transit Station, which has 463 total daily boardings and alightings. The transit station is close to Fayetteville Street and most of the main employers in downtown Raleigh.



Aerial Source: Google, 2006

Downtown Raleigh (Stop #201)		
Employment Density	77,495	Jobs/Square Mile
Population Density	714	People/Square Mile
4-way Intersection Density	127	Intersections/Square Mile
Boardings & Alightings	6	Riders/Day
Regional Buses	38	Buses/Day
Peak Service Regional Buses	15	Peak Buses/Day

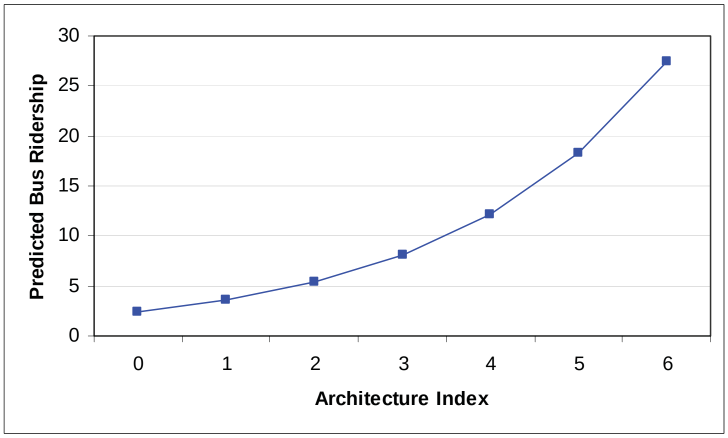


Figure 5.5: Architecture Index versus Ridership

The Architecture Index was highly significant (>99 percent) and positively correlated with ridership. A unit increase in the Architecture Index was associated with 50 percent more riders, indicating that the presence and features of the buildings around a bus stop affects ridership. Buildings that are set far back from roads or oriented away from roads with the bus stop discourages bus ridership; in addition, buildings designed with interesting features are likely to encourage ridership, possibly because they provide an interesting environment for people waiting for the bus. This index captures the fact that simply having buildings near a stop does not necessarily mean that it will have high ridership – the way those buildings are situated within a site is important. The mean score on the architecture index was 1.42 out of 6 possible points. An increase of one unit system-wide would mean raising the mean to 2.42. At this level, an "average" stop might have building setbacks between 20 and 40 feet from the road with the building oriented towards a street. Figure 5.5 displays the relationship between the Architecture Index and ridership.

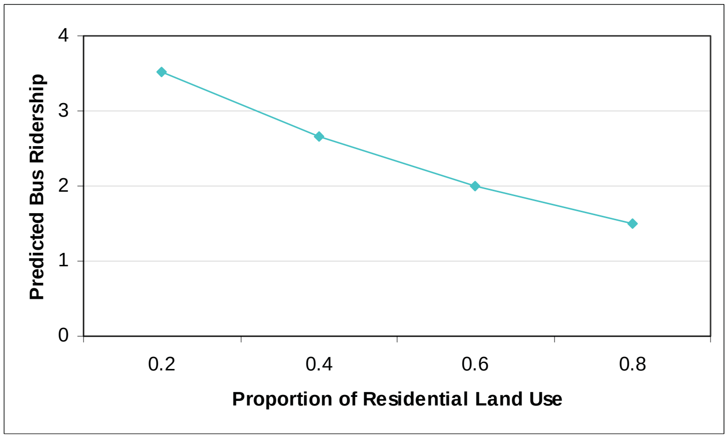


Figure 5.6: Proportion of Residential Uses versus Ridership

The proportion of residential land use variable was highly significant (>99 percent) and negatively correlated with ridership, suggesting that bus stops that are in areas dominated by solely residential uses have fewer bus riders. Bus stop surroundings that had more land area dedicated to other non-residential uses supported transit ridership. Figure 5.6 displays the relationship between the proportion of residential uses within the buffer and ridership.

