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The Land Use and Rapid Transportation Nexus in the Massachusetts Bay

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ABSTRACT

Throughout the last several decades a growing emphasis has been placed on creating sustainable places through innovative planning practices. Urban designers, researchers, planners, and policy makers have continuously examined the land use transportation nexus in order to develop methods to efficiently guide transit funding to encourage alternate modes of travel.

The United States is in the middle of a paradigm shift in generational behaviors. Baby boomers are downsizing and according to the Urban Land Institute are looking for more location-efficient residences. Similarly, Generation Y's attitudes are focused on living and working in close proximity. They are also waiting longer to obtain driver's licenses and are instead looking for alternate modes of travel.

This study looks at the Massachusetts Bay Transportation Authority's rapid transit system through the scope of a linear regression analysis using 2010 rapid transit ridership data, 2010 Census data, 2006-2009 American Community Survey estimates, and 2011 employment data.

This thesis examines previously researched themes and provides a new look at the transportation / land use nexus. It concludes that neither an increase in population density nor an increase in job density increase transit ridership. Instead, the physical built environment has the most influence over transit ridership in the Massachusetts Bay. When streets are dense and highly connected, access to transit

is more convenient, causing people's mode choice to shift from single-occupancy vehicles.

Governing bodies and transit agencies in the Massachusetts' Bay should create a close collaboration between municipalities, counties, and transit agencies if the MBTA wants to increase ridership levels on their rapid transit system. Land development regulations and zoning ordnances should encourage dense, well-connected streets and a high degree of land use mixing in areas where transit investments are likely to occur.

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CHAPTER ONE: INTRODUCTION

As the world's population continues to grow exponentially and age, more efforts and resources are concentrated on the problems our cities face regarding transportation, access, inclusivity, land use, and general growth patterns (Lutz, Sanderson, & Scherbov, 2004). Through complex collaborations, society must determine how to properly direct growth and to mitigate as many negative externalities as possible. Planners realize that one of the most influential tools in this process is land use policy. These policies affect every aspect of the built environment, including street patterns; housing and job density; the location of retail, commercial, and industrial zones; and resource management such as air and water pollution prevention, wetland preservation, and monetary resources for a city's capital stock and its maintenance.

This study examines the Massachusetts Bay rapid transportation system. The analysis is a look at the effects variables categorized by density, design, demographic, and destination have on rapid transit ridership levels at individual stations through the medium of a linear regression. This research provides an update to previous studies of the Boston area transportation system using ridership, survey, and census data.

This research uses data collected by the Massachusetts Bay Transportation Authority (MBTA), which services the Boston region in this paper. The MBTA has done a phenomenal job tracking and studying their transit riders in order to better serve the region. In 2008-2009 the MBTA conducted a new rider survey for all rapid transit rail lines in the region. The Central Transportation Planning Staff administered the survey and assembled the findings. Seventeen reports were compiled and each provided detailed data for every line and station, including the number of boardings and alightings, trip purpose, rider demographics, automobile ownership, and reasons riders chose this particular mode, as well as the perceived quality of the MBTA services. Despite the fact that seminal data for Boston already existed, much of it utilized travel surveys from the late 1980s and early 1990s. Today, evidence suggests that urban cores are seeing an influx of residents migrating towards the city center after decades of outward growth (Lee, 2012). In order to create policies that reflect this paradigm shift, Boston's ridership behaviors need to be reexamined using more current data.

This research quantifies the relationship between land use characteristics, the built environment, and demographics around transit stations to see how those variables are associated with transit ridership. There are several questions answered in this study. First, how do land use policies, such as Euclidean zoning, and the built environment around each station related to transit ridership levels, and if ridership levels are low, might policies be altered to encourage greater transit use? Is ridership affected more by the street pattern, the diversity of land uses, ages, or income levels in the area? Does the distance from the central business district affect ridership levels? Does the number of parking spaces available at stations influence the number of riders? What influences transit ridership more, a higher density of residents, or a higher density of jobs?

To answer these questions I chose a specific set of variables, based on the literature, to analyze the MBTA's rapid transit system. The variables in this paper, as summarized in Table 1, have been used numerous times by many well-respected researchers in the transportation field and provide a solid base to determine what characteristics are affecting transit ridership in the Massachusetts Bay within a quarter-mile Euclidean distance of each transit stop. These variables are identified below and are categorized by density, design, demographics, and destination characteristics. The importance and relevance of these variables are discussed at length in the following review of the literature.

Table 1: Variables Used in this Study by Category

<table>
<tr><th colspan="3">Variables Used in Study</th></tr>
<tr><td>Dependent Variable</td><td></td><td>Total Riders</td></tr>
<tr><td rowspan="16">Independent Variables</td><td rowspan="2">Density</td><td>Population Density</td></tr>
<tr><td>Job Density</td></tr>
<tr><td rowspan="2">Design</td><td>4-way Intersection Density</td></tr>
<tr><td>Line Terminus</td></tr>
<tr><td>Destination</td><td>Distance to CBD (number of stops)</td></tr>
<tr><td rowspan="2">Distance to Transit</td><td>Transfer Stations</td></tr>
<tr><td>Parking Spaces at Each Station</td></tr>
<tr><td rowspan="2">Demographics</td><td>Income</td></tr>
<tr><td>Age</td></tr>
<tr><td rowspan="6">Dummy Variables</td><td>Red Line</td></tr>
<tr><td>Red Mattapan Line</td></tr>
<tr><td>Orange Line</td></tr>
<tr><td>Green Line</td></tr>
<tr><td>Blue Line</td></tr>
<tr><td>Silver Line</td></tr>
</table>

CHAPTER TWO: THE LAND USE AND RAPID TRANSIT NEXUS

To produce research that will contribute to the literature, and an understanding of the public transit/land use relationship, I examined dozens of studies that focus on identifying how land use, the design of the built environment, including street layout and density, walkability levels, and demographics influence transit ridership levels. These studies are summarized and analyzed below. In particular, this vast literature provided direction for which variables would prove most reliable in the models below.

The D's: Density, Design, Diversity, Demographics, Destination Accessibility, and Distance to Transit

The relationship between land use, the built environment, and transportation are hot topics in the transportation research world. According to Ewing and Cervero's 2010 meta-analysis of the literature, there are more than two hundred studies, twelve surveys of the literature, and two reviews of the reviews looking to quantify the connection between the built environment and travel. The meta-analysis took a new approach and examined more than two hundred of these studies and analyzed the overarching findings for over fifty of them, comparing the elasticities between the variable of transit ridership and the variables of density, design, diversity, demographics, destination accessibility, and distance to transit (Ewing & Cervero, Travel and the Built Environment: A Meta-Analysis, 2010).

These categories stemmed from the initial 1997 study *Travel Demand and the 3Ds: Density, Diversity, and Design* (Cervero & Kockelman, 1997). This study laid out the theory that dense, compact, diverse, and pedestrian-oriented environments significantly influence travel mode choice. It supports the popular ideals of New Urbanism and those in favor of transit-oriented development, as well as traditional neighborhood developments. New Urbanists and advocates of Smart Growth are focused on solving roadway congestion by lessening the number and length of automobile trips while increasing the share of non-motorized trips, as well as promoting a higher quality of life by encouraging live-work communities and more active lifestyles (Calthorpe, 1993; Duany et al., 2010). Cervero and Kockelman studied fifty neighborhoods in the San Francisco Bay Area and found that residents living in dense, mixed-use neighborhoods with high levels of connectivity had a statistically significant reduction in personal vehicle-miles traveled for all trips compared to their counterparts in less dense, less connected areas. While these findings were significant for the transportation-planning field in general, the authors were unable to study how the 3Ds affect transit ridership, which could determine another facet of travel demand.

To rectify the limitations of Cervero and Kockelman's study and look at how the built environment affects public transit trips, specifically rapid transit, many more variables have been examined by researchers and the D categories were expanded to capture other factors influencing transit ridership.

To follow in the footsteps of Cervero and Ewing's meta-analysis, this review examines the variables affecting transit trips by category. I have provided the elasticities presented in the 2010 meta-analysis to help the reader compare individual research findings with the overarching themes found in the field with respect to the 6Ds: density, design, diversity, demographics, destination accessibility, and distance to transit. There is also a seventh D, *demand management,* which the meta-analysis did not cover.

These elasticities were calculated through a number of different methods presented in the meta-analysis. The authors obtained them directly from the articles, calculated the elasticities from regression coefficients using the mean of the independent variables, used datasets given to them by other researchers to derive the data, or obtained the elasticities directly from the original researchers (Ewing & Cervero, 2010).

Density

The first category I examined was transit trips with respect to density. Density is "always measured as the variable of interest per unit area" (Ewing & Cervero, 2010) It can refer to a plethora of topics, including population, employment, households, parcel density, and industry densities. Ewing and Cervero examined all of these items and Table 2 is a replica of the table included in their meta-analysis. This table is very informative as it shows that while many of the previous studies produced similar results, there were the occasional instances where researchers found the opposite effects on transit and elasticities, especially when examining population density and job density. While the majority of the studies found both job and population density positively associated with transit ridership, Rodriguez and Joo (2004) and Ewing et al. (2009) found population density to be statistically insignificant, thus having no influence on transit trips.. Similarly, in 2009, Greenwald found net job density to be negatively associated with transit ridership, at a statistically significant level. It is also interesting to see that a number of studies found neither population nor job density to be statistically significant, while Cervero (2006) found population density and Zhang (2004) found job density to be statistically significant at the ninety-nine percent confidence level. To better understand why these studies produced varying results, further analysis was undertaken.

Table 2: Elasticity of transit trips with respect to density

Study	*N*	*x*	*e*		*In meta-analysis?*
Bhatia, 2004	20	Household density	0.37	*	
Cervero, 2002a	427	Gross population density	0.39	*	y
Cervero, 2006	225	Population density	0.19	**	
Ewing et al., 2009	3,823	Population density	-0.01		y
Ewing et al., 2009	3,823	Job density	0.08		y
Fan, 2007	154	Parcel density	0.00		
Frank et al., 2008	8,707	Retail floor area ratio	0.21	**	y
Frank et al., 2008	10,475	Retail floor area ratio	0.17	**	y
Greenwald, 2009	3,938	Net residential density	0.41	**	y
Greenwald, 2009	3,938	Net job density	-0.05	*	y
Kuby et al., 2004	268	Population within walking distance	0.11	*	
Kuby et al., 2004	268	Employment within walking distance	0.07	*	
Rajamani et al., 2003	2,500	Population density	0.08		y
Reilly, 2002	7,604	Population density	0.20	*	y
Rodrigues & Joo, 2004	454	Population density	-0.20		y
Zhang, 2004 (Boston)	1,619	Population density	0.12	*	y
Zhang, 2004 (Boston)	1,036	Population density	0.13	*	y
Zhang, 2004 (Boston)	1,619	Job density	0.09	*	y
Zhang, 2004 (Boston)	1,036	Job density	0.00		y
Zhang, 2004 (Hong Kong)	20,246	Population density	0.01		y
Zhang, 2004 (Hong Kong)	15,281	Population density	0.01	*	y
Zhang, 2004 (Hong Kong)	20,246	Job density	0.01	**	y
Zhang, 2004 (Hong Kong)	15,281	Job density	0.01		y

*p<.05 **p<.01

Source: (Ewing & Cervero, Travel and the Built Environment: A Meta-Analysis, 2010)

An early study of mode choice in Washington State focused on the relationships between land use, density, jobs-housing mix, and travel behavior in order to influence policies at the local, state, and federal levels. Findings showed that employment density, population density, and mixed uses were negatively correlated with single-occupancy vehicle usage and were positively correlated with walking and transit use for both shopping and work-based trip generators (Frank L. D., 1994). This study was small in scope and prompted further inquiry in metropolitan areas across the country, including research by the authors of *Travel Demand and the 3Ds: Density, Diversity, and Design*.

In 1995, Robert Cervero analyzed the effect residential densities and mixed-uses have on commuter mode choice. Utilizing a binomial logit analysis for automobile, mass-transit, and non-motorized trips, Cervero looked at 1985 American Housing Survey data for eleven metropolitan statistical areas. He found that neighborhood densities have a greater influence over mode choice than mixed land-uses; that people are more likely to commute by public transit, biking, or walking when retail shops or transit stops are within three hundred feet or several city blocks of dwelling units; and that vehicle ownership levels are reduced in mixed-use, high density neighborhoods, especially when the neighborhoods are associated with shorter commute times (Cervero, 1996).

Though dozens of studies show a significant relationship between land use and travel data, the beginning of the new millennium brought renewed interested in refining research techniques and increased skepticism about data validity. Badoe and Miller (2000) found that research prior to 2000 increased the lack of clarity for creating public policy due to data and methodology weaknesses. These authors realized that in order to determine what was causing a reduction in vehicle miles traveled, *all* variables including neighborhood design characteristics, land use, socioeconomic factors, and all transit modes available needed to be considered; researchers also needed to explain how and why these interactions influence mode choice and vehicle miles traveled (Boarnet, 2011). Crane (2000), in *The Influence of Urban Form on Travel: An Interpretative Review*, studied numerous articles and concluded that even though research was progressing in both its form and scope, there were still several risks in creating policies relying on earlier research. Crane found the research to be lacking in linkages between neighborhood characteristics and trip cost variables, to have unreliable variations in geographic scale, and to place little emphasis on user attitudes and individual choice.

To provide more accurate and reliable research data, the influential transit researchers Ewing and Cervero (2001) performed a comprehensive survey (a precursor to their meta-analysis) of more than fifty previous studies. They looked at elasticities of travel demand and how they relate to design, density, diversity, and accessibility. They weighted the key variables used in previous studies and their effects in determining research outcomes on travel behavior, and found that both population density at trip origin and job density at trip end are important in terms of transit ridership, but emphasize that the latter is most likely more important than the former.

Cervero's 2002 study of Montgomery County, Maryland also found that when controlling for various factors like travel times and costs, higher job and population densities consistently have a positive relationship with transit riding and a negative relationship with drive-alone automobile travel (Cervero, 2002).

A similar outcome with regards to density was also found in the Transit Cooperative Research Program's *Report 128* (Cervero & Arrington, 2008). This report broke down travel characteristics, land use influences, resident demographics, and numerous other categories in order to easily review the impacts of transit-oriented developments. It focused on transit-oriented developments influence on housing, parking, and travel. Cervero and Arrington found that "employment densities at trip ends have more influence on ridership than population densities at trip origins" (p. 3).

In 2007, Zhang found both similar and contradicting results concerning trip ends in a study quantifying how land use characteristics affect mode choice in Boston in comparison with those of extremely dense Hong Kong. The author looked at the quality of design at the micro scale, streetscape, safety, comfort, convenience, the density of people, land use mixtures, and street network connectivity. Zhang's study showed that "for non-work travel in Boston, population density at the trip origin and job density at the destination no longer mattered, although they did for commuting to work" (pg. 355). However, he found that in Boston, regardless of trip purpose, (work or non-work) land use at trip end was more influential in mode choice than land use at trip origin. In Hong Kong he determined that when people live and work in dense communities their propensities for utilizing transit are higher, but at a statistically insignificant level. He also concludes that density affects perception in regards to mode-choice. When areas are denser, they often increase congestion causing “uncertainty, discomfort, and fears of high accident risks” (pg. 350). Zhang found that these perceptions cause people to find driving less attractive and instead they find alternate modes of travel that are unaffected by roadway congestions, such as grade-separated transit lines and non-motorized modes. He suggests that this is especially true in Boston where transit services are more convenient than driving in downtown. The elasticities of density, with regard to the probability of driving were also examined in this study. Zhang’s computed elasticities showed that “in Boston elasticity of driving probability with respect to population density was about -0.04 for both work and non-work trips. This means that doubling Boston’s current new population density would decrease driving probability by about four percent, all other factors being held constant” (pg. 356). However, he mentioned that the elasticities of driving costs outweighed the elasticities of density and other land use factors.

There are many more articles about density similar to the ones listed above. While most tell the same story, there are always a few outlying studies that demonstrate opposite findings. There are many factors that may influence density including transit system breadth and longevity, reliability, and the length of time developments have had to expand near transit stations. Zhang’s analysis provides the most insight into what kind of results I can expect to see in this study since it is a look at the same geographical area with similar variables. My research tests whether there are any conflicting results regarding population density or job density in the Boston area.

Design

The second category provided by Ewing and Cervero is *Design.* Design is an important factor and one of the main components of Smart Growth principles, Traditional Neighborhood Developments, and New Urbanist ideals. In this study I refer to design as "street network characteristics within an area," (Ewing & Cervero, 2010). Ten studies were examined in the 2010 meta-analysis and the elasticities referenced by Ewing and Cervero are displayed below in Table 3. The elasticities demonstrated that the emphasis placed on creating a connected built environment is relevant to transit ridership. All design variables show a positive relationship with respect to transit trips; however, few variables are statically significant. In fact, the only variable that was ever statistically significant at the ninety-nine percent confidence level was *percent of four-way intersections at destination* (but only in one study and not another) while the only variables that were ever significant at the ninety-five percent confidence level are *intersection density* (in two studies) and *sidewalk coverage*. The overall elasticities for design with regard to all transit trips, including bus and rapid transit, covered the entire spectrum. Some studies found no relationship between transit and design (Cervero & Kockelman, 1997; Fan, 2007) while other researchers found a high association between the design variable and transit use (Lund, 2004; Cervero, 2007).

Table 3: Elasticity of transit trips with respect to design

Study	N	x	e		*In meta-analysis?*
Cervero, 2002a	427	Sidewalk ratio	0.16		
Cervero, 2007	726	% 4-way intersections	1.08		y
Cervero & Kockelman, 1997	1,544	Proportion front and side parking	0.00		
Cervero & Kockelman, 1997	1,544	Proportion 4-way intersections	0.00		
Cervero & Kockelman, 1997	1,544	Sidewalk width	0.00		
Cervero & Kockelman, 1997	1,544	Proportion quadrilateral blocks	0.19		
Fan, 2007	154	% connected intersections	0.27		
Fan, 2007	154	Sidewalk length	0.00		
Frank et al., 2008	8,707	Intersection density	0.20	*	y
Frank et al., 2008	10,475	Intersection density	0.24	Ψ	y
Frank et al., 2008	2,675	Intersection density	0.12		y
Greenwald, 2009	3,938	Intersection density	0.37	*	y
Lund et at., 2004	967	% 4-way intersections at destination	1.08	**	y
Rajamani et al., 2003	2,500	% Culs-de-sac	0.00	a	y
Rodrigues & Joo, 2004	454	Sidewalk coverage	0.28	*	
Rodrigues & Joo, 2004	454	Path directness	0.01	Ψ	
Zhang, 2004 (Boston)	1,619	Street connectivity	0.08	Ψ	y
Zhang, 2004 (Boston)	1,036	Street connectivity	0.04		y

a. Sign reversed   Ψ p<.10   *p<.05   **p<.01

Source: (Ewing & Cervero, 2010)

Peter Calthorpe, one of the founding members of the New Urbanist movement, realized how instrumental multi-modal transportation is to a well-designed, compact, functional, and desirable environment. Under New Urbanist conventions, all communities and land uses are built around transportation networks that link communities and regions to each other. Calthorpe (1993) argued that to create livable places, three principles need to be met:

> "First, that the regional structure of growth should be guided by the expansion of transit and a more compact urban form; second, that our ubiquitous single-use zoning should be replaced with standards for mixed-use, walkable neighborhoods; and third, that our urban design policies should create an architecture oriented toward the public

> domain and human dimension rather than the private domain and auto scale," (Calthorpe, 1993).

These principles are the basis for transit-oriented development and walkable neighborhoods constructed adjacent to public transit stops. However, not all transit stations are located in transit-oriented developments, so it is more important to observe the general types of land uses, densities, and street patterns surrounding these stops.

Kockelman and Cervero did just this in their 1997 study of *Travel Demand and the 3Ds*. While I already touched on this seminal work, it is necessary to take a deeper look at their research pertaining to *design*, especially since four of their design variables are included in the meta-analysis elasticity table. Again, this study looked at vehicle-miles traveled, but also computed the probability of travel by a non-single occupancy vehicle for non-work trips and the probability of travel by a non-personal vehicle for work-trips. The elasticity table presented in their analysis is inserted below for easy reference.