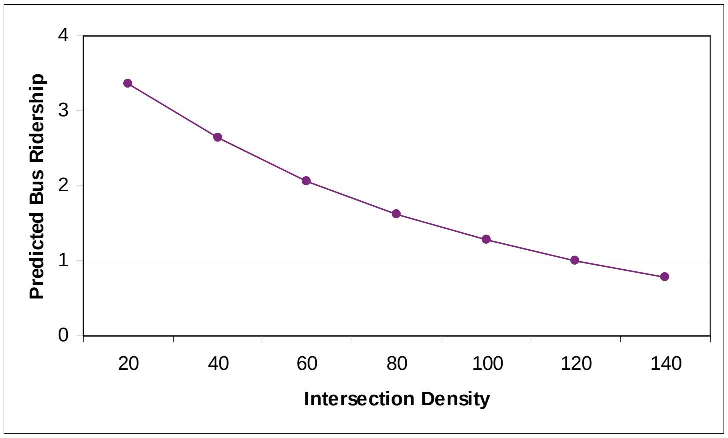


Figure 5.7: Intersection Density versus Ridership

Intersection density was significant (>95 percent) and negatively related to bus ridership. One more intersection per square mile is associated with 1 percent fewer

Case Study: RTP - Davis Drive at Nortel

This stop is located along Davis Drive next to the BASF building, a chemical company in RTP. This building is significantly set back from the street, approximately 700 feet, and a transit user must walk up the long driveway to the main building entrance. There is a walking and bicycle path though up on the hill away from the street. Pedestrian connections are possible along Davis Drive. However, the distance from one corporate campus to the next makes it unlikely that a person would use the path for anything other than recreational walking during a break from work.

Buildings are set far back from the road along most of Davis Drive so the natural landscape is the all that is visible from the broad. The road has two through lanes and three total lanes to cross with a width of 50 feet and speed limit of 45 miles per hour. The only use present across the street is the corresponding bus stop.

Ridership is lower than most RTP stops and the TTA average, however the employment density is above average for the stops sampled. Despite the location of a major corporate headquarters in the area, the bus ridership may be low since it is not a particularly convenient place to take transit. It would be difficult to use transit to commute to work, and then to go out for lunch or run errands from this location.

Aerial Source: Google, 2006

RTP at Davis Drive (Stop #154)		
Employment Density	3,670	Jobs/Square Mile
Population Density	12	People/Square Mile
4-way Intersection Density	0	Intersections/Square Mile
Boardings & Alightings	3	Riders/Day
Regional Buses	24	Buses/Day
Peak Service Regional Buses	7	Peak Buses/Day

riders. This contradicts with our expectation that an increase in the intersection density should increase bus ridership. However, the extremely small coefficient of this variable means that its effect on ridership is almost negligible. Figure 5.7 displays the relationship between intersection density and ridership.

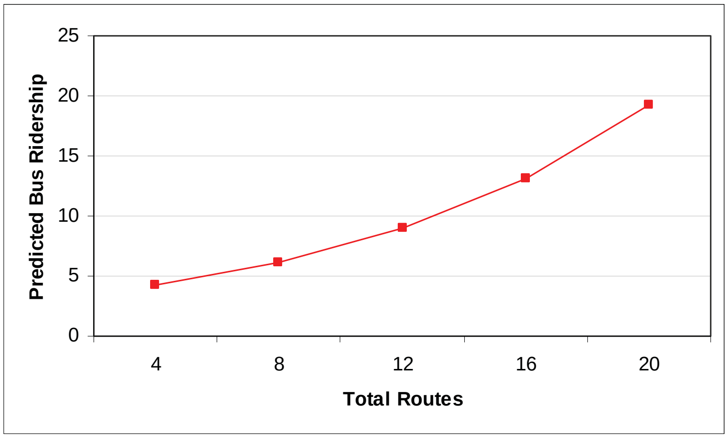


Figure 5.8: Total Buses versus Ridership

Service supply was highly significant (>99 percent) and positively associated with ridership. The addition of one extra bus per day serving a bus stop was associated with 9 percent more riders. This variable did not distinguish between different types of buses.

Two of the variables in our analysis were found to be insignificant. The Road Design Index and Land Use Mix variables were not significant. Potential reasons for their insignificance are discussion in the next section.

Table 5.4 shows the results from the second set of negative binomial regressions, excluding stops in the Research Triangle Park from the analysis. The negative binomial regression models shown were statistically significant (chi-squared = 137.08 and 138.64, df = 10; $p < 0.001$). Removing the RTP stops did not noticeably change the results in either the initial or final models. The bus stop index coefficient was higher, with a 3 percent higher ridership increase associated per unit bus stop index increase. The pedestrian index was less significant and the coefficient was lower. The architecture index coefficient was higher, with a 4 percent higher ridership increase expected per unit change. The residential proportion coefficient was lower, with a 3 percent lower ridership increase expected per unit change. The total buses index was less significant, possibly because local buses don't serve RTP.