Table 4: Elasticities between measures of the built environment and travel demand, using mid-point (mean and mode) values for explanatory variables (design)

Built Environment	Travel Demand					
	Person vehicle miles for traveled per household for*		Probability of travel by			
			Non-SOV for:	Non-personal vehicle for:		
	All trips	Non-work	Non-work trips	Non-work	Pers.bus	Work
Design						
Walking quality factor	--	--	0.085	0.183	0.174	0.119
Four-way intersections	--	-0.592	0.501	--	--	--
Quadrilaterals	0.185	0.463	--	--	--	--
Sidewalk width	--	--	--	0.087	--	--
Front and side parking	--	--	-0.505	-0.121	--	--

Source: (Cervero & Kockelman, 1997)

In all instances where the variable pertained to the layout and design of the street network, there was a positive association with the probability of using a non-single occupancy vehicle. The only built environment design variable that negatively impacted the probability of travel for non-work trips was parking. This outcome follows the premise that the more parking available, the more people will commute by single-occupancy vehicle. Cervero and Kockelman conclude that walking quality was more influential on mode choice than density for non-work trips. "Neighborhoods with high shares of four-way intersections, as a proxy for grid-iron street patterns, and limited on-street parking abutting commercial establishments tended to average less single-occupant vehicular travel for non-work purposes," (p. 217).

Even though many developments are designed around New Urbanist principles, in 2001, Ewing and Cervero, in their article *Travel and the Built*

Environment: A Synthesis determined that socioeconomics plays a greater role than the built environment in determining trip frequencies, the built environment has greater influence than socioeconomics in regards to trip length, and that mode choice depends equally on *both* built environment and socioeconomics.

In a study of Montgomery County, Maryland, Cervero found that when sidewalks were present more people were apt to ride transit; however this finding was not at a statistically significant level when p= 0.2935 (Cervero, 2002). He also computed elasticities in a mode choice model, and learned that sidewalk ratio elasticities in regards to drive-alone motorized vehicle travel were negative while sidewalk ratio elasticities were positively associated with transit. This finding was echoed by Fan (2007) who examined travel data from the Research Triangle near Chapel Hill, North Carolina. Fan looked at *percent connection intersections* and *sidewalk length* and discovered that "grid street patterns and the presence of sidewalks are both associated with higher activity density and more alternative mode share" (pg. iv).

Transit-oriented developments (TOD) are generally designed with a high degree of roadway connectivity. Lund et al. studied TOD projects in California and found that employees in offices located in TODs are 3.5 times more likely to use transit compared to surrounding regions (Lund, Cervero, & Willson, Travel Characteristics of Transit-Oriented Development in California, 2006). However, Lund el at., suggest continued investments in streetscape and designs in and around

TODs are needed to help increase the attractiveness of living and working in denser neighborhoods (Lund, Cervero, & Willson, 2004).

Often, TODs are also focused around multi-modal transit. With regards to the built environment, a study by Rajamani et al. utilized a multinomial logit model to examine non-work activities by mode including: drive-alone, shared-ride, transit, walk, and bike. They found that when people could easily access their destination by an alternate mode they would. The major variable they used (also included in the meta-analysis) was *percent of cul-de-sacs*, which provided results showing that "traditional neighborhood street design with few cul-de-sacs and a grid like geometry has the potential to encourage walking" (p. 164). This study also demonstrated that cul-de-sacs have a higher elasticity with regard to transit than drive-alone mode shares with 0.0004 and 0.0002 respectively.

Zhang (2007) also studied the connectivity levels for Boston and Hong Kong and found that connectivity levels had a positive influence over mode choice for walking, biking, and transit, but not at a statistically significant level. He used the variable *percent non-cul-de-sacs intersections at origin* and *percent cul-de-sac intersection at destination.* High levels of connectivity also tend to have higher levels of mixed land uses, especially in transit-oriented developments. Therefore, it is important to examine the mix of land uses at trip end and trip destination and their influence on transit ridership.

Diversity

"Diversity measures pertain to the number of different land uses in a given area and the degree to which they are represented in land area, floor area, or employment" (Ewing & Cervero, 2010). Diversity is the last of the original 3Ds and has quite a bit of influence over transit ridership at a statistically significant level. Table 5**,** below, reports the elasticities found in Ewing and Cervero's meta-analysis and shows five studies with statistically significant variables. While the majority of them pertain to the land use mix, the only variable that was statistically significant at the ninety-nine percent confidence level was *distance to closest commercial use*, in Reilly's 2002 study (Reilly, M. K., 2002, as cited by Ewing and Cervero, 2010). The other statistically significant variables include *land use mix (entropy index),* which was significant in two studies, *jobs-housing balance, and distance to nearest park*. Further analysis is needed to understand why some studies reported statistical significance of these variables while others found them to be insignificant.

Table 5: Elasticity of transit trips with respect to diversity

Study	*N*	*x*	*e*		*In meta-analysis?*
Bento et al., 2003	4,456	Jobs-housing imbalance	0.60	a	y
Cervero, 2002a	427	Land use mix (entropy index)	0.53	*	y
Cervero & Kockelman, 1997	1,544	Land use dissimilarity	0.00		
Cervero & Kockelman, 1997	1,544	Proportion vertical mix	0.00		
Cervero & Kockelman, 1997	1,544	Proportion of population within 1/4 of store	0.00		
Fan, 2007	154	Retail store count	-0.04	Ψ	
Frank et al., 2008	8,707	Land use mix (entropy index)	0.09	*	y
Frank et al., 2008	10,475	Land use mix (entropy index)	0.19		y
Greenwald, 2009	3,938	Jobs-housing balance	0.23	*	y
Greenwald, 2009	3,938	Job mix (entropy index)	0.04		
Kitamura et al., 1997	14,639	Distance to nearest park	0.11	*	
Rajamani et al., 2003	2,500	Land use mix (diversity index)	-0.04		y
Reilly, 2002	7,604	Distance to closest commercial use	-0.19	**	
Zhang, 2004 (Boston)	1,619	Land use mix (entropy index)	0.00		y
Zhang, 2004 (Boston)	1,036	Land use mix (entropy index)	0.12		y

a. Sign reversed Ψ p<.10 *p<.05 **p<.01

Source: (Ewing & Cervero, 2010)

A study of five diverse San Francisco neighborhoods completed by Kitamura, Mokhtarian, and Laidet (1997), who used *distance to nearest park*, solidified Cervero's 1996 findings that density and mixed land uses are in fact positively correlated with the amount of non-motorized trips. In other words, people are more likely to choose a mode of transit other than a personal vehicle when densities are higher and land uses are more mixed. They also confirmed that neighborhood characteristics (parks) affect travel and mode-split at a statistically significant level when demographic and socio-economic differences are accounted for.

Cervero and Kockelman (1997) included diversity in their original model on the 3Ds and found that land use mixing was positively associated with non-single occupancy vehicles for non-work trips. They also found that population within a quarter mile of a store was positively related to choosing a non-personal vehicle for work trips. These associations are shown in Table 6 for easy reference.

Table 6: Elasticities between measures of the built environment and travel demand, using mid-point (mean and mode) values for explanatory variables (diversity)

Built Environment	Travel Demand					
	Person vehicle miles for traveled per household for*		Probability of travel by			
			Non-SOV for:	Non-personal vehicle for:		
	All trips	Non-work	Non-work trips	Non-work	Pers.bus	Work
Diversity						
Land use mixing	--	--	0.111	--	--	--
Vertical mixing	--	-0.141	--	--	--	--
Population within 1/4 mile of store	--	--	--	--	--	0.365

Source: (Cervero & Kockelman, 1997)

Ewing and Cervero (2001) reported similar results and concluded that population and land use patterns influence mode choice more than any other factor, and that "transit use depends primarily on local [residential] densities and secondarily on the degree of land use mixing" (p. 92).

Frank et al., also looked at mixed land uses and their relationship to transit use and learned that when controlling for socio-demographic characteristics, land use mixes, residential densities, street connectivity, and retail density significantly increased multi-modal transit and also showed a positive relationship between land use mixes and trip complexity and frequency (2008).

Fan (2007) found that when land use patterns are diverse, there are also generally more diverse activity densities, but he found that higher activity densities lowered the percent of alternate mode choice. This is an interesting finding, since advocates of Smart Growth and New Urbanism often champion a higher mixing of uses and mode choices simultaneously.

Alternatively, Zhang (2007) showed that for both Boston and Hong Kong, land uses did indeed influence mode choice when controlling for travel variables (fees, gas, maintenance, and travel time) and parking prices. The study also found that in Boston, travelers' choices relied on the land use features at the trip end rather than the travel mode options at trip origin.

Two of the many reasons people live and work where they do, whether in the CBD or a nearby suburban activity center, are the number of residential units in a particular neighborhood and availability of acceptable employment. The jobs-housing balance, "the ratio of the number of employees to the number of households in a geographical area," is one of the largest influences on transit and transportation choices (Cervero, 1991). There are numerous published studies quantifying jobs-housing balance and measuring its relationship with commuting choices. Peng (1997), in a study of the Portland region, focused on the linkage between jobs-housing balance and trip length and vehicle miles traveled. Peng found that "only in job-poor or very job-rich areas do vehicle miles traveled per capita and trip length change noticeably as the job-housing ratio changes" (1997, p. 1234). The author noted that any change in policy for housing and/or jobs locations would have little to no effect on the amount of vehicle miles traveled at the regional level. This is due to barriers from local governments' land use policies, residents' attitudes, and exclusionary zoning practices, which prohibit the mixing of land uses.

Cervero and Duncan (2006) compared the jobs-housing ratio and the retail-housing mix in the San Francisco Bay Area to determine which might reduce vehicle travel more. They found that the jobs-housing balance plays a far greater role in reducing vehicle miles traveled than the retail-housing mix. They also concluded that this study, along with several others, solidifies the idea that the jobs-housing balance can significantly influence the amount of vehicle miles traveled; however, the authors also realized that even if land use policies promote an adequate jobs-housing balance, because of individual residential choices, planners cannot assume residents will reside and work in the same location.

The jobs-housing balance directly relates to the next D presented in the meta-analysis, *Destination Accessibility*. Since studies show housing and job density in close proximity to transit increases and directs a person's mode choice away from a single-occupancy vehicle toward an alternate mode, it is important to understand how spatial and temporal distance from destinations via these alternate modes influences choice.

Destination Accessibility

According to Ewing and Cervero, "*destination accessibility* measures ease of access to trip destinations" (2010). This variable looks specifically at travel time or distance to major employment or residential neighborhoods, and is related to self-selection, which is described in detail below. Travel time relative to trip purpose is highly related to mode choice, and it is common transportation knowledge that people making work trips are willing to travel longer and further than for non-work trips. Ewing and Cervero took this into consideration in their meta-analysis and show the effects of destination accessibility in the elasticity table shown below. The elasticities reported in their study were compiled from six studies, which used five different variables. The only variable used that was not statistically significant was *population centrality*. The rest of the variables were highly significant or showed varying results. *Distance to CBD, job accessibility to transit, average time to other stations, and job accessibility by auto* were all statistically significant at a ninety-nine percent confidence level in at least one study; however *job accessibility by transit* demonstrated various degrees of significance in different studies. Also, all variables, with the exception of *job accessibility by auto* were positively related to transit trips. Further research must be done to understand why the significance of *job accessibility by transit* varies across the board.

Table 7: Elasticity of transit trips with respect to destination accessibility

Study	***N***	***x***	***e***		***In meta-analysis?***
Bento et al., 2003	4,456	Population centrality	0.00		
Cervero, 2006	225	Distance to CBD	0.21	**a	
Ewing et al., 2009	3,823	Job accessibility by transit	0.29	**	
Ewing et al., 2009	2,697	Job accessibility by transit	0.16	*	
Greenwald, 2009	3,938	Job accessibility by transit	0.05		
Kuby et al., 2004	268	Average time to other stations	0.95	**a	
Lund et al., 2004	967	Job accessibility by auto	-0.70	**	

a. Sign reversed   Ψ p<.10   *p<.05   **p<.01

Source: (Ewing & Cervero, 2010)

In a regression analysis of more than two hundred light-rail stations, researchers concluded that a station does not need to be located within the CBD to obtain high ridership levels (Kuby, Barranda, & Upchurch, 2004). However, this might not hold true for every transit system in the United States, as some light rail systems are new and have not yet developed the densities around suburban stations to solicit such a broad conclusion.

The Transit Cooperative Research *Report 128* found that ridership levels are highly correlated with transit times relative to auto travel times (Cervero & Arrington, 2008, p. 2). This means that users are more likely to utilize transit when it is efficient and reliable, with low overhead or low wait times.

Frank et al., studied the effect travel time has on mode choice extensively in their 2008 study. They found that individuals place a high value on time, and it significantly impacts their travel mode. "For a mode to be viable, in terms of time, it is important that it compete favorably with the time required to accomplish a specific trip objective using a personal automobile," (p. 48). The authors also showed that people are much more sensitive to travel times than they are cost. The research showed that waiting for transit is much more costly than in-vehicle time. This can help policy makers with a number of important decisions when it comes to increasing transit costs. If transit is able to provide an efficient commute with low wait times, compared to driving alone, providers may be able to increase fare rates without losing too much patronage.

Distance to Transit

Destination accessibility can also relate directly to distance to transit. Often people utilize park and rides to reach their destinations faster by transit than by a personal automobile. "*Distance to transit* is usually measured as an average of the shortest street routes from the residences or workplaces in an area to the nearest rail station or bus stop," (Ewing & Cervero, 2010). This category, similar to destination accessibility, considers a number of the previously discussed variables since street patterns, walkability levels, and the overall connectivity of a street network often stipulate distance to transit. Distance to transit can also be counted as distance between stations and the number of stations within a set geographical area. It can also relate to the distance of residents and jobs to park and rides where people are able to easily access transit. The table presented below was compiled by Ewing and Cervero in their meta-analysis and examines the elasticities of the previously mentioned variables. The five studies they examined each used a different variable pertaining to transit trips with respect to transit access. Of the five variables, only two were statistically significant, *distance to rail stations* and *percent within walking distance of bus* at the ninety-nine percent and ninety-five percent confidence levels, respectively. All variables studied had a positive relationship with transit trips, but the elasticities varied across the studies.

Table 8: Elasticity of transit trips with respect to transit access

Study	***N***	***x***	***e***		***In meta-analysis?***
Bento et al., 2003	4,456	Distance to transit stop	1.00	a	y
Ewing et al., 2009	3,823	Bus stop density	0.08		
Frank et al., 2009	2,697	Distance to bus stop squared	0.02	b	y
Kitamua et al., 2007	14,639	Distance to rail station	0.13	**a	y
Rajamani et al., 2003	2,500	% within walking distance of bus	0.42	*	

a. Sign reversed b. sign revered and multiplied by 2 Ψ p<.10 *p<.05 **p<.01

Source: (Ewing & Cervero, 2010)

Advocates of New Urbanism and Traditional Neighborhood Developments (TND) understand the importance of locating people within a walking distance of transit stops. This distance varies between modes, as people are generally willing to walk further to rapid transit stations than bus stations. The walking shed for rapid transit is approximately a quarter-mile to half-mile, whereas the walking shed for bus stops is considerably less.

One of the factors that may influence distance to transit is the amount of available parking at or in close proximity to parking. Researchers discovered that while it is difficult to determine mode choice in regards to transportation, people's perception of time when walking versus driving is dramatically different. "Most auto users find a minute of walking to be much more of a burden than a minute of driving," (Frank, Bradley, Kavage, Chapman, & Lawton, 2008). Frank et al., concluded that if policies are changed to include more convenient parking near transit stations, there may be a large cross-mode effect influencing more people to use transit.

Another factor that may influence distance to transit is the system's breadth and longevity. Bento et al., in a study of eleven cities with and without rapid transit services found that "the probability of driving to work is lowest in the oldest three cities in the table—New York (0.40), Boston (0.73) and Chicago (0.74), each of which has an extensive rail and bus system," (p. 476). The authors also compared the differences of vehicle-miles traveled in Boston and Atlanta. They discovered that vehicle-miles traveled in Boston were drastically lower than in Atlanta due to Boston's rapid transit supply and urban form. According to the authors, Boston's population is much more centrally located compared to Atlanta's. Boston also has a much higher job-housing balance than Atlanta making it easier for Bostonians to live and work in closer proximity than Atlantans.

Demographics

Demographics, while not pertaining to the built environment, is the seventh D. Ewing and Cervero do not provide any elasticity analysis for transit trips, but demographic and socio-economic variables are used in nearly every single land use/transportation study. These variables help control for age, income, ethnicity, gender, automobile owners, and other similar descriptive variables that are important for researchers to study to help direct policy decisions. They also help to better explain research findings for location, both within a city and regionally.

In 2003, Rajamani et al. found several interesting factors concerning multi-modal transit in Portland, Oregon. First, higher income households tend to drive more than middle and lower income households. The latter households have a higher propensity to use transit, walk, or bike to reach their destination. The authors also found that as the number of vehicles increases in a household, the likelihood of using alternate transportation decreases. Similarly, more adults living in a household increases single-occupancy vehicle use. Age is also an interesting socio-demographic variable to examine, and Rajamani et al. discovered "older individuals prefer to rideshare for their non-work trips," (p. 162).

Since demographics vary by geographical areas as small as blocks and block groups it is important to include these variables into any statistical analysis of mode choice, especially for transit trips.

Self-Selection

While self-selection is not one of the Ds included in the meta-analysis, it is a factor Ewing and Cervero took into consideration when examining the studies. Of all the studies they looked at, only three studied the effects of self-selection with transit use.

Planners must understand how local and regional policy affects the built environment and how land uses relate to resident attitudes, behaviors, and choices. Studies in Boston and Atlanta, two very different cities in terms of density, built form, and population demographics, investigated these effects. Levine, Inam, and Torng (2005) found that Bostonians who prefer denser neighborhoods were more likely to live in transit-oriented developments than Atlanta residents who preferred these same types of neighborhoods, due to highly regulated land-uses and multiple barriers to Smart Growth initiatives in Atlanta. Levine et al. suggest that if some policy barriers were removed, the market would be able to produce developments that can ultimately reduce vehicle miles traveled, especially for residents of lower socioeconomic status.

Kitamura, Mokhtarian, and Laidet (1997) found that vehicle miles traveled and mode choice are strongly and directly associated with traveler attitudes towards transit use. These authors suggest that policy changes to promote higher densities and mixed land uses may not alter travel behavior unless there is also a shift in user attitudes.

Frank et al. in a study of Puget Sound, Washington, found that self-selection plays an important role in travel decisions especially when it pertains to travel times. They note that often policy makers implement changes to the built environment by increasing roadway capacity and multi-modal transit simultaneously. Frank et. al. found that these decisions may cancel each other out. People will often use multiple modes of travel because they may be faster than an individual mode, but when you implement both at the same time, single person motorized vehicle travel time often decreases, at least for a period of time before the land uses intensify around the roadway.

Researchers have also found that self-selection plays an important role in transit ridership in TODs. In Switzer's 2002 study of Portland's Center Commons TOD, recent residents used a non-automobile mode of transport for forty six percent of work trips. Prior to living in a TOD, respondents utilized alternate modes for forty-four percent of work trips (Switzer, 2002 as cited by Cervero & Arrington, 2008, p. 11). Therefore, Switzer's study shows that living in a TOD only change one's transportation mode choice behavior slightly compared to the preferences they express when not living in a TOD.

In another similar survey of Merrick, a transit-oriented development in the Portland area, Dill observed that residents utilize transit to a significantly greater degree than the remainder of Portland residents (Dill, 2005). A total of seventy percent of survey respondents use transit more now than prior to living in a TOD.

A further study of Portland's TODs found that approximately twenty percent of all commuters substituted an alternate mode for automobile travel (Dill, 2008). Dill also discovered that of all recently relocated residents in the four TODs studied, over ten percent chose to sell their cars. More than fifty percent of the residents living in the Portland TODs ranked living close to transit as one of the most important factors when choosing a home while regular transit riders living away from the TOD found alternate methods of accessing transit such as a park-and-ride option.

In 2004, Lund, Cervero, and Wilson conducted an analysis of residents living in transit-oriented developments in California's four largest metropolitan areas. They examined twenty-six separate residential sites and found that residents living in transit-oriented developments are frequent transit patrons. Twenty-nine percent of respondents living in these areas used transit services every day. The authors found that people tend to relocate to transit-oriented developments due to their desire to use public transit as their primary mode choice for work trips.

The type of dwellings in transit-oriented developments also warrants consideration. Renne (2005) found there to be a higher percentage of renter-occupied dwelling units in transit-oriented developments compared to surrounding regions, and it is continuing to increase. This creates an opportunity for governmental policy, especially concerning affordable housing. Renne concluded that only in California has the government played a critical role in helping to provide affordable rental housing units in transit-oriented developments. Since low-income households generally utilize alternate modes of travel at greater levels than middle- or higher-income households, providing affordable housing in these mixed-use developments adjacent to transit stops is necessary. As the literature points out, there is currently a high percentage of people from middle and high incomes living in transit-oriented developments (Duncan, 2011; Litman & Steele, 2012).

Renne (2005) pointed out that if demand to reside in transit-oriented developments grows faster than developments are constructed, market prices may soon exclude the low- and middle-income households that depend on such efficient places to survive. Therefore, governments must be proactive to create standards for affordable units in transit-oriented developments.

Literature Review Conclusion

The literature on transit and land use is extremely large, and this literature review is in no way exhaustive. Rather, it is broad in scope, highlighting the major components and findings of most public transit studies, which are very helpful in influencing future transit research in the Boston region. Cervero and Kockelman's meta-analysis has provided a plethora of information regarding the 7Ds and solidified the relevance of the variables I chose for my research.

In the meta-analysis, Ewing and Cervero summarize some of the variables used by numerous studies and examined the average elasticities of transit use. This table is replicated below. They found that distance and design variables have the highest elasticities, followed by diversity, and finally density, which they found to be relatively unimportant with an elasticity of 0.07.

Table 9: Weighted average elasticities of transit use with respect to built environment variables

		Total number of studies	Number of studies with controls for self-selection	Weighted average elasticity of transit use
Density	Household/population density	10	0	0.07
	Job density	6	0	0.01
Diversity	Land use mix (entropy index)	6	0	0.12
Design	Intersection/street density	4	0	0.23
	% 4-way intersections	5	2	0.29
Distance to transit	Distance to nearest transit stop	3	1	0.29

Source: (Ewing & Cervero, 2010)

Presented below in Table 10, the independent variables used in the study are highlighted by D category including, the variable name, their relationship to transit (whether it is positively affected, negatively affected, or still undetermined), and the studies that utilized similar variables. The studies included in the table are not all-inclusive, but only represent the literature examined prior to and during this research.

Table 10: Independent variables effect on transit ridership

Independent Variables Effect on Transit Ridership			
Effect Strength **++ Strong Positive Relationship** **+ Positive Relationship** **+/- Mixed or Nuanced Findings** **-- Strong Negative Relationship** **- Negative Relationship** **? Inconclusive Results**			
D	**Variable**	**Effect on Transit**	**Previous Studies**
Density	Population Density	++/-	(Frank, 1994) (Litman & Steele, 2012) (Cervero & Kockelman, 1997) (Crane, 2000) (Kitamura, Mokhtarian, & Laidet, 1997) (Levine, Inam, & Torng, 2005) (Zhang, 2007) (Dunphy & Fisher, 1996) (Peng, 1997) (Krizek, 2003) (Cervero & Arrington, 2008) (Renne, 2005) (Cervero, 1984) (Kuby, Barranda, & Upchurch, 2004)
	Job Density	++/-	(Frank, 1994) (Litman & Steele, 2012) (Cervero & Kockelman, 1997) (Ewing & Cervero, 2001) (Crane, 2000) (Kitamura, Mokhtarian, & Laidet, 1997) (Levine, Inam, & Torng, 2005) (Buliung & Kanaroglou, 2006) (Zhang, 2007) (Peng, 1997) (Cervero & Duncan, 2006) (Krizek, 2003) (Renne, 2005) (Kuby, Barranda, & Upchurch, 2004)
Design	4-way Intersection Density	+	(Litman & Steele, 2012) (Cervero & Kockelman, 1997) (Ewing & Cervero, 2001) (Crane, 2000) (Levine, Inam, & Torng, 2005) (Zhang, 2007) (Zielstra & Hochmair, 2011) (Krizek, 2003) (Crane & Crepeau, 1998)
	Line Terminus	?	(Kuby, Barranda, & Upchurch, 2004)
Destination	Distance to CBD (number of stops)	+/-	(Litman & Steele, 2012) (Cervero & Kockelman, 1997) (Cervero, 1996) (Kitamura, Mokhtarian, & Laidet, 1997) (Zhang, 2007) (Cervero & Arrington, 2008) (Crowley, Shalaby, & Zarei, 2009) (Alshalalfah & Shalaby, 2007) (Kuby, Barranda, & Upchurch, 2004)
Distance to Transit	Transfer Stations	?	(Kuby, Barranda, & Upchurch, 2004)
	Parking Spaces at Each Station	?	(Litman & Steele, 2012) (Cervero & Kockelman, 1997) (Zhang, 2007) (Cervero & Arrington, 2008) (Frank, Bradley, Kavage, Chapman, & Lawton, 2008)
Demographics	Income	+/-	(Frank, 1994) (Litman & Steele, 2012) (Cervero & Kockelman, 1997) (Cervero, 1996) (Badoe & Miller, 2000) (Kitamura, Mokhtarian, & Laidet, 1997) (Dieleman, Dijst, & Burghouwt, 2002) (Buliung & Kanaroglou, 2006) (Zhang, 2007) (Dunphy & Fisher, 1996) (Cervero & Duncan, 2006) (Krizek, 2003) (Crane & Crepeau, 1998) (Dill, 2005) (Crowley, Shalaby, & Zarei, 2009) (Dill, 2008) (Kim, Ulfarsson, & Hennessy, 2007) (Kuby, Barranda, & Upchurch, 2004)
	Age	-	(Cervero & Kockelman, 1997) (Badoe & Miller, 2000) (Zhang, 2007) (Cervero & Duncan, 2006) (Crane & Crepeau, 1998) (Crowley, Shalaby, & Zarei, 2009) (Alshalalfah & Shalaby, 2007) (Renne, 2005) (Dill, 2008) (Kim, Ulfarsson, & Hennessy, 2007) (Kuby, Barranda, & Upchurch, 2004)

As discovered by this literature review and Ewing and Cervero's meta-analysis, Boston and the Massachusetts Bay have provided researchers with answers to many pressing transportation/land use questions. Most of the previous literature utilized Census Bureau's 1990 Census or 2000 Census and rider surveys from the early 1990s thus, there is a need to reexamine previous findings with 2010 Census and 2010 rapid transit ridership data to confirm or contest earlier research.

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

Research Problem and Question

With transportation funding decreasing and the costs associated with single-occupancy vehicles increasing it is necessary to examine how the Ds presented by Ewing and Cervero in 2010 influence transit ridership levels on rapid transit systems. Many cities across the United States are in the process of updating and implementing rapid transit modes such as subways, light-rail, and bus rapid transit, in addition to other multi-modal transit like bikeways and an increase of walkable street networks. While the previously discussed studies touch on these subjects, this project solely examines how the Ds affect rapid transit ridership levels. This study seeks to answer the following questions in order to guide future rapid transit transportation funding.

1. Do land use policies, such as Euclidean zoning, around each station affect transit ridership levels, and if ridership levels are low, how can policies be altered to encourage greater transit use?

This first question is the driving force behind this research, but in order to determine how land use policies and the built environment affect ridership levels, several other questions are addressed. They are:

2. How is ridership affected by the street pattern, including connectivity and network density near stations?
3. How is ridership affected by demographics near stations such at median age and income levels in the area?
4. Does the distance from the central business district affect ridership levels?

5. Does the number of parking spaces available at stations influence the number of riders?

Area and Unit of Analysis

This study uses the Massachusetts Bay Area surrounding Boston, Massachusetts as a case study. Since it has been examined previous times to answer other transportation questions pertaining to the Ds, it provides a good foundation for which to base a new study. There are also many new sources of information concerning Boston and the Massachusetts Bay that have not yet been examined.

The area and unit of analysis for this research is a quarter-mile Euclidean distance (as the crow flies) from rapid transit stations in the Massachusetts Bay. A quarter-mile geographical area was chosen because it is often the measurement used by proponents of New Urbanism and Traditional Neighborhood Developments. It is also the distance someone is willing to walk to a public transit station. A quarter-mile distance, or a five minute walk, has traditionally been the standard of measurement in research pertaining to the land use/ transportation nexus and has been used in numerous studies found in the literature (Rodriguez & Joo, 2004; Lund, Cervero, & Wilson, 2004; Crowley, Shalaby, & Zarei, 2009; Cervero & Kockelman, 1997; Ewing & Cervero, 2001).

Data Sources

Data sources include:

Table 11: List of sources in analysis

Sources of Data	
U.S. 2010 Census and American Community Survey 2005-2009	Population Density
	Income
	Age
MassGIS: Office of Geographic Information (Online)	Transfer Stations
	Line Terminus
	Distance to CBD
ESRI Business Analyst Online (BAO)	Job Density
Data provided by the MBTA	Ridership
	Parking Spaces
ESRI Arc GIS	Intersection Density

Despite Boston being one of the most studied cities for transit, in my analysis of the literature no one at the time of this study has examined the Massachusetts Bay through the scope of the recently released data from the United States Census Bureau's 2010 Census. This, along with summary data from the U.S. Census Bureau's American Community Survey 2005-2009 estimates, provided enough data on which to base a new study on the region. These sources will provide figures for population density, average median income, and average median age.

Another new easily available source for researchers is the job data provided by ESRI's Business Analyst Online (BAO). BAO compiles job data from Infogroup within any geographical area specified by the user. The job data is reported in several different forms including total jobs, and then broken into SIC and NAICS codes. This research looked at the total number of reported jobs within a quarter-mile of each station. To determine the number of jobs around each station ESRI used a complex method of extraction. “ESRI extracts its business data from a comprehensive list of businesses licensed from Infogroup. This business list contains data for nearly 12 million US businesses- including business name, location, franchise code, industry classification code, number of employees, and sales volume—current as of January 2011” (Esri, 2011).

I obtained geographical information system shapefiles from MassGIS: Office of Geographic Information to use in ESRI’s ArcGIS. MassGIS provides a plethora of detailed shapefiles in vector and raster formats. I employed the shapefiles for the rapid transit systems in the Massachusetts Bay. From this source, I was easily able to access station names, locations, and line data from which to collect and analyze the data provided by the Census and BAO. Station point data provided the inputs to create a quarter-mile buffer around each station. These shapefiles also helped determine distance to the central business district, transfer stations, and line termini.

I used ArcGIS and Bing Maps data layers to count the number of four-way intersections within the determined quarter-mile station buffer. I only included intersections where four or more streets converged in the same space. If the streets did not line up perpendicularly, the intersection was not counted. Please see Figure 1 and Figure 2 for a visual representation of four-way intersections.

Figure 1: Alewife Station- few 4-way intersections

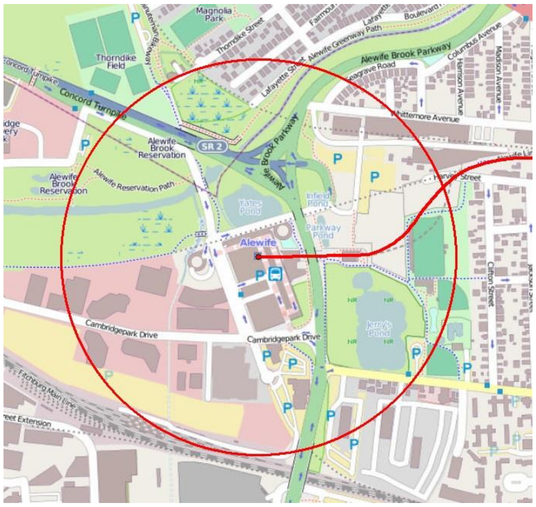
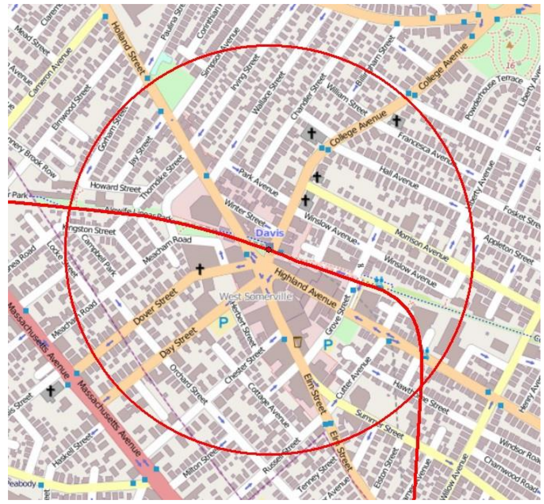


Figure 2: Davis Station- many 4-way intersections



Another source with new information was the Massachusetts Bay Transportation Authority (MBTA), the agency that provides transit service to the entire Boston region. I obtained ridership data from 2010, to provide ridership information assembled at a similar time as the census, in the *2010 Thirteenth Edition of Ridership and Service Statistics*, otherwise known as the *2010 Bluebook.* The *2010 Bluebook* was solicited by the MBTA, and was compiled by Central Transportation Planning Staff (CTPS). This report systematically analyzes each line and station according to total riders, day of the week, and time of day.

Parking space information for each station was obtained from the MBTA on their user website at http://www.mbta.com.

The MBTA with the help of CTPS solicited an On Board Ridership Survey during 2008-2009 on the system's rapid rail transit lines and in 2007 for a bus rapid transit line. The reports compiled are very detailed and provide data needed to confirm results pertaining to self-selection and rapid transit convenience factors.

It is necessary to utilize the on board travel survey studies from the MBTA, demographic data from the 2010 United States Census and the 2005-2008 ACS, and ridership data from the MBTA's 2010 Bluebook to confirm and/or challenge the results of previous studies of the Boston region.

Dependent Variable
Riders

The first variable examined was the dependent variable *riders.* I utilized the total number of average weekday boardings on the Massachusetts Bay Transportation Authority's Rapid Transit Lines by station that was presented in the Thirteen Edition of *Riders and Service Statistics* otherwise referred to as the *2010 Bluebook*, complied by Central Transportation Planning Staff. As discussed earlier, if the station was a transfer point, the ridership was tabulated by line rather than as a total per station.

The University of California Los Angeles' Institute for Digital Research and Education (IDRE), suggest utilizing the natural log transformation to reflect percentage change; therefore to make the results of this analysis more generalizable to other systems the transformation was made. IDRE also emphasizes the fact that the natural log transformation has the ability to create a more normal distribution of the variables.

After computing the natural log of riders, initial detailed summary tests were completed for both *riders* and *lnriders* to determine the mean and standard deviation of the variables and ensure that the transformation was appropriate. All 157 stations were accounted for in both datasets. Therefore, there was no missing data and the mean and standard deviation were found to be within normal ranges ensuring data accuracy. Since the minimum number of *riders* was seven, the inputs where double checked and Dry Dock Avenue on the Silver Line did indeed only service seven riders a day.

Table 12: Detailed summary of riders and natural log of riders

Detailed Summary of Riders and Natural Log of Riders		
	Riders	***lnriders***
Observations	157	157
Mean	3,797.975	7.464
Standard Deviation	4,207.757	1.454
Skewness	1.673	-0.785
Minimum	7	1.9459
Maximum	21,868	9.9928

Source: The MBTA and Author

After looking at the details of *riders* and *lnriders* researchers examined the histograms of the two variables to determine the shape of the distribution. Initial tests were analyzed and showed *riders* skewed significantly toward the right.

Figure 3: Histogram of riders

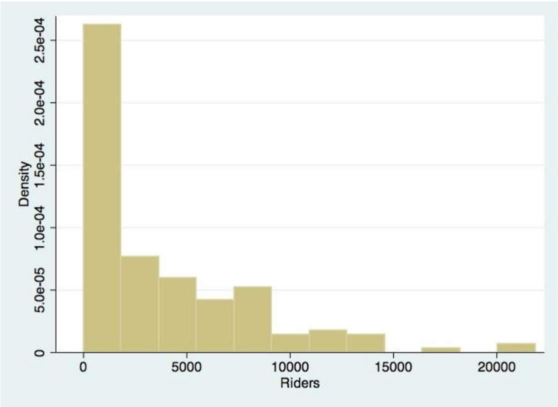
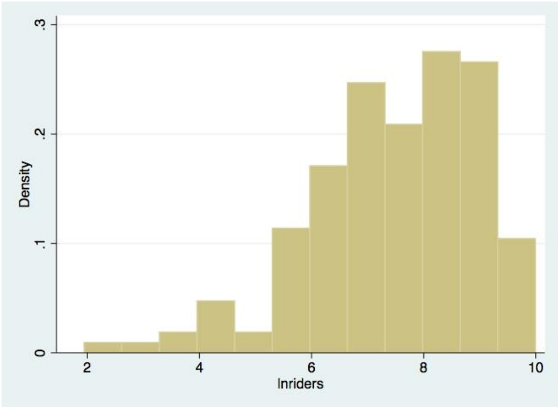


Figure 4: Histogram lnriders



These images show that the natural log of riders displays a more normal distribution. To double check these results kernel density plots were also examined, since according to IDRE "kernel density plots have the advantage of being smooth and of being independent of the choice of origin, unlike histograms," (Chen, Ender, Mitchell, & Wells, 2003)

The Kernel Density estimate tests clearly showed that the natural log of riders was much closer to the normal curve than the non-transformed variable *riders*. The natural log of *riders*, or *lnriders* closely followed the normal curve with a slight variation between eight and ten, and was much more normally distributed than the significant variation of *riders* between 0 and 5,000.

Figure 5: Kernel Density: Riders

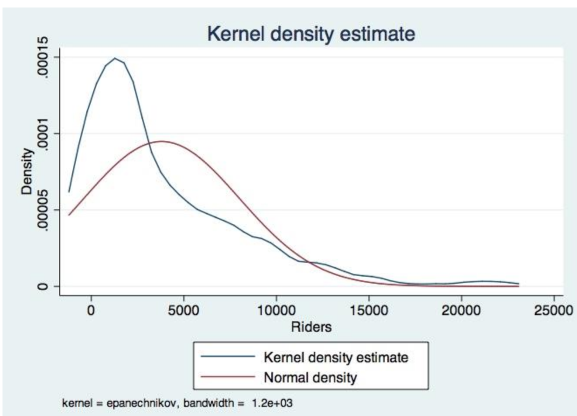
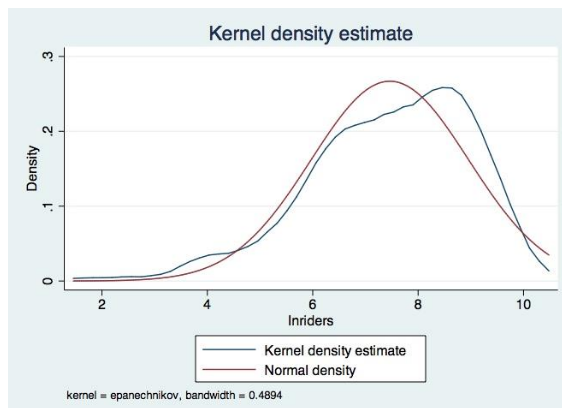


Figure 6: Kernel Density lnriders



To see if there is a particular reason why the curves did not follow normal distribution, I checked to see if there were any outlying figures causing the discrepancy using a boxplot. The results showed that there were far more outliers when the data had not been transformed and compared it to *lnriders* which showed very few outliers. The outliers for the raw *riders* count are the stations that receive very high ridership such as Harvard Station and South Station which both had over twenty thousand riders a day. The dependent variable *riders* was skewed to the right, whereas the dependent variable *lnriders* was skewed to the left, however *lnriders* was far less skewed than *riders*.