In summary, our analysis identified a number of built environment characteristics that are related to TTA bus use. As expected, our models consistently showed the characteristics of the stops, the design of the buildings close to the stop, and the presence of suitable destinations are positively related to boardings and alightings. Other models showed less consistently that the pedestrian environment also was related to higher TTA use. However, the proportion of the ¼-mile area around each stop devoted to residential uses, the Neighborhood Features Index, and the density of 3 and 4-way intersections for each stop were negatively related to TTA use. The latter was surprising, since we expected higher connectivity to be related to more use. However, since our models control for a host of other characteristics that appear to support transit, it may be that connectivity on its own may have a detrimental effect on ridership because it encourages auto traffic.

Table 5.4 Binomial Regression Models predicting total boardings and alightings for 2005 for non-RTP stops

Initial Model (no RTP stops)

TOT_BA_2005	B	Std. Err.	exp(B)	% change *	P>z
Constant	-0.22	0.69	0.80	-20.00	0.75
Int_Den	-0.01	0.01	0.99	-0.95	0.06
lu_mix	-0.37	0.90	0.69	-30.92	0.68
res_prop	-1.46	0.69	0.23	-76.78	0.04
Total_Routes	0.08	0.04	1.09	8.83	0.02
StopIndex	0.16	0.04	1.17	17.41	0.00
DestinIndex	0.39	0.11	1.47	47.37	0.00
PedIndex	0.07	0.06	1.07	7.33	0.21
RoadIndex	-0.01	0.07	0.99	-1.43	0.85
NeighborhoodIndex	-0.16	0.08	0.86	-14.42	0.05
ArchitectureIndex	0.25	0.08	1.28	28.04	0.00
/lnalpha	0.15	0.16			
alpha	1.16	0.18			

Likelihood-ratio test of alpha=0: chibar2(01) = 1371.01 Prob>=chibar2 = 0.000

Summary Statistics

N	141	Log likelihood	-376.39
LR chi2(10)	137.08	Pseudo R2	0.15

Final Model (no RTP stops)

TOT_BA_2005	B	Std. Err.	exp(B)	% change *	P>z
Constant	-0.34	0.63	0.71	-28.76	0.59
Int_Den	-0.01	0.01	0.99	-1.32	0.01
lu_mix	-0.23	0.85	0.79	-20.64	0.79
res_prop	-1.55	0.68	0.21	-78.83	0.02
Total_Routes	0.09	0.04	1.09	9.16	0.02
StopIndex2	0.27	0.07	1.31	31.14	0
DestinIndex2	0.35	0.11	1.42	42.40	0
PedIndex2	0.22	0.11	1.24	23.99	0.05
RoadIndex2	0.13	0.12	1.14	13.83	0.26
NeighborhoodIndex2	-0.21	0.10	0.81	-18.64	0.04
ArchitectureIndex2	0.43	0.12	1.54	54.02	0
/lnalpha	0.14	0.16			
alpha	1.15	0.18			

Likelihood-ratio test of alpha=0: chibar2(01) = 1011.44 Prob>=chibar2 = 0.000

Summary Statistics

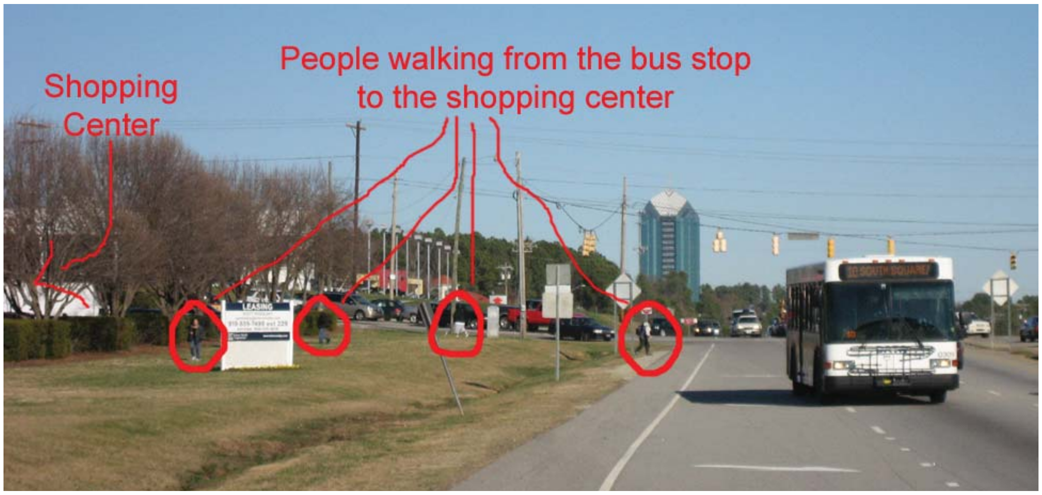
N	141	Log likelihood	-375.61
LR chi2(10)	138.64	Pseudo R2	0.16