Figure 7: Graph Box: Riders

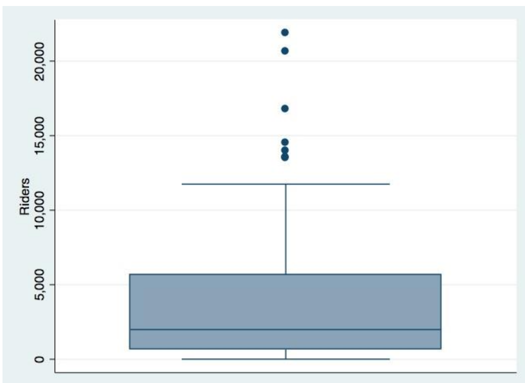
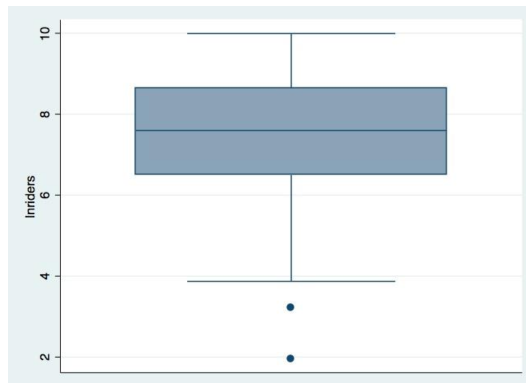


Figure 8: Graph Box: lnriders



To further examine the distribution of variables a symmetry plot graph was examined for both *riders* and *lnriders*. As expected, *riders* and *lnriders* were not symmetric. The less symmetric the variable the more likely it is to find heteroskedasticity of the dependent variable (Kohler & Kreuter, 2005). *Riders* showed a right-skewed distribution, which also increases the risk of heteroskedasticity. According to Kohler and Kreuter, authors of *Data Analysis Using Stata,* one way to correct this is to apply a logarithmic transformation, which has already been done. The variable *lnriders* followed the median of the line much more closely than *riders* and had less chance of producing heteroskedasticity.

Figure 9: Symmetry Plot: Riders

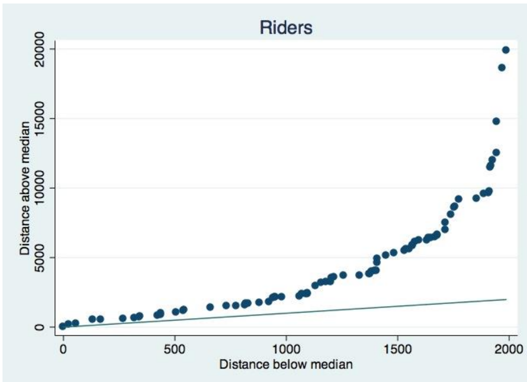
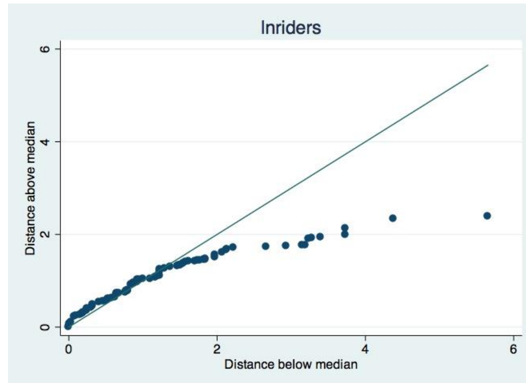


Figure 10: Symmetry Plot: lnriders



To complete the normality tests for *riders* and *lnriders* a normal quantile plot graph and a normal probability plot were computed. The following tests solidified *lnriders* as the most appropriate variable to use for the remainder of the analysis.

Figure 11: Normal Quantile: Riders

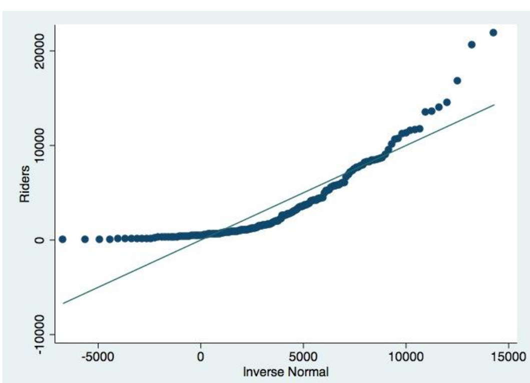


Figure 12: Normal Quantile: lnriders

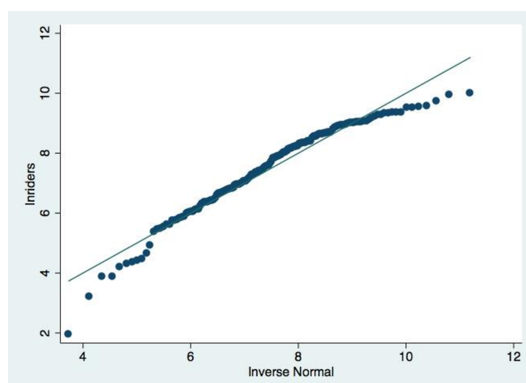


Figure 13: Normal Probability: Riders

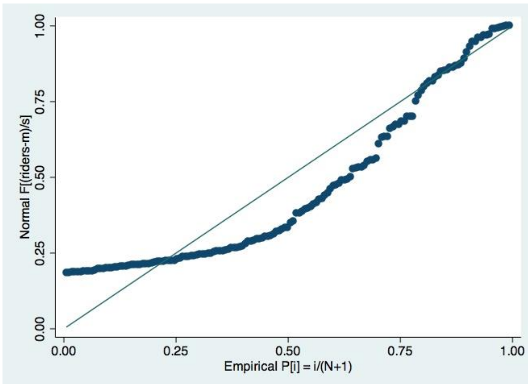
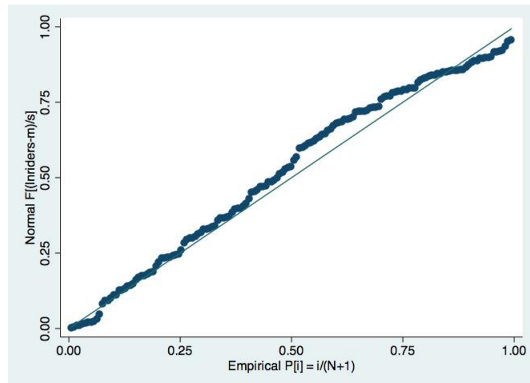


Figure 14: Normal Probability: lnriders



As shown by the above graphs, the normal probability test confirmed the assumption that the natural log of riders provided a better fit for use in regression analysis and had less chance of breaking the law of homoskedasticity and other regression assumption tests in order to produce more reliable results (Kohler & Kreuter, 2005). The normal quantile of *riders* was far more sensitive to non-normality near the tails than the normal quantile of *lnriders*. Similarly, the normal probability of *riders* was much more sensitive near the center of the distribution than the normal probability of *lnriders*. These tests solidified the hypothesis that *lnriders* provided the most reliable and accurate variable in order to proceed with the following regression analysis.

Independent Variables

Density Variables:
Population Density

Population density was calculated within a quarter-mile of each station using ESRI Business Analyst. ESRI collected the data from the United States Census Bureau's 2010 Census for total number of people, households, and households without children within this geographical area employing a hybrid approach using centroid in or centroid out to gather the most accurate data. To verify that all the data was input correctly and that the data was reliable a detailed summary of the independent variable *population* was calculated to determine the total number of observations, mean, standard deviation, skewness, and the minimum and maximum population around each station.

Table 13: Detailed summary of population density

Detailed Summary of Population	
	Population Density
Observations	157
Mean	3,761.395
Standard Deviation	2,583.327
Skewness	0.3361
Minimum	0
Maximum	9,661

This detailed summary confirmed that all data was correctly added to the spreadsheet with a total of 157 station inputs. The data was double checked to ensure accuracy for the minimum and maximum population density inputs.

To further analysis the reliability of the data several more statistical tests were computed in Stata. A histogram and a graph box were used to examine the distribution. There are several stations with zero people, especially around Logan Airport and the Industrial Marine Park. These stations had to be given special treatment because variables like per capital income could not be calculated, as will be discussed below. The remainder of the distribution is spread relatively evenly, with no extreme outlying values and the majority of the stations falling within between the first and third quartiles. The box graph also showed that the values are skewed slightly to the right.

I also looked examined a two-way scatter plot comparing the dependent variable *lnriders* and the independent variable *population* and found that as population density around stations increases the number of transit riders also increases.

Figure 15: Histogram- Population Density

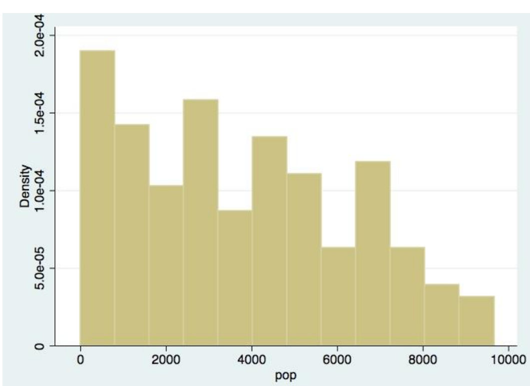
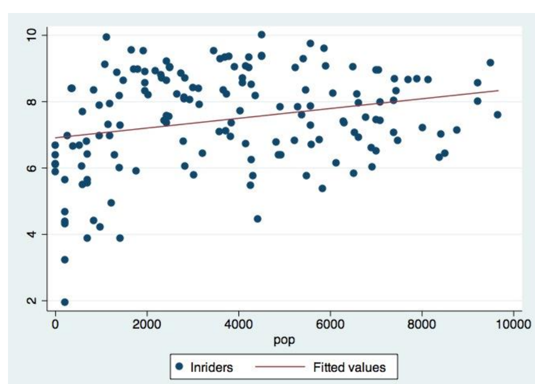


Figure 16: Two-way Scatter Plot- Population Density



The correlation between the dependent variable *lnriders* and the independent variable *population* was 0.254 level.

Jobs Density

Job density was calculated by determining the total number of jobs located within a quarter-mile of each rapid transit station. To ensure that the job density variables were accurate, researchers employed the same statistical tests in Stata that were used to examine the dependent variable *riders* and *lnriders*.

Table 14: Detailed Summary of Job Density

Detailed Summary of Jobs	
	Jobs
Observations	157
Mean	9,840.478
Standard Deviation	16,910.01
Skewness	2.49
Minimum	0
Maximum	83,017

The summary tests showed that all stations were accounted for in the data and that the minimum and maximum numbers are accurate. “State Station” is the station with 83,017 jobs within a quarter-mile and “Airport Terminal C” has zero jobs reported within a quarter mile. The reason for this may be because the majority of jobs are tabulated around the other four airport terminal stations.

For further analysis of the variable *jobs*, a histogram and box graph were both computed. As shown below, the *jobs* variable is skewed significantly to the right. While it is correct that there are several outlying stations that are located near a high concentration of jobs, over half the stations have less than three thousand jobs within a quarter-mile, so this rightward skewing seems accurate. The small handful of stations with a high density of jobs is located near stations in the CBD and can be seen in the Job Density Map on page 90.

The dependent variable *lnriders* and the independent variable *jobs* were examined using a two-way scatter plot. This test showed that as job density around stations increases the number of transit riders also increases.

The correlations between the dependent variable *lnriders* and the independent variable *jobs* were 0.359 percent.

Figure 17: Histogram - Job Density

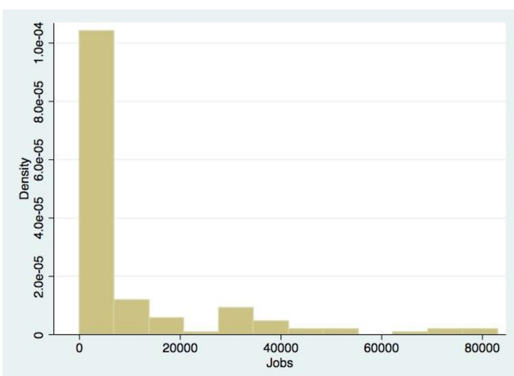
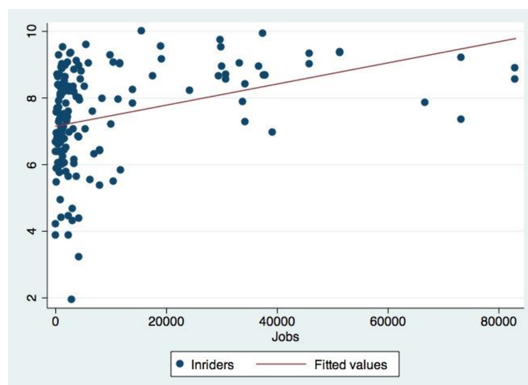


Figure 18: Two-way Scatter Plot - Job Density



Design Variables:
Four-way Intersection Density

The detailed summary of the independent variable *Four-way Intersections* is:

Table 15: Detailed Summary of 4-way Intersections

Detailed Summary of Four-way Intersections	
	Four-way Intersections
Observations	157
Mean	7.395
Standard Deviation	6.226
Skewness	1.177
Minimum	0
Maximum	28

This detailed summary confirmed that all data were correctly added to the spreadsheet with a total of 157 station inputs. The minimum and maximum four-way intersections were double-checked and were found to be accurate. The histogram and the box graph both show that the four-way intersection variables are skewed to the right. This means that there are many geographical areas with a small number of four-way intersections compared to the number of stations with many four-way intersections. Both of these graphs also show that the values are skewed slightly to the right, but are relatively evenly distributed with the exception of some outliers, all of which are located within Boston Proper in or in close proximity to the CBD.

The two-way scatter plot shows that as four-way intersection density increases rapid transit ridership also increases.

The correlations between the dependent variable *lnriders* and the independent variable *four-way intersections* was 0.363.

Figure 19: Histogram - 4-way Intersections

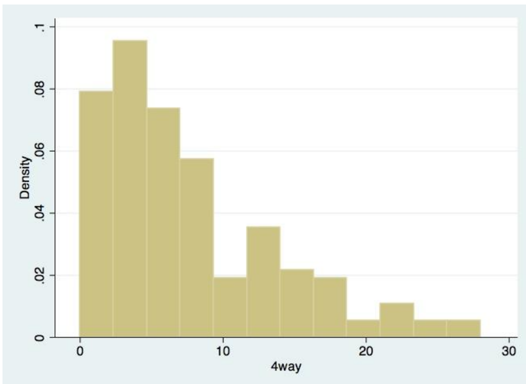
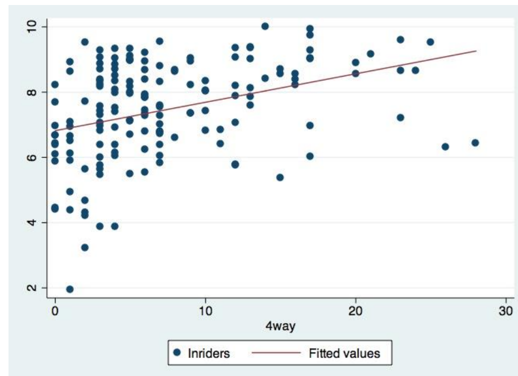


Figure 20: Two-way Scatter - 4-way Intersections



Line Terminus

Another important factor to look into is whether or not a station is at the terminus of a line. I hypothesized that a line terminus would have a greater number of riders, due to travelers commuting by car to the station from outer suburbs that are not yet served by rapid transit. In other words, a station that is located at the line terminus has a much larger capture areas than stations located nearer the CBD.

The line terminus data were gathered from the Massachusetts GIS rapid transit station shapefiles. Stations at terminus points were ranked “1” while the remainder was given a score of “0”. This summary report shows that all 157 stations were included in the analysis.

Table 16: Detailed Summary of Line Terminus

Detailed Summary of Line Terminus	
	Line Terminus
Observations	157
Mean	0.08554
Standard Deviation	0.29490
Skewness	2.751
Minimum	0
Maximum	1

Histogram and box graphs were utilized to better understand the *line terminus* data. These tests show that there are no outlying variables and that the data is accurate. A two-way scatter plot was also computed and shows a slight positive relationship between *lnriders* and *terminus*.

The correlation between the dependent variable *lnriders* and the independent variable *Line Terminus* is 0.115.

Figure 21: Histogram - Line Terminus

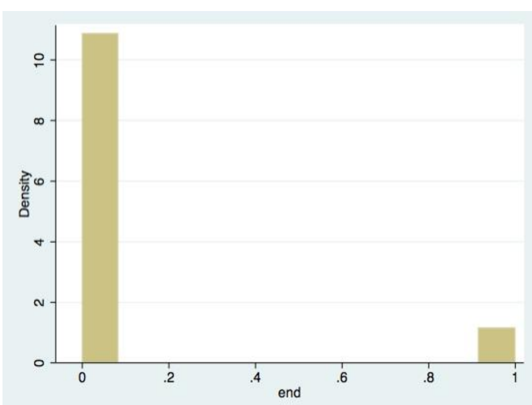
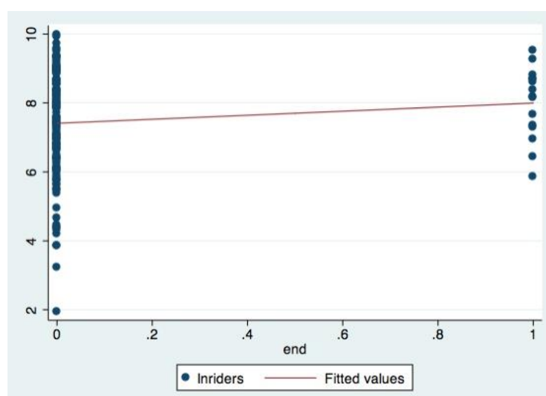


Figure 22: Two-way Scatter Plot - Line Terminus



Destination Variables

Distance from the Central Business District

I hypothesized that distance from the CBD would be important in terms of transit ridership. Historically the CBD was the major employment hub and one of the oldest portions of the city; therefore, the CBD has had the longest amount of time to gain and retain job growth, as well as housing and permanent residents. To test the significance of distance to CBD in relationship to the number of riders on the rapid transit system several statistical tests were run.

The detailed summary for *Distance from the CBD* confirmed that all observations, 157 total, were accounted for and the minimum and maximum inputs were correct. There are five stations, one for each line, that are zero (which was calculated as noted above). The Green Line has a maximum of one station twenty-three stops from the Green Line's hub. The summary test also determined the mean, standard deviation, and skewness of this variable.

Table 17: Detailed Summary of Distance from the Central Business District

Detailed Summary of Distance from the Central Business District	
	Distance from CBD
Observations	157
Mean	7.637
Standard Deviation	5.150
Skewness	0.681
Minimum	0
Maximum	23

The histogram, as displayed below, shows that the variable has many stations that are zero to nine stops away from the CBD and that as distance increases the number of stations decrease, as is to be expected. The box graph shows that the majority of the stations fell within the first and third quartiles and that there are several outlying stations. This is accurate since only the Green Line contains stations that are a significant distance from the CBD.

The two-way scatter plot comparing the dependent variable *lnriders* and the independent variable *Distance from the CBD* shows that as distance from the CBD increases rapid transit ridership decreases. The correlation between *lnriders* and *distance to CBD* is -0.042.

Figure 23: Histogram - Distance from CBD

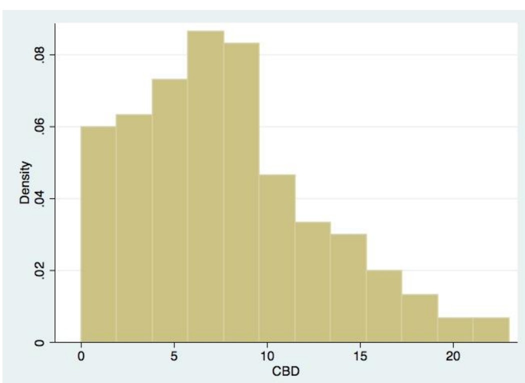
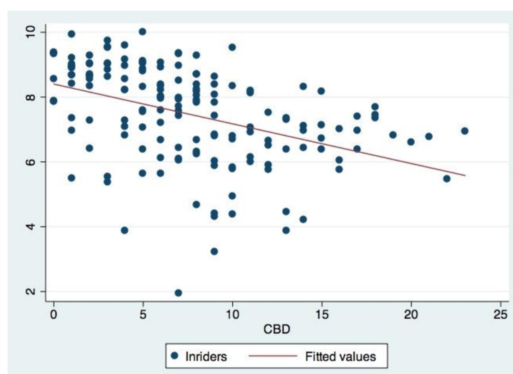


Figure 24: Two-way Scatter - Distance from CBD



Distance to Transit Variables

Transfer Stations

Transfer stations, where one or more lines share one station and passenger transfers are easily made, were included in this research because they are presumed to influence the number of rapid transit riders at a station. According to the MBTA data, transfer stations tended to have a higher degree of transit patrons, because they are generally centrally located, and provide access to more parts of the region than non-transfer stations. The ridership at transfer stations was calculated for each leg of a trip; for instance a rider was counted as an alighting when exiting the Green Line and counted as a boarding when he transferred to the Blue Line. To keep the data simple and reliable a dummy variable was created which equaled "1" if the station was indeed a transfer station and a "0" was input if a station had no rapid transit transfers (regular bus transfer locations were not included in this analysis).

Table 18: Detailed Summary of Transfer Stations

Detailed Summary of Transfer Stations	
	Transfer Stations
Observations	157
Mean	0.1201
Standard Deviation	0.3482
Skewness	2.073
Minimum	0
Maximum	1

Transfer Stations was examined with the help of a histogram and a box graph. Both tests show that there were no outlying inputs and that the data were input correctly. The histogram also provided an alternative method of looking at the number of transfer stations versus non-transfer stations.

A two-way scatter plot comparing the dependent variable *lnriders* and the independent variable *Transfer Stations* was also examined. This test solidified the earlier findings that the variables were input accurately, and also shows that if a station was a transfer point, transit ridership was likely to be somewhat higher than if the station was not a transfer point. The correlation between *lnriders* and *transfer stations* is 0.337.

Figure 25: Histogram - Transfer Stations

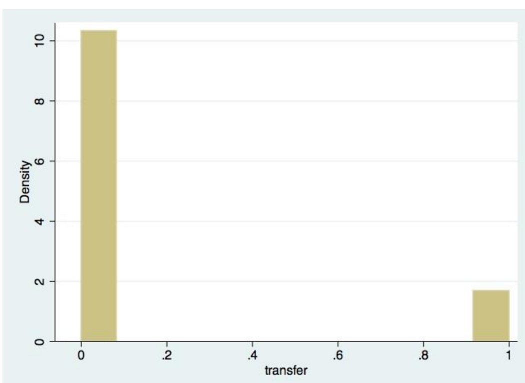
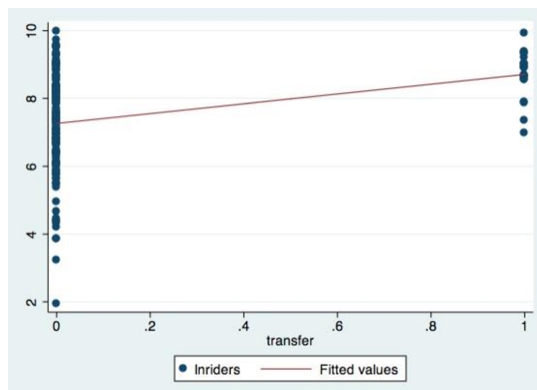


Figure 26: Two-way Scatter - Transfer Stations



Parking Spaces at Stations

The number of parking spaces was compiled from the Massachusetts Bay Transportation Authority's website at http://www.mbta.com. The MBTA breaks down the lines and summarizes the number of parking spaces, bus connections, handicapped accessibility, and number of bicycle parking facilities by station.

To verify that all the data were input correctly and that the data were reliable a detailed summary of the independent variable *parking* was computed.

Table 19: Detailed Summary of Parking Spaces

Detailed Summary of Parking Spaces	
	Parking Spaces
Observations	157
Mean	121.8153
Standard Deviation	408.8339
Skewness	4.306
Minimum	0
Maximum	2,733

This detailed summary confirms that all data were correctly added to the spreadsheet with a total of 157 station inputs. The minimum and maximum parking spaces were double checked and found to be accurate as well.

The histogram showed what was expected, that the majority of the stations had a value of zero, which was accurate since only twenty-eight stations on the entire rapid transit system had parking spaces. Alewife Station had 2,733 spaces, the maximum number of spaces referenced in the detailed summary. The box graph made the parking variables look like they are all outliners which was because the few stations with actual parking spots can be considered outliers.

The two-way scatter plot compared the dependent variable *lnriders* and the independent variable *parking spaces* and found that as the number of parking spaces around stations increases the number of riders increase. The correlation between the dependent variable *lnriders* and the independent variable *parking spaces* was 0.227.

Figure 27: Histogram - Parking Spaces

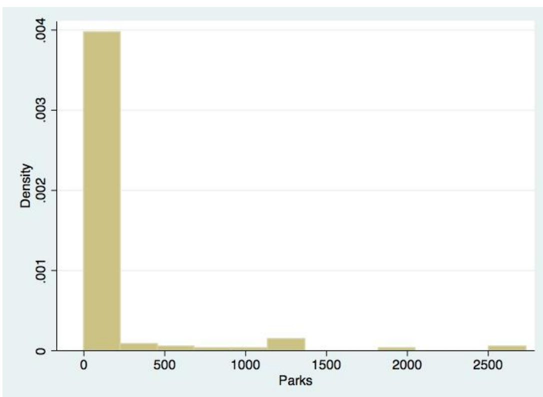
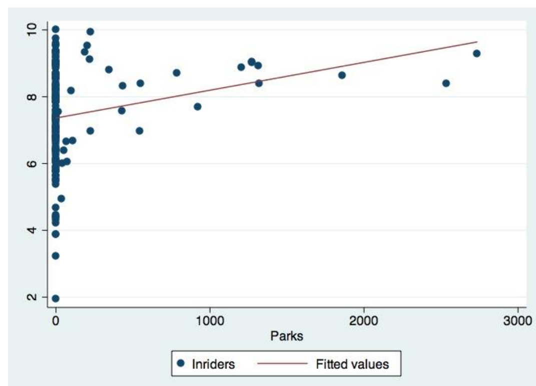


Figure 28: Two-way Scatter - Parking Spaces



Demographic Variables
Income

The final independent demographic variable analyzed was *income*. The variable *income* was calculated with the help of Esri Business Analyst, similar to the previous variables, and was obtained for a quarter-mile radius around each station.

To verify that all the data were input correctly and that the data were reliable researchers ran a detailed summary of the independent variable *income* to determine the total number of observations, mean, standard deviation, skewness, and the minimum and maximum income around each station. There were eleven stations that reported no average median income, which posed a problem. Since there were so few stations and a high number of independent variables, preserving each case was very important. To deal with this issue I ran my models using "casewise deletion," dropping the stations missing income, and alternately filled in the average median income for all stations that were missing data. The regression model was examined using both methods with little change in the results, so to preserve the number of cases I opted for the latter.

Based on methods used by previous researchers, it is prudent to take the natural log of income since people are generally more responsive to proportional changes in income rather than absolute income changes (Hout, 2004). In other words, a small increase in income for a household with a low median income matters much more than a small increase in income for a household with a high median income. Thus, after all fields were populated, I took the natural logarithm of *Income Average.*

Table 20: Detailed Summary of Income, Income Average and Lnincome Average

Detailed Summary of Income, Income Average, and Natural Log of Income Average			
	Income	***IncomeAve***	***LnIncomeAve***
Observations	146	157	157
Mean	86,392.27	86,392.25	11.294
Standard Deviation	35,501.62	34,227.09	0.3775
Skewness	1.0949	1.135	0.1617
Minimum	36,948	36,948	10.517
Maximum	218,110	218,110	12.292

To further analyze the variables *income,* and *lnincome average* histograms and box graphs were run. The histogram showed the variable *lnincome average* to be a near perfect bell curve. The box graph showed that all of the variables fell between the first and third quartiles, in contrast to the box graph for *income* that had outlying observations.

Two-way scatter plots comparing the dependent variable *lnriders* and the independent variables *income* and *lnincome average* were studied and confirmed the earlier tests, showing that the values were fairly normally distributed with the exception of a few outliers. The two-way scatter plots drawn below showed that as income increases rapid transit ridership decreases. This result seems appropriate as many researchers have studied the effects on income and mode choice and found that as income increases, single-occupancy vehicle usage also increases, while alternate modes such as rapid transit and bus transit decreases (Schimek, 1996).

Figure 29: Histogram – Income

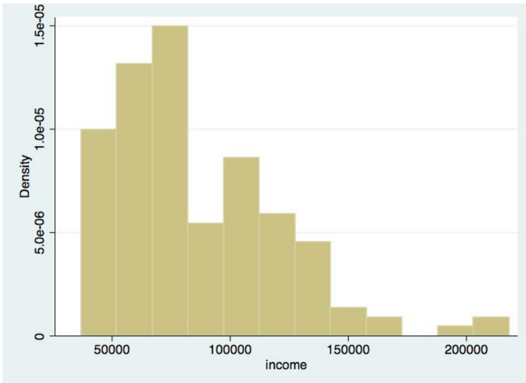


Figure 30: Two-way Scatter - Income

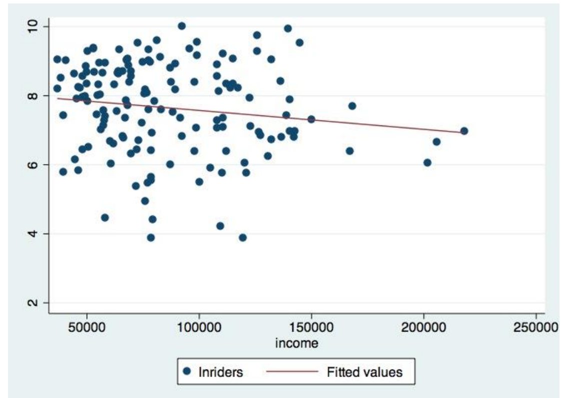


Figure 31: Histogram - lnincome Average

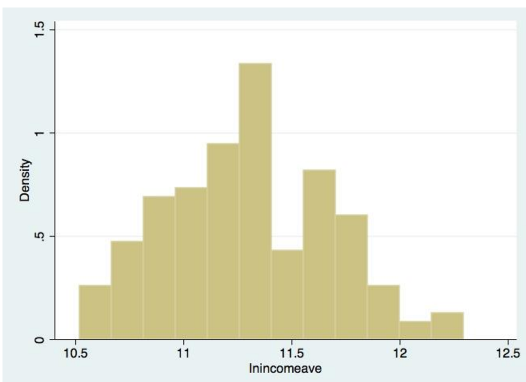
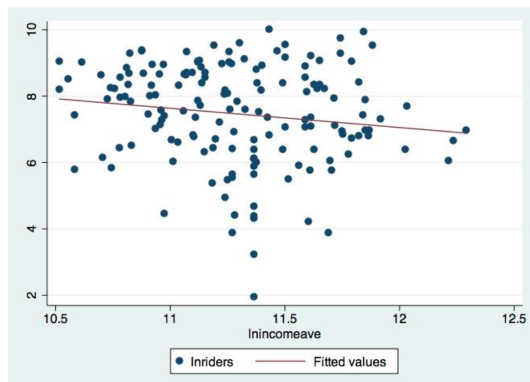


Figure 32: Two-way Scatter - lnincome Average



I also examined the bivariate correlations between the dependent and independent variables and found them all to produce similar correlations with regards to *lnriders*.

Table 21: Correlation of Lnriders

Correlation of Lnriders	
	Lnriders
Income	-0.1461
Income Average	-0.1253
LnIncome Average	-0.1466

It was surprising that the correlations were so low, but since the On Board Travel Surveys concluded that income was not a factor strongly influencing transit ridership in the riders that took the survey, these data this was not of great concern. CTPS staff also suggested that income had less influence over transit ridership in Boston compared to other similar cities since the system is so convenience. As such, many higher paid employees utilize the rapid transit system because it is easier than driving and parking at a destination. Also, Pucher and Renne (2003) examined the National Household Travel Survey and found that an increasing number of higher income groups were utilizing rapid transit while lower income groups' transit usage was waning.

Age

Age is another important independent variable that was examined. The average median age was found within a quarter-mile of each station. Age plays a large role in transit ridership levels because younger and older generations often do not have the skills or means required to operate a single-occupancy vehicle and need an alternate mode of transportation (Pucher & Renne, 2003).

Table 22: Detailed Summary of Age, AgeAve, and Age^2

Detailed Summary of Age, AgeAve and Age^2			
	Age	**AgeAve**	**AgeAve^2**
Observations	151	157	157
Mean	31.7324	31.7235	1038.597
Standard Deviation	5.806	5.693	372.3086
Skewness	0.2409	0.25	0.8196
Minimum	21	21	441
Maximum	48.4	48.4	2342.56

Examination of the age variable highlighted a discrepancy in the data, as there were only 151 observations. After careful analysis, it was determined this was due to the fact that six stations reported no population according to the 2010 Census. These stations were primarily located near Logan Airport and the Marine Industrial Park. Similar to income, this posed a problem since there were only 157 observations in the entire analysis, making each station very important considering the number of variables used to predict ridership. (As a rule of thumb, in OLS regression 10 to 15 observations are needed for each variable, a limit I approach). Several different scenarios were examined to find the best model. The regression model was tested with the six stations omitted and with the average median age from the entire dataset inserted into the fields with no data. Both methods produced similar results and did not create large variations in the model. I opted to populate the empty fields with the average median age in order to keep all cases. This completed the number of observations so that the research could analyze all 157 stations to help determine what causes rapid transit ridership.

Further analysis of the data and previous research methods prompted researchers to transform the variable *age* even further to help better explain the connection between *age* and *lnriders*. It is common practice to add the quadratic term age squared since the relationship between age and transit ridership might not be linear. Generally the relationship between age and transit is shaped like a bell, ridership is low when age is low, increases with age and employment, and then decreases after a certain point as age increases and mobility becomes more difficult.

The analysis of *age*, *age average*, and *age average*^{2} using a histogram and a box graph produced some interesting results. The histogram and the box graph show somewhat similar results but researchers found that *age* and *age average* were more evenly distributed compared to *age average*^{2}, which made sense since squaring any variable greatly increased the number of outliers. These tests also showed that there is not much difference between *age* and *age average*; in fact correlation analysis between the two variables was only.005.

In order to determine how age actually affects transit ridership levels age and *age average*^{2} were included in the model.

Figure 33: Histogram – Age

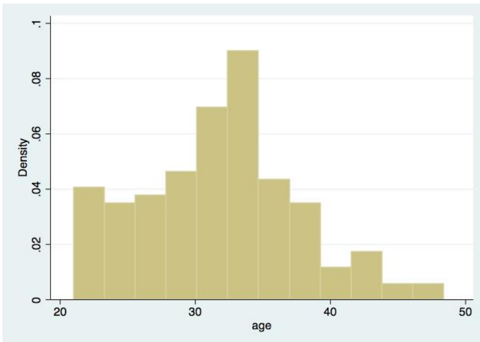
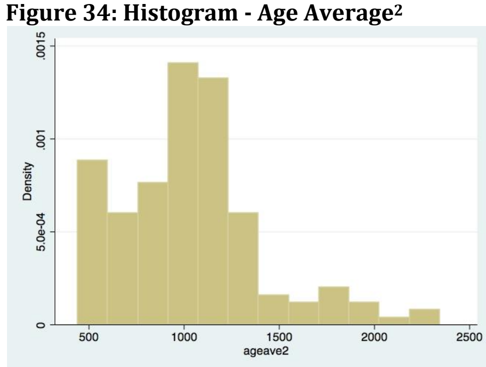


Figure 34: Histogram - Age Average[2]



Line-Specific Variable

To provide the most accurate results a set of line-specific dummy variables has been included in the ordinary least squares linear regression model. The dummy variables have been applied to all fixed individual lines and also to the Mattapan Trolley, which is a continuation of the Red Line, for a total of six dummy variables. The method used was similar to that for *terminus* and *transfer station*. A "1" was input if the station was on a particular line and a "0" was added to the remainder of the fields.

There are several reasons why using dummy variables are important. First, it accounted for any variations between the physical rapid transit lines. This study examined multiple rapid transit modes including above and below grade subway, light-rail, trolley, and bus rapid transit. Each of these modes have varying degrees of capacity, speed, and overall level of service, and these factors need to be included in the model since it affects the number of riders on each line. This is why the Red Line was given two dummy variables, one for the subway and one for the trolley.

Dummy variables are also helpful to distinguish between the developments on each line. As shown in Figure 38 each line has varying degrees of ridership due in part because of the land uses that are positioned along each line. Some lines serve major destinations such as Harvard University, Boston College, and Logan Airport, while others serve mainly residential areas.

Other things that can contribute to ridership levels on the lines that are distinguished with the help of dummy variables are train frequencies, some lines have more cars and lower headways between trains than others; age of the line, some lines have been in service for more than a century while other lines have only been in service a few decades; and finally, some lines have more transfer points providing access to more riders.

CHAPTER FOUR: SETTING

Prior to running the regression and testing the variables, the system as a whole was studied. This helped gain knowledge of the system and provided the perspective to determine if the results of the regression analysis were indeed accurate. Offered below is the background of the MBTA and a look at all five rapid transit lines. There are detailed line descriptions located in Appendix II at the end of this document.

History of Transportation in the Massachusetts Bay

Boston and the Massachusetts Bay Area have a long history with mass transportation. According to Massachusetts Bay Transportation Authority the first mass transportation in the Boston region began in 1631 when freight needed to be transported by ox cart on a two-day journey from Chelsea to Boston, and a year later the first chartered transportation began when ferry service started moving goods and people back and forth between these two cities.

After nearly two centuries the ferry service ended and bridges were constructed to connect Boston to nearby communities across the Charles River and the harbor (Massachusetts Bay Transportation Authority). In the late 1700s to early 1800s Boston and the surrounding towns introduced two separate types of mass transit: stage coaches that served individual cities and towns with no stops between, and the OMNI, a larger stagecoach that was able to serve people along the routes between towns. The OMNI resembled today's traditional bus service.

Fixed-rail transportation started in the Boston region in the mid-1850s when a horsecar line started servicing a route from Cambridge to West Boston. Initially citizens objected the laying of rail in the streets and both the OMNI and horsecars offered services simultaneously. Due to service issues and the problems that arose with caring for over eight thousand horses, which were prone to ill-health associated with pulling heavy loads of passengers for extended periods of time, officials began searching for a new mass transit technology (Massachusetts Bay Transportation Authority). After toying with the idea of cable cars, government officials decided to go another route. In January 1889, Boston made transportation history when the construction of an electric streetcar line began. This line opened in 1897, followed in 1901 with the first rapid transit system, Boston's elevated rail, known today at the Orange Line (Ba Tran, 2011).

Figure 35: Historic image of Boston's elevated rail line

Source: Bradley H. Clarke collection (as cited by www.boston.com)

Throughout the 20th Century, Boston's rapid transit lines continued to expand. After originally serving only fourteen cities and towns, in the mid-1950s, tracks were extended to more than seventy nearby communities. On August 3, 1964 the MBTA became "one of the first combined regional transportation planning and operating agencies to be established in the United States" (Massachusetts Bay Transportation Authority). With the expansion of the Green Line, Blue Line and the implementation of bus rapid transit the MBTA has continued to grow and serve an increasing amount of the Massachusetts Bay. In 2011 the Orange Line and the Red Line celebrated 110 and 100 years of service, respectively.