Limitations

While the study was carefully conducted, there are several limitations that must be discussed. First is our limited sample size. Despite our effort to audit at least three segments for each stop, we were able to reach under 150 stops. A larger number of stops may improve our estimates. A second limitation is that our results cannot be considered as causal. The built environment and transit service supply may affect ridership, but the opposite is also possible. In the parlance of econometricians, this is called simultaneity. This simultaneous effect is difficult to control in the absence of longitudinal data. Future studies may address the simultaneity between service supply and ridership using ridership from previous years. Likewise, built environment data from past years can assist in clarifying the simultaneity between the built environment and ridership.

A final limitation is that, although we intended to use an audit that relied on established instruments that have been extensively tested, we found that existing audits were too limited to be used in a transit context. Thus, we ended up with a hybrid audit, with a selection of questions borrowed from established audits, and other questions designed by us. The reliability and validity of the new questions needs to be examined in further studies.

Figure 5.9 Some bus riders must walk through a ditch to get to their destination



6. CONCLUSIONS AND RECOMMENDATIONS

Many transit advocates feel that bus stop amenities such as signs, shelters, and lighting increase both the visibility of a stop and the comfort of riders while waiting for the bus. Our study found that the bus stop environment is important to transit riders. Since the bus stop attributes are the predictive factor for ridership over which TTA has authority, we recommend that TTA implement a system for providing and maintaining basic facilities at all stops. While signs should be placed at all existing stops, stops with high ridership or expected increases in ridership should be prioritized for shelters. Local governments should strongly encourage developers along existing or potential transit routes to include bus stop amenities in their projects.

Destinations located close to bus stops are associated with higher ridership. We theorize that when people are going to places at which they will spend a relatively long period of time. Employment is a major destination where people spend extended periods; however other destinations such as restaurants, libraries and parks were also included in this study. Considering the length of the stay, it seems reasonable that people may be more amenable to riding a bus for these types of trips, especially when using bus routes that only run every 30-60 minutes. When several destinations are located near one another, riders may fill the time that would be spent waiting for the bus by running errands or completing other tasks. Taking this into account, TTA should locate stops where riders have access to multiple destinations in the immediate surrounding area.

Since bus trips typically start or end on foot, the rider requires a means of accessing the bus stop. For TTA, despite many riders accessing through park and ride, this is still important as the majority of riders access the bus by foot directly or after connecting from another bus. It is not surprising that sidewalk presence, completeness, and connectivity are important elements in predicting ridership because so many riders access the bus by walking. Unfortunately, these sidewalks characteristics are generally poor in the Triangle area. Measures that improve safety – such as pedestrian signals, signs, and crosswalk pavement markings – were also associated with higher ridership. Local governments should institute ordinances requiring developers to build sidewalks and should initiate sidewalk-focused public works programs along existing transit routes. Where existing sidewalk policies are in place, they should be expanded to require connections with adjacent sites and set minimum quality standards for materials, width, and ongoing maintenance. Localities should create sidewalk policies that incrementally add new facilities regardless of location as well, to support future transit expansion. When roads or intersections along bus routes are improved or otherwise altered, the addition of pedestrian signals, signs, and crosswalks should become standard procedure.

Buildings placed close to and oriented towards the street were associated with higher ridership. In addition, the outward appearance of buildings and presence of distinguishing features – such as porches, dormer windows or interesting awnings – are also important. Existing land use regulations in much of the Triangle require large setbacks and do little to address building orientation or design. Local governments should examine existing codes to determine if setbacks are unnecessarily large for uses compatible near the street such as retail and office. Ordinances should be written to include maximum, rather than minimum setbacks, thus encouraging developers to place buildings closer to roads. Through site plan review and commenting processes, local government officials can encourage orientating buildings towards the street rather than towards internal parking lots or driveways. When possible, buildings should be created with unique features through application of design standards. Additionally, TTA should develop stop area guidelines for municipalities that offer guidance on developing around transit.