Today, the MBTA is the fifth largest mass transit system in the United States and is one of two systems in the nation that utilizes all modes of transportation (Massachusetts Bay Transportation Authority). According to the 2010 United States

Census the MBTA “serves a population of 4,817,014 (people) in 176 cities and towns with an area of 3,249 square miles” (Massachusetts Bay Transportation Authority). On average, the system transports approximately 1.3 million passenger trips per day using buses, bus rapid transit, rapid transit, light rail, trackless trolley, commuter rail, vans, and sedans. In 2012, even though transit fares increased, passenger vehicle miles have risen. MBTA’s ridership has steadily increased over the past two years, despite fare hikes, which were predicted to decrease ridership by five percent. Instead ridership increased 5.6 percent from October 2012 to November 2012 (Werthmann, 2012).

Figure 36: Arial view of the Massachusetts Bay in 2012

Source: Photo courtesy of Huffington Post, January 2013

Massachusetts Bay Rapid Transit System

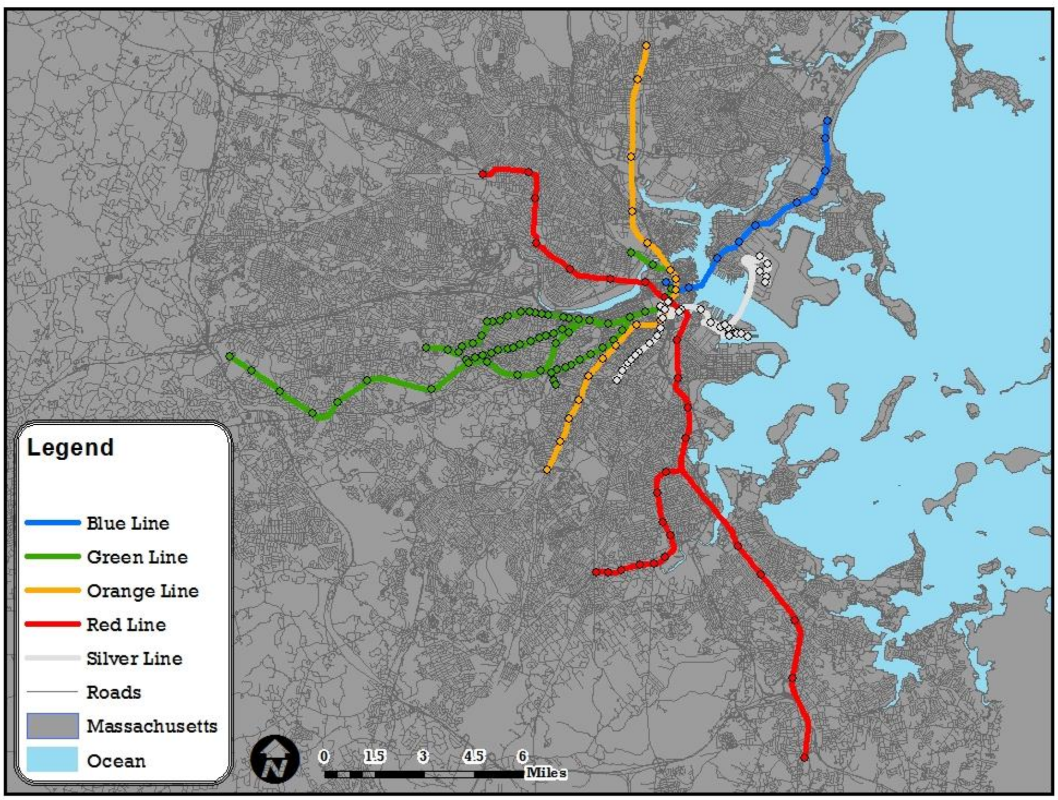
The Massachusetts Bay Transportation Authority is the public operator of five rapid transit lines. The rapid transit system, known as the “T”, consists of three subway lines (Red, Blue, and Orange), one light rail line (Green), and one trolley line (an extension of the Red Line subway) stretching across the city in a mostly radial pattern emanating from downtown. Moreover, one bus rapid transit line (the Silver Line) serves downtown, Boston’s Logan Airport, and portions of Boston Harbor. There are a total of 161 rail and bus rapid transit stops serving over 596,000 passengers per day, according to the *2010 Bluebook*. For the purposes of this study, the stations have been pooled (though still classed by line), for a total of 157 rapid transit stations (four stations are at junctions of two lines). Inbound and outbound riders were combined for all rapid transit lines, and transfer stations were counted as stops on each of the two lines. For instance, if one station served the Blue Line and the Orange Line, it was counted twice, once for each line. These stations consist of aboveground bus rapid transit stops, elevated rail stations, trolley line stations, and underground subway stations. There are seventy-seven miles (one-way) of rapid transit coverage in the MBTA, serving sixty-five cities and towns in the Massachusetts Bay (Massachusetts Bay Transportation Authority, 2010). The Red Line (including Mattapan Trolley) covers the greatest distance, with twenty-four miles of track followed by the Green Line with twenty-three miles of track.

Table 23: MBTA Routes

The MBTA Routes	
Line	***Miles of Track***
Red Line (including the Mattapan Trolley)	24
Orange Line	11
Blue Line	6
Green Line	23
Silver Line	13
Total	**77**

Source: The MBTA

Figure 37: The MBTA rapid transit system



Source: www.mass.gov

The Red Line services the highest number of riders on the system daily and has four out of the top five, and eight out of the top fifteen most-frequented stations on the MBTA rapid transit system. The Red Line is followed by the Green Line with 174,722 riders, and the Orange Line with 141,052.

Table 24: The MBTA rapid transit average daily ridership by line

The MBTA Rapid Transit Average Daily Ridership by Line		
Line	***Number of Riders***	***Percent of Total***
Red Line	186,494	32%
Mattapan (Red) Line	10,605	2%
Blue Line	44,233	7%
Orange Line	141,052	24%
Green Line	174,722	29%
Silver Line	39,176	7%
Total Riders	**596,282**	**100%**

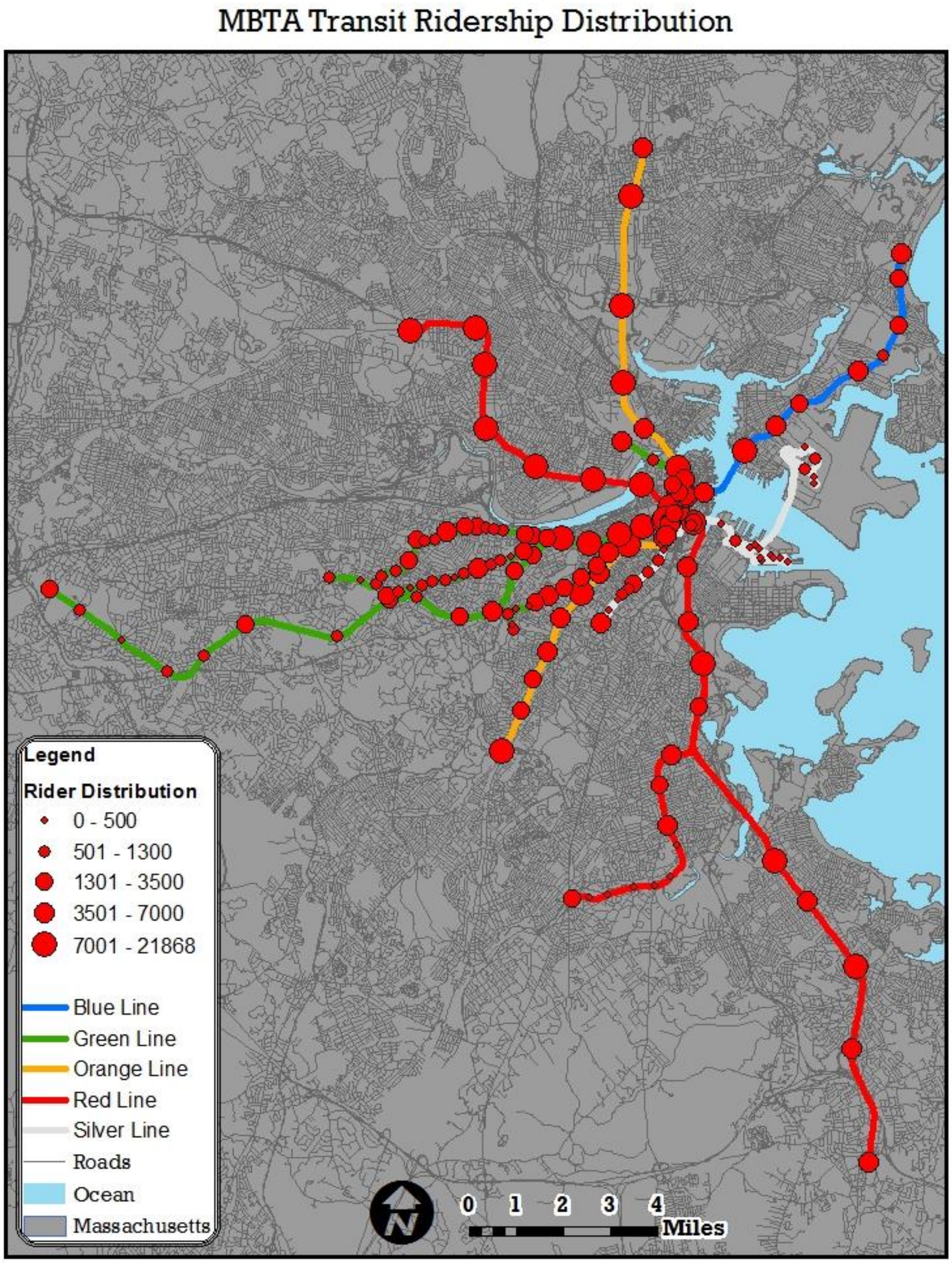
Source: 2010 Bluebook

Table 25: The MBTA Rapid Transit Stations with the High Average Daily Ridership

The MBTA Rapid Transit Stations with High Average Daily Ridership		
Station	***Line***	***Average Daily Riders***
Harvard	RED	21,868
South Station	RED	20,647
Back Bay	ORANGE	16,769
Central	RED	14,531
Kendall/MIT	RED	13,975
Forest Hills	ORANGE	13,568
Copley	GREEN	13,500
Downtown Crossing	RED	11,746
Davis	RED	11,628
Downtown Crossing	ORANGE	11,563
Malden Center	ORANGE	11,258
Park Street	GREEN	11,169
Alewife	RED	10,657
Charles/MGH	RED	10,615
Government Center	GREEN	10,072

Source: 2010 Bluebook

Figure 38: The MTBA Rapid Transit Ridership Distribution



Source: www.mass.gov

There are a total of 19,123 parking spaces on the MBTA rapid transit system. Park-and-Ride lots hold anywhere from 2,733 vehicles at Alewife Station to only eighteen at Savin Hill Station, both on the Red Line. Only seventeen percent of stations, twenty-seven in total, have any parking available.

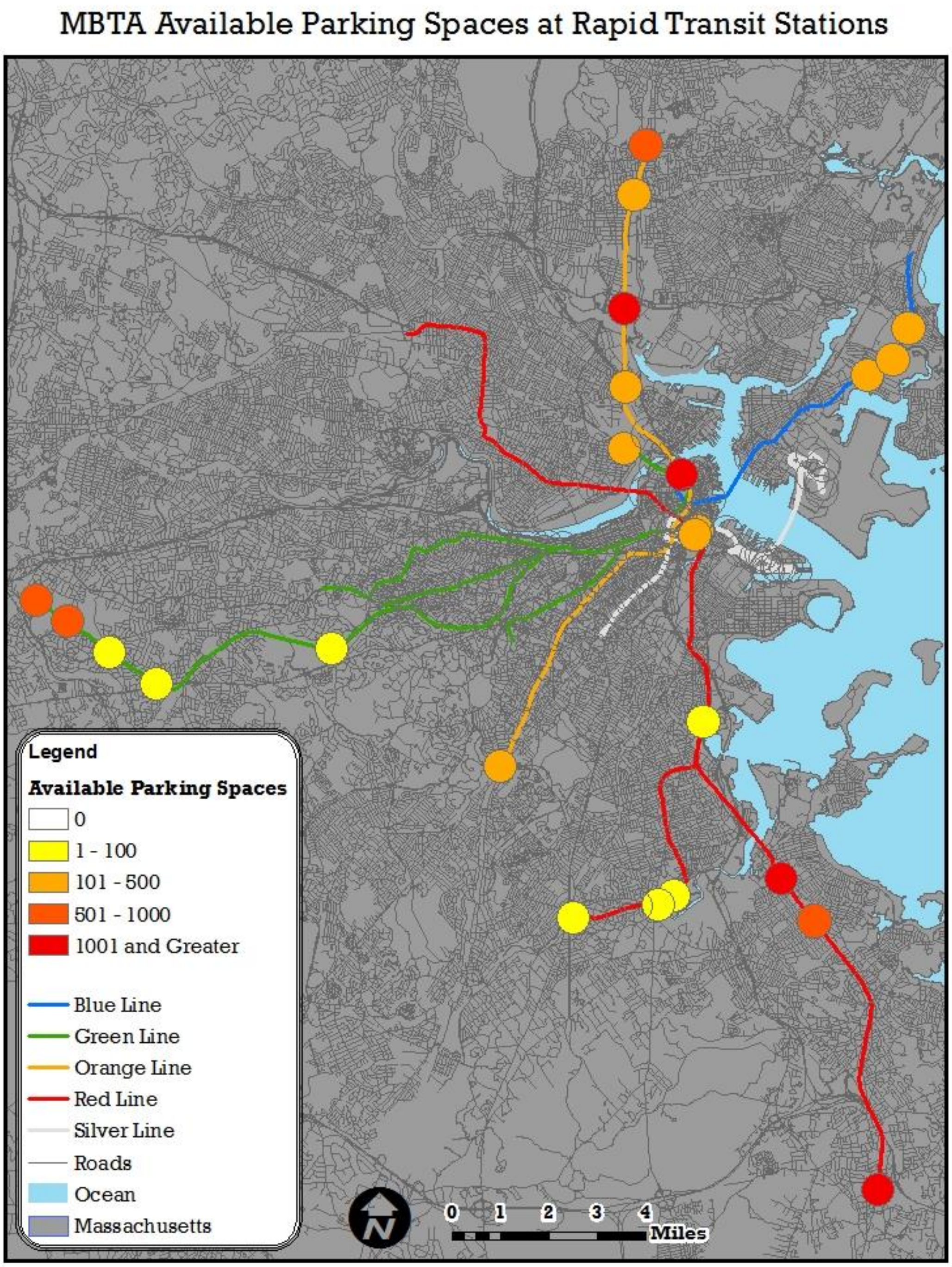
As shown in Table 26 the majority of stations that have available parking are in the outlying suburban areas, with exception of parking on the Red Line, which has several stations located in the CBD with parking spaces.

Table 26: Total parking spaces available on the MBTA

Total Parking Spaces Available on the MBTA					
Station	***Line***	***Parking Spaces***	***Station***	***Line***	***Parking Spaces***
Alewife	RED	2733	Lechmere	GREEN	347
Quincy Adams	RED	2538	South Station	RED	226
Wonderland	BLUE	1862	South Station Essex St.	SILVER	226
Braintree	RED	1322	Sullivan Square	ORANGE	222
Wellington	ORANGE	1316	Forest Hills	ORANGE	206
North Station	GREEN	1275	Malden Center	ORANGE	188
North Station	ORANGE	1275	Suffolk Downs	BLUE	110
North Quincy	RED	1206	Mattapan	Mattapan	100
Riverside	GREEN	925	Waban	GREEN	74
Oak Grove	ORANGE	788	Chestnut Hill	GREEN	70
Wollaston	RED	550	Eliot	GREEN	55
Woodland	GREEN	548	Milton	Mattapan	41
Orient Heights	BLUE	434	Butler	Mattapan	40
Beachmont	BLUE	430	Savin Hill	RED	18

Source: The MBTA

Figure 39: The MBTA available parking spaces at rapid transit stations



Source: www.mass.gov

The MBTA rapid transit system is one of the nation's most utilized systems. Moreover, there are high concentrations of people near stations. According to the United States Census Bureau's 2010 Census, 590,539 people in 258,057 households live within a quarter-mile of a rapid transit T station. The rapid transit system in the Massachusetts Bay serves both urban and suburban areas and connects passengers to many other travel modes such as bus, commuter rail, air travel (i.e., Logan Airport), intercity rail, and ferries. The densest area served by rapid transit system is Boston proper near the CBD though it also extends into outer ring suburban neighborhoods with lower densities.

Table 27: The MBTA stations with largest population within a quarter-mile

The MBTA Stations with Largest Population within a Quarter-Mile		
Station	***Line***	***Population***
Symphony	GREEN	9,661
Hynes Convention Ctr/ICA	GREEN	9,511
Northeastern	GREEN	9,231
Massachusetts Ave	ORANGE	9,225
Griggs Street	GREEN	8,765
Worcester Square	SILVER	8,514
Allston Street	GREEN	8,427
Massachusetts Ave	SILVER	8,381
Tufts Medical Center	ORANGE	8,133
Newton Street	SILVER	8,019

Source: The MBTA *2010 Bluebook*

Table 28: The MBTA stations with the smallest population within a quarter-mile

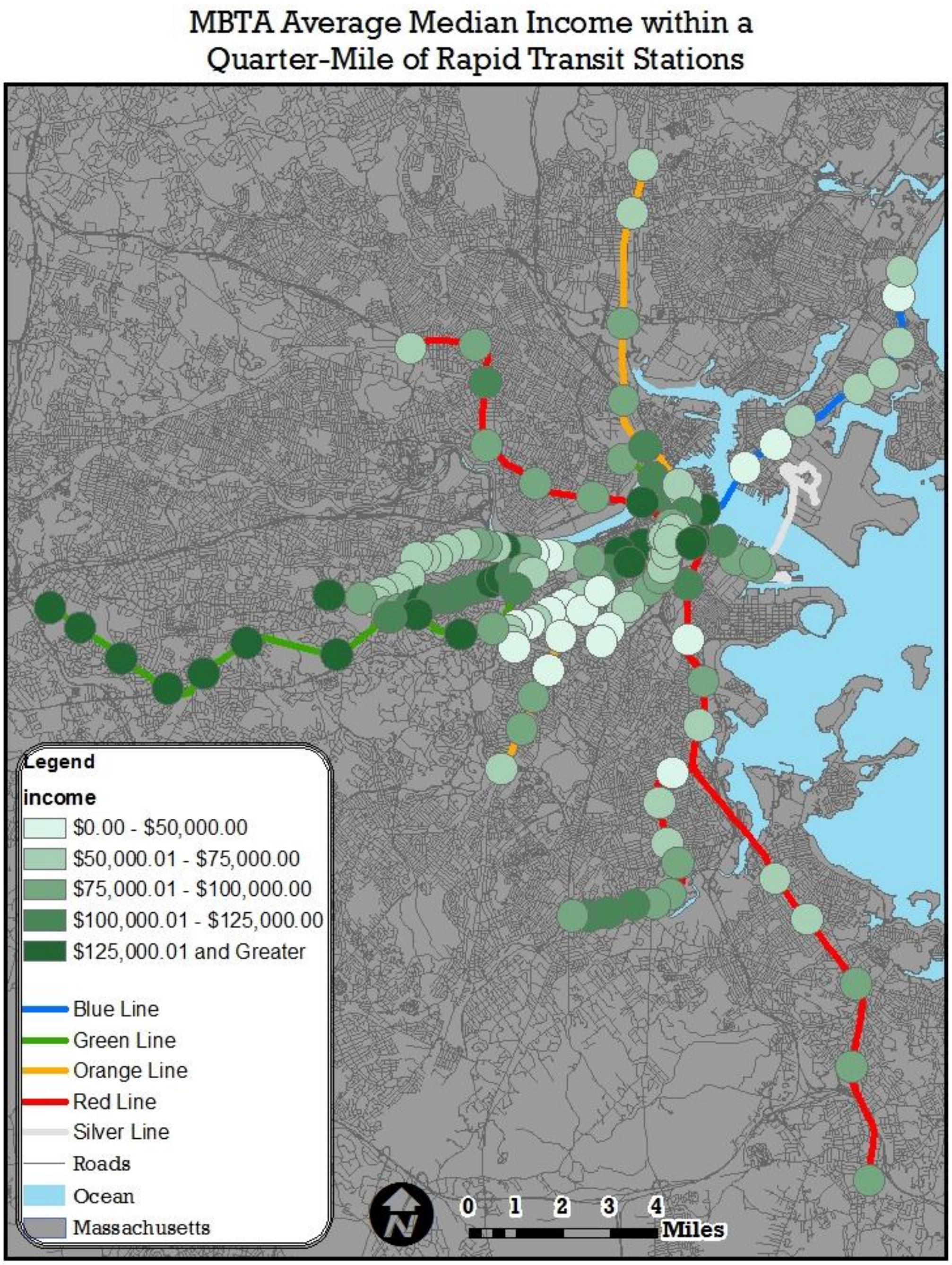
The MBTA Stations with the Smallest Population within a Quarter-Mile		
Station	***Line***	***Population***
Boston University West	GREEN	681
Riverside	GREEN	599
Court House	SILVER	590
Waban	GREEN	574
Suffolk Downs	BLUE	523
Chestnut Hill	GREEN	386
Quincy Adams	RED	366
Braintree	RED	353
Woodland	GREEN	266
Northern Avenue at Tide Street	SILVER	207

Source: The MBTA *2010 Bluebook*

The average median income in households within a quarter mile of MBTA T-stations is $86,392, according to the American Community Survey 2005-2009. Woodland Station, Chestnut Hills Station, and Riverside Station boast the highest income levels while Ruggles Station, Dudley Square Station, and Jackson Square Station are areas with the lowest average median income within a quarter-mile radius of each station (not including rapid transit stations near Logan airport or the Boston Marine Industrial Park which report no income since there are no residents).