Bus ridership was lower when the area within ¼ mile of a stop had a large proportion of residential housing. If a new development is predominately residential, it is unlikely that TTA can extend service and achieve high ridership. This would leave residents of such developments without many transportation options. Mixing land uses within the quarter-mile area around the bus stop would avoid high concentrations of residential uses and potentially increase bus ridership. Since residential developments will likely comprise large percentage of the Triangle's growth in the future, providing housing in mixed-use or denser environments will make transit service more viable. Municipalities can accommodate population growth while minimizing the amount of new roads necessary if residents can use transit or walk to fulfill some of their daily needs. Local governments should allow and encourage mixing of land uses and more intense use of existing spaces. However, decision-makers should use caution in how "mixed-use" is defined. The presence of a quick stop retail use (such as a gas station) in a solely residential neighborhood does not go far enough to qualify as a truly mixed-use area. Mixed-use should be defined as an area that has a wide variety of uses – with more than one use on a single property – not two uses on the opposite sides of an arterial road. By offering mixed-use at a place where people are likely to stay for a long period of time, it may create an environment that would encourage transit ridership.


Figure 6.1: Transit supportive design can make a difference, as found on Franklin Street in Chapel Hill.

A bus stop with a high number of intersections within a quarter-mile was associated with a small decrease in ridership, holding everything else constant. This was contrary to our expectation that higher intersection density would be associated with higher ridership. One possible explanation is that areas with high intersection density are more attractive to drivers than those with lower density.

The extremely small effect of intersection density means that there are no clear policy implications for TTA or local jurisdictions.

Higher levels of service at a stop are strongly associated with higher ridership. This is true for total service supply including local and regional buses. The prevalence of transfers within the existing TTA ridership implies that riders are not averse to changing from TTA to local systems where such connections exist. These results indicate that TTA should locate its routes where local services already exist to allow for transfers with other bus systems. In addition, TTA and local operators should strive to better coordinate schedules to minimize wait times between transfers.

Although road design proved to be insignificant in the final analysis, this does not mean that the built environment characteristics included in this index do not affect bus ridership. The audit questions in the index simply did not capture features that had a significant effect on ridership. Our expectation was that roads with more lanes to cross and fewer traffic control devices would exhibit lower ridership, because other studies have found that road design affects walkability. However, the insignificance of this variable indicates that though it may affect walkability, the relationship between road design and ridership is not clear in the Triangle. The presence of more traffic control devices on road with more lanes may have caused one factor to cancel the other out. This result also may be due to the fact that many destinations are located on streets with many lanes, while streets with few lanes may have few destinations – thus this index may not apply well in the Triangle. This index also did not take into account other important road design factors such as speed and lane width. Our index relied heavily on the expectation that road design characteristics that make an area walkable would also increase transit ridership. We cannot make that conclusion based on this study.

The land use mix variable was especially insignificant. Consistent with the academic literature on the topic, this measure assumed that an equal mix of three major uses was ideal. However this approach may be lacking empirical and theoretical basis. Considering that previous studies have found land use mix to be most significant at a micro-scale level, the level of analysis of land use mix in this study may have been too broad to produce meaningful result.

Applicability to Other Regions

The Triangle area and the TTA service are unique; therefore other metropolitan areas should use caution in applying specific conclusions from our study to their cities. For example, the Triangle has a number of major destinations where parking is strictly controlled and priced, in particular universities and downtowns. In addition to parking policies at several major destinations, Chapel Hill's extensive free transit system probably spurs some of TTA's transfer ridership. TTA's regional focus as a transit agency is also unique, as is the interaction between the regional transit agency and numerous local agencies. In other regions of similar size, transit may not be separated into multiple systems. These qualifications aside, some of our findings are applicable for bus systems in other areas, particularly areas with regional transit systems like TTA.

Metropolitan areas characterized by low-density growth should view our results as an affirmation of the importance of the built environment in achieving higher transit ridership. Such areas may be able to spur higher ridership on existing systems or implement new systems by planning routes carefully and giving more attention to planning around bus stops. In addition, our findings indicate that increased attention should be given to the bus stop environment in the same manner that it is given to rail station environments. Transit oriented developments in the United States have typically been planned around rail stations, yet the same principles can be extended to bus stop areas. Bus stop amenities, destination types, pedestrian facilities, and architectural design all correlate with higher ridership. These items should be given special attention by local planners.
Our findings indicate that the bus stop environment should not be ignored or discounted in the planning process. Indeed, bus ridership has the potential to increase if municipalities consider TTA routes early in the planning process and encourage new development to incorporate smaller setbacks, connected sidewalks, and multiple destinations into the area surrounding bus stops.

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