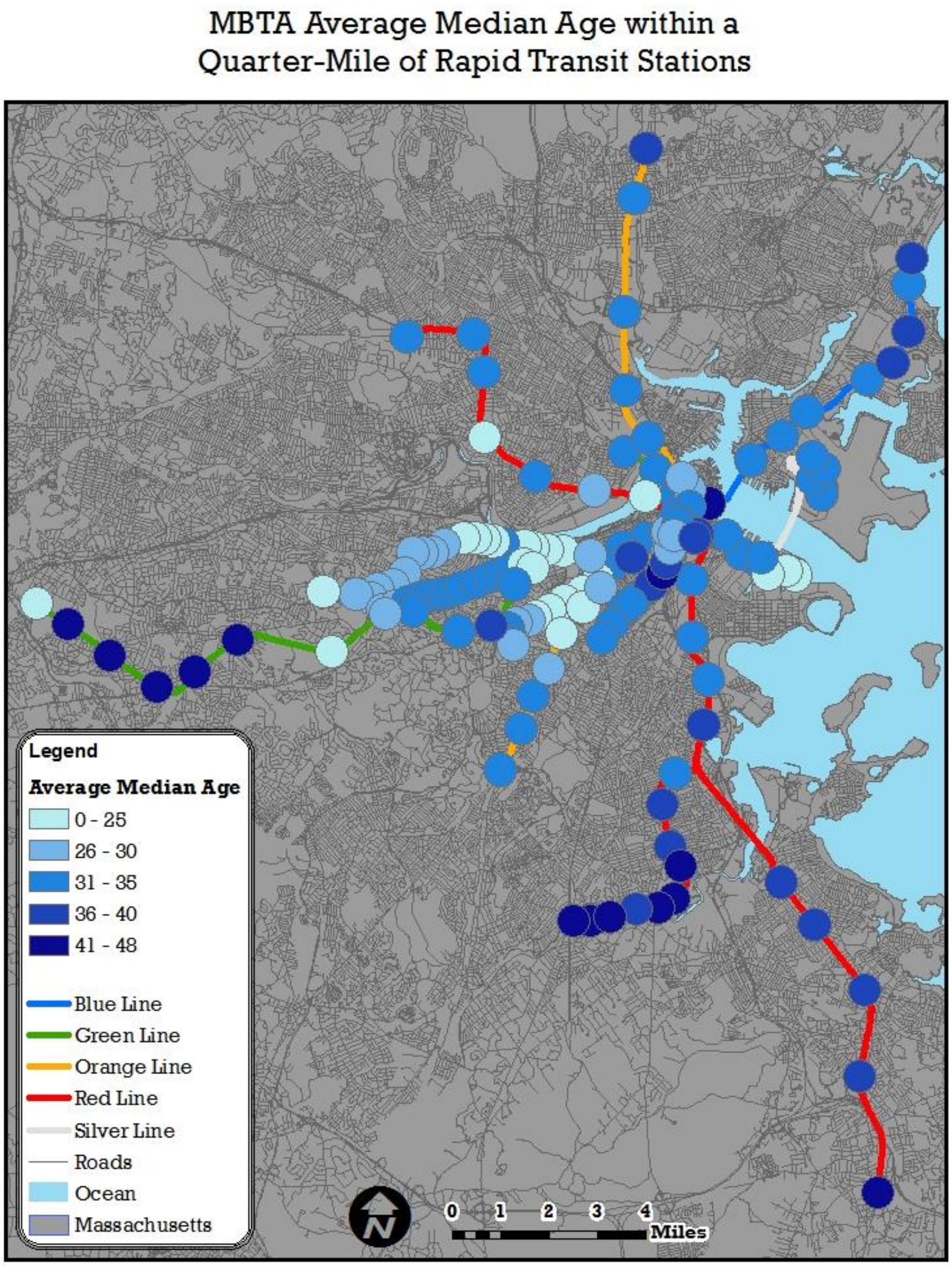
The average age of residents living near the rapid transit lines is 31.7 years of age according to the 2010 U.S. Census, which varies greatly across the Massachusetts Bay service area. Average median age ranges between 21 and 48.8. Shown in Figure 41, the stations with a higher median age are located on the periphery and the stations with lower average ages are located near the CBD and near educational institutions such as Harvard, Boston University, Boston College and MIT.

Figure 40: The MBTA average median income within a quarter-mile of rapid transit stations



Source: US Census ACS 2005-2009

Figure 41: The MBTA average median age within a quarter-mile of rapid transit stations



Source: US 2010 Census

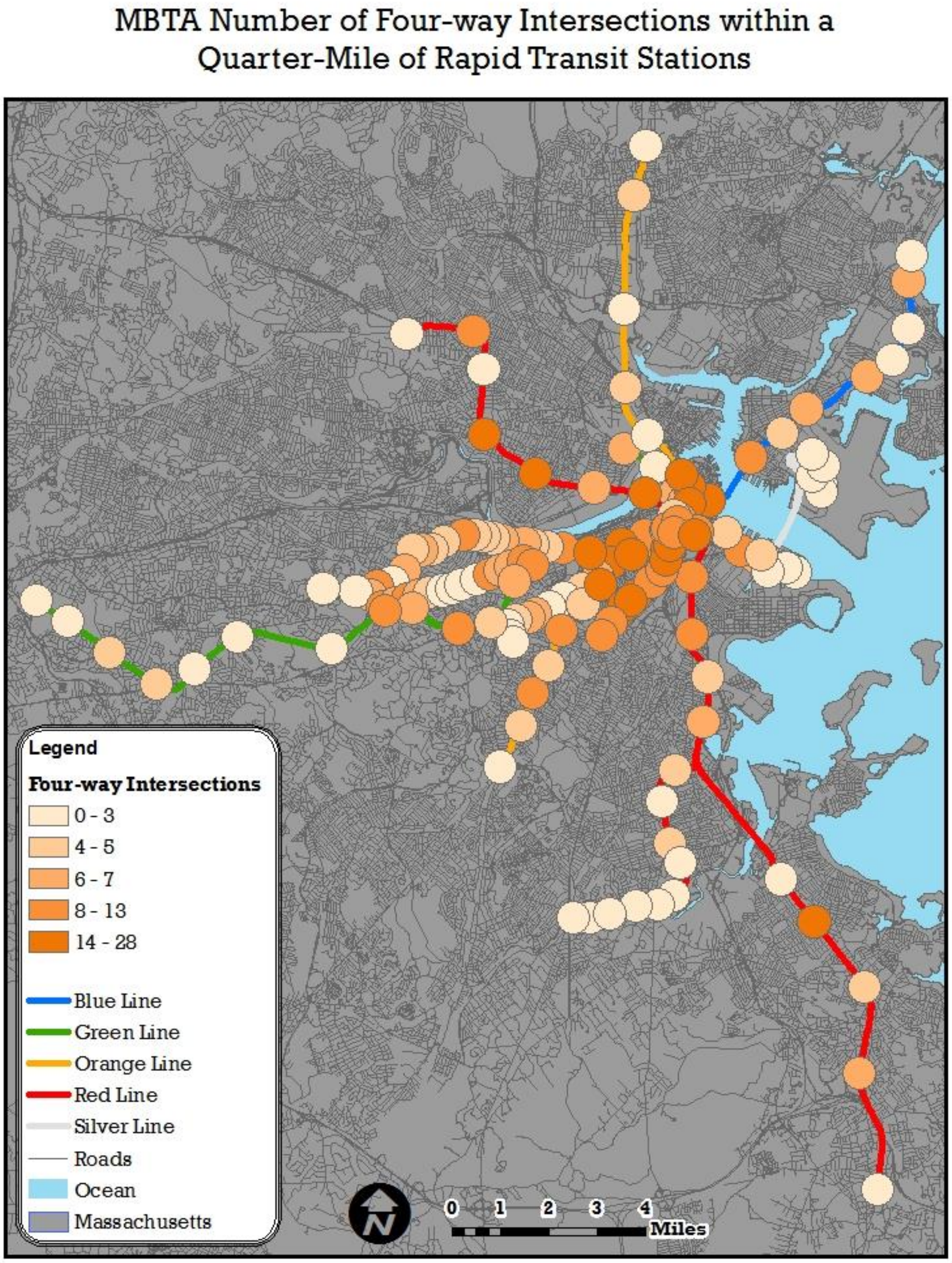
The density of four-way intersections in a given geographical area helps determine street density and network connectivity. Four-way intersections are often found in older sections of cities and in CBDs. This holds true for the Massachusetts Bay. Figure 42 depicts where roadway networks are more connected, and the map shows that four-way intersection density is greater in Boston proper than in the surrounding communities. With the exception of the Red Line, stations on the periphery tend to have less four-way intersections than stations located closer to the CBD.

Table 29: Top ten stations with a high number of four-way intersections by line

Top Ten Stations with a High Number of Four-way Intersections by Line		
Station	***Line***	***# of 4-way Intersections***
Worcester Square	SILVER	28
Massachusetts Ave	SILVER	26
Copley	GREEN	25
Tufts Medical Center	ORANGE	24
Central	RED	23
Tuffs Medical Center	SILVER	23
Newton Street	SILVER	23
Hynes Convention Ctr/ICA	GREEN	21
State	ORANGE/BLUE	20
North Station	GREEN/ORANGE	17

Source: Author

Figure 42: The MBTA number of four-way intersections within a quarter-mile of rapid transit stations



Source: Author

On the MBTA rapid transit system there are 1,544,955 jobs located within a quarter-mile around transit stations (ESRI Business Analyst). This data might be slightly skewed as some stations are counted multiple times to account for individual lines at each station.

Table 30: The MBTA stations with the highest number of jobs

The MBTA Stations with the Highest Number of Jobs		
Station	***Line***	***Jobs***
State	ORANGE/BLUE	83,017
Government Center	GREEN/BLUE	73,271
Downtown Crossing	RED/ORANGE/SILVER	66,705
Park Street	GREEN/RED	45,889
South Station Essex St.	SILVER	39,161

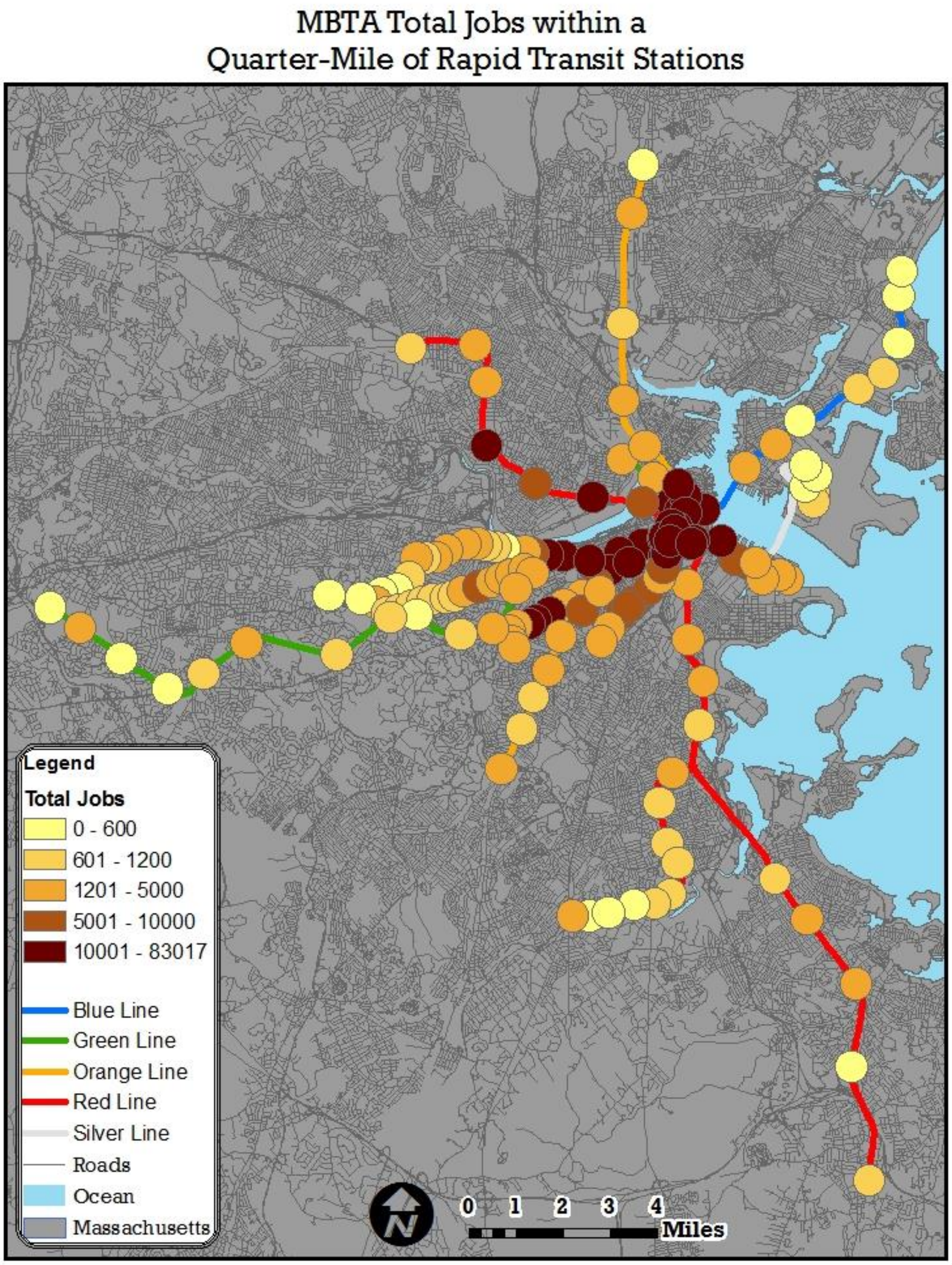
Source: Esri Business Analyst Online

Table 31: The MBTA stations with the lowest number of jobs

The MBTA Stations with the Lowest Number of Jobs		
Station	***Line***	***Jobs***
Boston University West	GREEN	342
Oak Grove	ORANGE	333
South Street	GREEN	250
Beachmont	BLUE	221
Boston College	GREEN	171
Airport Terminal E	SILVER	116
Valley Road	MATTAPAN	97
Eliot	GREEN	84
Capen Street	MATTAPAN	67
Airport Terminal C	SILVER	-

Source: Esri Business Analyst Online

Figure 43: The MBTA total jobs within a quarter-mile of rapid transit stations



Source: ESRI Business Analyst Online

CHAPTER FIVE: FINDINGS

The final variables used in the linear regression model after transformations were made are listed below. The variables in bold have been transformed.

Table 32: Variables Used in Regression

Variables Used in Regression		
Dependent Variable		**Lnriders**
Independent Variables	*Density*	Population Density
		Job Density
	Design	4-way Intersection Density
		Line Terminus
	Destination	Distance to CBD (number of stops)
	Distance to Transit	Transfer Stations
		Parking Spaces at Each Station
	Demographics	**Lnincome Average**
		Age Average
		Age Average2
	Dummy Variables	Red Line
		Red Mattapan Line
		Orange Line
		Green Line
		Blue Line
		Silver Line

Statistical Tests of the Model

Once the variables were transformed and the model was stable, several statistical tests (described at the beginning of this chapter) were computed in Stata to ensure the model's accuracy and validity.

The first test, Cameron and Trivedi's Decomposition of IM-test, generated a p-valued of 0.9968, which showed that there was no heteroskedasticity.

Table 33: Cameron & Trivedi's Decomposition of IM-test

Cameron & Trivedi's Decomposition of IM-test			
Source	***chi2***	***df***	***p***
Heteroskedasticity	76.30	113	0.9968
Skewness	15.53	15	0.4139
Kurtosis	0.89	1	0.3466

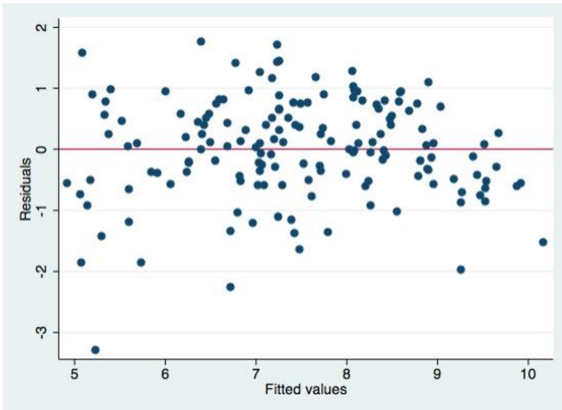
The second test was the Breusch-Pagan / Cook-Weisberg Test, which generated a p-value of 0.0203. Thus, I rejected the null hypothesis that the residuals were homogenous across different values of the dependent variable with a ninety-five percent level of confidence.

Table 34: Breusch-Pagan / Cook-Weisberg Test

Breusch-Pagan / Cook-Weisberg Test	
Chi2 (15)=	28.22
Prob > chi2=	0.0203

To check for heteroskedasticity, the residuals were plotted against the predicted values, and the results are presented below. This again showed that no patterns exist and my model is valid and useful.

Figure 44: Residuals versus Predicted Values



The Variance Inflation Factors (VIF) were also examined to check for multicollinearity between the variables. I hypothesized that some multicollinearity would be witnessed due to the fact that both *age average* and *age average*^{2} are explaining the same thing.

Table 35: Variance Inflation Factors

Variable	VIF	1/VIF
Age Average^2	77.46	0.012910
Age Average	75.56	0.013235
Green	8.24	0.121298
Silver	5.5	0.181719
Red	4.45	0.224598
Job Density	4.16	0.240342
Orange	4.13	0.242285
Transfers	3.49	0.289861
Blue	2.94	0.340472
CBD	2.49	0.408030
Population Density	2.45	0.485803
Lnincome Average	2.06	0.542174
4-way	1.84	0.542174
Parking Spaces	1.47	0.681918
Terminus	1.31	0.762203
Mean VIF	13.17	

The hypothesis was correct and *age average^2* and *age average* demonstrate large VIF factors. Again, this is normal and expected since they virtually explain the same thing. The rest of the variables all have VIF factors well within an acceptable range (under 10.0) and with the exception of the Green Line and the Silver Line dummy variables, all are within the ideal range (under 5.0). Multicollinearity between the Green Line and the Silver line is acceptable because they are all negatively correlated with each other, meaning that riders on the Silver Line are not riders on the Green Line.

A few interesting relationships exist, one between *job density* and *transfers*, which helps to validate this model since all transfer stations, are located within the CBD and another between the design variables *four-way intersections* and *line terminus* which shows two completely different forms of the built environment being contained in the model.

Correlations

A correlation table was computed to determine the relationships between the variables and *lnriders*. I have previously reported on the individual correlations above, but it is necessary to look at how the independent variable correlations compare to each other.

The correlations allow researchers to see the linear relationship between the dependent and independent variables, and shows how accurately one variables relationship is to another. Correlations range anywhere from 1.00 to -1.00. As a correlation approaches 0.00, the harder it is to predict one variable from another. The correlation table on the previous page shows that ridership on the Silver Line, the Green Line, and the Mattapan can expected to be lower than the ridership levels on the Red Line, Orange Line, and the Blue Line. These correlations may be attributed to transfer stations and popular developments such as Harvard or Logan Airport that may be located on particular lines.

The correlations also show that ridership is positively related to *terminus, parking spaces, four-way intersections,* and *transfer stations*. This shows that if the station is a terminus point or a transfer station it will attract more riders than if it were not. Similarly, if parking spaces are present at a station and there are a higher number of four-way intersections there (relative to the rest of the stations), it is likely to have more riders than stations that do not possess these qualities.

Population and *job density* are both positively associated with *lnriders,* with *population density* more likely to predict ridership than *job density.* The *distance to CBD* is negatively correlated to *lnriders* meaning that the further the station is from the CBD the more likely it is to lack riders. Similar to the regression results, *age average*^{2} and *income* show little association to *lnriders* and it is difficult to find a relationship between the independent variables and the dependent variable.

Table 36: Correlations

	lnriders	Red Line	Mattapan	Orange Line	Green Line	Blue Line	Silver Line	Terminus	Parking Spaces
lnriders	1.0000								
Red Line	0.3789	1.0000							
Mattapan	-0.2634	-0.0911	1.0000						
Orange Line	0.3334	-0.1458	-0.0860	1.0000					
Green Line	-0.0626	-0.3347	-0.1973	-0.3160	1.0000				
Blue Line	0.1003	-0.1130	-0.0667	-0.1067	-0.2450	1.0000			
Silver Line	-0.4409	-0.1949	-0.1149	-0.1840	-0.4224	-0.1427	1.0000		
Terminus	0.1154	-0.0004	0.1218	0.0123	-0.0573	0.0696	-0.0524	1.0000	
Parking Spaces	0.2278	0.2271	-0.0564	0.0805	-0.1503	0.0808	-0.1394	0.3432	1.0000
Job Density	0.3588	0.0021	-0.1251	0.1338	-0.1453	0.1631	-0.2900	-0.1250	-0.1180
Population Density	0.2542	-0.1303	-0.2047	0.0497	0.3496	-0.1230	-0.1676	-0.1774	-0.2294
Age Average	-0.0800	0.1293	0.3894	-0.0442	-0.3061	0.1669	-0.0212	0.0720	0.1699
Age Average2	-0.0999	0.1124	0.4185	-0.0592	-0.2795	0.1633	-0.0412	0.0667	0.1624
lnincome Average	-0.1466	-0.0141	0.0571	-0.1777	0.1954	-0.1095	-0.0431	-0.0337	-0.0262
4-way	0.3632	0.0835	-0.1968	0.1054	-0.1353	-0.0067	0.1231	-0.1952	-0.0877
CBD	-0.4223	-0.2237	0.1743	-0.2059	0.4975	-0.2038	-0.2174	0.2213	-0.0009
Transfer	0.3370	0.0031	-0.0935	0.1878	-0.1579	0.0220	0.0763	-0.1312	0.0145

	Job Density	Population Density	Age Average	Age Average2	lnincome Average	4-way	CBD	Transfer
lnriders								
Red Line								
Mattapan								
Orange Line								
Green Line								
Blue Line								
Silver Line								
Terminus								
Parking Spaces								
Job Density	1.0000							
Population Density	0.0982	1.0000						
Age Average	-0.0230	-0.4316	1.0000					
Age Average2	-0.0408	-0.4284	0.9920	1.0000				
lnincome Average	0.0730	-0.3965	0.3818	0.3944	1.0000			
4-way	0.4160	0.3884	-0.0244	-0.0512	-0.0071	1.0000		
CBD	-0.5793	0.0205	-0.0146	0.0153	0.1186	-0.4119	1.0000	
Transfer	0.8070	0.0746	-0.0317	-0.0567	-0.0465	0.3675	-0.5147	1.0000

OLS Regression of *lnriders*

Stata used the following equation to compute the linear regression used in this study.

$$lnriders = (\beta_0 + \beta_1 Red + \beta_2 Mattapan + \beta_3 Orange + \beta_4 Green + \beta_5 Blue + \beta_6 Silver + \beta_7 Terminus + \beta_8 ParkingSpaces + \beta_9 JobDesnity + \beta_{10} Popoulation\ Density + \beta_{11} AgeAverage + \beta_{12} AgeAverage2 + \beta_{13} lnincomeaverage + \beta_{14} 4way + \beta_{15} CBD + \beta_0 Transfers + \in)$$

Overall the regression analysis was very successful in predicting which variable was more influential over transit ridership at stations in the MBTA, and which variables have little to no effect. Here are the results:

Table 37: OLS Regression Model of lnriders

lnriders	*Coef.*	*Std. Err.*	*t*	*P> t*	*[95% Conf. Interval]*	
Red	2.147833	0.43000160	4.99	***0.000	1.29774900	2.9970170
Mattapan	0.000000	(omitted)				
Orange	1.878429	0.43208830	4.35	***0.000	1.02422000	2.7326380
Green	1.297197	0.40348940	3.21	***0.002	0.49952560	2.0948670
Blue	1.145220	0.44744240	2.56	**0.012	0.26065680	2.0297830
Silver	-0.463688	0.40877680	-0.08	0.259	-1.27181200	0.3444358
Terminus	1.257359	0.27028820	4.65	***0.000	0.72301810	1.7917010
Parking Spaces	0.000163	0.00020610	0.79	0.430	-0.00024450	0.0005705
Job Density	-0.000001	0.00000839	-0.08	0.934	-0.00001730	0.0000159
Population Density	0.000079	0.00004220	1.87	*0.063	-0.00043000	0.0001624
Age Average	-0.011307	0.10623950	-0.11	0.915	-0.22133510	0.1987215
Age Average2	0.000238	0.00162395	0.14	0.885	-0.00301410	0.0034902
Lnincome Average	-0.106968	0.26446340	-0.40	0.686	-0.62979410	0.4158580
4-way	0.040370	0.01517900	2.66	***0.009	0.01036190	0.0703777
CBD	-0.104613	0.02130110	-4.91	***0.000	-0.14672400	-0.0625025
Transfers	0.483559	0.37311130	1.30	0.197	-0.25405670	1.2211740

**** p=99%   **p=95%   *p=90%*

Table 38: Regression Statistics: R-squared & Adjusted R-squared

Number of Obs	=	157
F(15, 141)	=	21.37
Prob > F	=	0.00000
R-squared	=	0.69450
Adj R-squared	=	0.66200
Root MSE	=	0.86917

The regression model shown is a valid and reliable source of information to examine the relationships between the dependent variable *lnriders* and the independent variables. The model produced an adjusted R^2 of 0.662. The adjusted R^2 accounts for any variance in the model, and generally decreases as more independent variables are added. Since my model utilized a total of fifteen independent variables, including the dummy line variables and two variables examining age, the adjusted R^2 shows stability in the model. Also, as previously discussed, this number changed very little with the addition and subtraction of different variables and variable transformations.

The dummy variables allow Stata to determine collinearity between the lines, and Stata then omits one line from the model. This allows for an easier analysis of the lines and the affects each independent variable has on *lnriders*. Stata omitted the Mattapan Line as it supplied the least amount of riders on the entire system and used its riders as a base for the analysis. Stata then used the Mattapan Line as point zero, and any positive or negative coefficient on a line dummy is relative to the Mattapan Line.

I also ran the model five more times, each time manually omitting a different dummy line variable to see how the model reacted. Each scenario produced similar results in regards to the non-dummy independent variables. The dummy variable's significance factors varied only slightly depending on what line was omitted, but the R^2 remained constant. Since Stata chose the line with the least number of riders, that is the model I used for the remainder of the analysis.

The regression produced a number of statistically significant variables including four of the six transit lines (Red, Orange, Green, and Blue), *terminus*, *population density, four-way intersections,* and *distance to the CBD*, and proved fruitful to answer the questions posed by this research.

CHAPTER SIX: IMPLICATIONS FOR THE MBTA

The first question I examined with the regression model outputs was how the built environment within a quarter-mile Euclidean Distance (as a crow flies) of each station affects transit ridership. The five variables used in the models, which were analyzed individually above, were: *parking spaces* (p=0.43), *four-way intersection density* (p=0.009), *distance from CBD* (p=0.000), *transfer stations* (p=0.197), and *line terminus* (0.000). The outcomes for three out of five of these variables were statistically significant at the ninety-nine percent confidence level or higher.

Transfer stations and *parking spaces* were the only built environment variables to not be statistically significant where b=0.484 and p=0.194, and b=0.000163 and p=0.43, respectively. Both of these results were surprising since transfer points are generally high ridership traffic areas, and parking spaces as shown in the literature can attract a higher number patrons. One explanatory factor for transfer stations can be obtained from the On Board Ridership Survey, which showed that the majority of people exited on the same lines they entered.

Table 39: Exits from the MBTA System

Exits on Same Line	
Red Line	79%
Green	75%
Orange	84%
Blue	63%
Silver	--

Source: The MBTA On Board Travel Survey

The variable *parking spaces* also shows no statistical significance. These results seem to have a direct connection with the On Board Travel Surveys, where parking was ranked fairly low in importance among the station amenities convenience factors. Respondents located near Boston proper ranked parking as a relatively unimportant factor with regard to rapid transit ridership, whereas respondents from more suburban areas said that while they may have been more inclined to drive to the station if more parking was available, it ranked relatively low in the degree of overall importance (Central Transportation Planning Staff, 2009).

Table 40: Parking Importance Ranking in Survey Data

Parking Importance Rank out of 11 (1= high importance; 11= low importance)	
Red	8
Green	9
Orange	8
Blue	7
Silver	--

Source: The MBTA On Board Travel Survey

These results answered another of the original questions posed by this project; whether parking spaces available at stations influence the number of riders.

According to this analysis the answer is no, the number of parking spaces at stations have no influence on transit ridership levels. Further research into a cost analysis of parking spaces both at trip origin and trip ends may provide planners and policy makers with more data with which to base further parking investment decisions.

The other three variables were all statistically significant with a confidence level of ninety-five percent or greater, and performed in accordance with earlier assumptions. The variable *CBD* was found to be statistically significant at the ninety-nine percent confidence level where b=-0.104613 and where p=0.000. There are several reasons why this may be the case in the Boston, but the biggest reason may be the convenience factor of the rapid transit. This variable may be indicating that stations closer to the CBD are more easily accessed. As shown in Figure 37 the stations are located much closer to each other, thus making travel time much shorter. Station distance from the CBD has a direct link to the length of time it takes to travel to it from other stations, which along with on-time performance and frequency of service were ranked extremely high in service quality importance on the On Board Travel Survey.

Table 41: Service Quality Percentages

Service Quality Percentages				
	Blue Line	***Green***	***Red***	***Orange***
Reliability	**28%**	**29%**	**29%**	**29%**
Safety and Security	17%	13%	15%	17%
Cleanliness	6%	6%	6%	7%
Courtesy of Crew	3%	3%	2%	2%
Station Announcement	2%	2%	2%	2%
Available Seating	5%	7%	5%	5%
Frequency of Service	**20%**	**23%**	**22%**	**21%**
Travel Time/Speed	**13%**	**16%**	**15%**	**12%**
Parking Availability	3%	1%	2%	2%
Station Amenities	1%	1%	1%	1%
Fare Collection System	2%	2%	2%	2%
Total	100%	100%	100%	100%

Source: The MBTA On Board Travel Survey

Regardless of how far away a station is from the CBD it may still be faster, cheaper, and easier to choose a rapid transit mode rather than choosing to drive a motorized vehicle. Since the majority of people on each line demonstrated that their number one reason for choosing transit was convenience factor this conclusion seemed reasonable. My research results paralleled user preferences for service quality found in the On Board Travel Survey. The survey respondents ranked travel time/speed, frequency of service, and reliability high priorities for using the rapid transit system. Since reliability, frequency of service, and travel time/ speed increases the closer the station is to the CBD, it makes sense that station distance matters. If rapid transit can provide a faster and more reliable trip alternative than driving alone, as long as the cost is affordable, it should be successful. In fact, the regression model shows that for every station one-stop further away from the CBD, ridership will decrease by ten percent. Therefore, from examining the built environment variables, the question of whether distance from the CBD influenced transit ridership can be answered with a yes, and the results are statistically significant.

The last two variables that were statistically significant at the ninety-nine percent confidence level were *terminus* and *four-way intersections* where p=0.000 for both. As previously mentioned, *line terminus* stations have the chance to capture a high number of outlying suburban residents; however the relationship between *line terminus* and *lnriders* was surprising. The regression model showed a large positive relationship between the variables where the estimated coefficient was b=1.257. This means that if a station is at a terminus, then ridership compared to all other stations increases more than 125 percent. As mentioned earlier, terminus stations have a much larger capture area than other stations, but there may have been several factors influencing the number of riders at the line terminus. An in-depth analysis of these individual stations should be examined to fully understand if there are additional reasons why being at the line terminus is so influential in the model.

Finally, *four-way intersection density* had a large influence over the number of riders utilizing the MBTA system. This finding was consistent with decades of previous research done all over the United States and globally; a high degree of street connectivity has a positive correlation with transit ridership. For the MBTA the relationship between *lnriders* and *four-way intersections* had an estimated coefficient of b=0.049. This suggests that for every extra four-way intersection within quarter mile of a rail station, ridership rises five percent. Again, this result was statistically significant at the ninety-nine percent confidence level. There are several reasons why four-way intersections matter to this extent. They reflect dense and connected street networks that make it easy to walk to stations. However, it should be noted that this variable only captures one element of the street system. "Street networks are characterized by street connectivity, directness of routing, block sizes, sidewalk continuity, and many other features," (Ewing & Cervero, 2001).

This research by Ewing and Cervero looked at many studies done over the past three decades and came to the conclusion that despite the fact four-way intersections influence transit in a positive way, there are many other moving parts at work. This research also did not take into consideration the conditions at the street level or the design of the pedestrian realm. Some neighborhoods may have had well-connected sidewalks, or street lighting geared toward the human scale making the areas safer at night. However, I would still advise policy makers and governing bodies in the Massachusetts Bay to work together to provide more connected street patterns in developments adjacent to transit in order to improve rapid transit ridership levels.

In this research, there is a high concentration of four-way intersections in the older, more mature sections of the Massachusetts Bay. These neighborhoods had much more time to develop employment and residential centers compared to newer suburban areas that have had less time to fill-in, but the model takes this into consideration and controls for both employment and job density.

The question of the relationship between four-way intersections and demographic variables was one that was considered at the beginning of this study, and was answered with the help of the regression model. As has been noted, this project used two demographic variables - *age average, age average*^{2} (both represent one variable), and *lnincome average*, and neither were found to be statistically significantly at or above the ninety percent confidence level. At this time there are no explanatory factors as to why there are no significant figures for these demographic variables. The On Board Travel Survey had respondents from all age levels greater than eighteen years of age. Further analysis should be done to see if socio-demographics influence rapid transit ridership in the MBTA region.

The final question I hoped to answer with this new dataset was whether high densities of residents and jobs influence transit ridership. Moreover, one of the most common factors cited in the literature was the jobs and housing balance in regards to mode choice. According the regression model population density had a much higher influence over rapid transit ridership and was statistically significant at the ninety percent confidence level, while job density showed no significant relationship to *lnriders* when p=0.0.934.

Population density, with an estimated coefficient of b=0.000079, shows that each additional thousand persons per square mile is associated with a 7.9 percent increase in boardings and alightings, whereas job density had no significant influence on riders. This was surprising as a majority of the trips on the rapid transit systems were home-based work trips or work-based work trips, and the literature showed densities at trip end were greater than densities at trip beginning (Cervero & Arrington, 2008). However, these results follow suit with Ewing and Cervero's meta-analysis conclusion that population and job density do not matter as much as researchers once believed (2010, p. 275).

At the end of the day it seemed that the greatest influencer of transit rider on the MBTA was the line. The high capacity lines are indistinguishable from each other, but are statistically significantly above the Silver Line and the Mattapan Line while the Mattapan Line and the Silver Line are indistinguishable from one another. Red Line stations receive more than two hundred percent more ridership than the Mattapan. Similarly the Orange Line, the Green Line, and the Blue Line all receive more than one hundred percent more than the ridership on the Mattapan Line with 189 percent, 130 percent, and 115 percent, respectfully.

Despite any discrepancies in the data, transformed variables, or line differences this research can guide planners and policy makers at the MBTA and within the Massachusetts Bay area. This research showed that of the Ds - *density, design, destination, distance to transit, and demographics* - that design of the roadway network is the best variable to explore in order to increase transit ridership on the MBTA. The results were similar to other studies done in the Boston area that also suggested the high degree of importance of factors that are supported by advocates of smart growth and the Congress for New Urbanism (Zhang, 2007). The regression results also showed that demographic and household characteristics were more influential than jobs and housing. This however, should be approached with caution, particularly if using this study to guide development in regions other than the Massachusetts Bay. It also showed that the MBTA should allocate transit dollars cautiously when expanding the system. The Green Line already has the highest number of stops away from the CBD and fewer riders per stop than the Orange Line, Red Line and Blue Line. Perhaps the MBTA should look at expanding the Red Line or Blue Line since they have the least amount of stations, since travel times on these routes are currently shorter compared to the other lines. Any increase in parking at stations should also be made cautiously since they show no significant impacts to ridership levels.

The region studied has the benefits of system longevity and strength and land uses have had many years (sometimes more than a century) to develop around stations. Cities and regions hoping to implement a new transit system or a significant upgrade to an existing system should study travel behavior and the job housing balance as it pertains to each region before advising or changing any growth or transit policies.

CHAPTER SEVEN: LIMITATIONS AND FUTURE RESEARCH

Data Collection Limitations

As mentioned throughout the previous section there are limitations to this research as it pertains to guiding future policies for the land use and transportation nexus, and any decisions should be carefully examined to determine cause and effect on each system. There are many pieces to every puzzle and the transportation land use nexus is a huge puzzle; it is different for every climate, culture, region, and city.

This research only paints a tiny portion of the larger picture of the transportation land use nexus. With only a small number of cases to study, the number of variables used to create a valid analysis could be no more than ten to fifteen, despite the fact that several dozen more variables could help explain the connections between transit ridership and how policies affect these levels. Although most of the key factors examined by other researchers are present in my model, researchers have used a multitude of variables described in the earlier literature review, previous reviews of the literature, and meta-analysis reviews of the reviews of the literature (of which there are at least two). The data used in this analysis was chosen partially because of importance, but also due to availability, time, and funding constraints. With unlimited resources, more data could have been obtained, such as the square footage of built land uses (retail, commercial, industrial, etc.) that could have given a more detailed description of what was happening on the ground.

There are also shortcomings with the data used in this research. The inputs included were obtained from multiple sources, all with their own methods of collecting and analyzing data. A majority of the data was obtained from ESRI's online interfaces and can be accessed anytime. This company's methods of data extraction from the 2010 Census and the American Community Survey may be different than what previous researchers have done in the past through different user interfaces. However, since all demographic and job data was obtained from the same company rather than several different sources, the extraction methods should all be somewhat similar and more reliable.

There are then barriers within the data sources themselves. There is always some degree of error in both the census and ACS survey data, but luckily, ESRI also reports the reliability of the data used. Most of the information provided by the census bureau had a high to medium degree of reliability, with only a few stations providing a low degree of reliability. The majority of these stations were located near the Logan Airport and the Marine Industrial Park at Dry Dock. ESRI obtains job data from Infogroup, a corporation that collects employment data from over sixty thousand businesses daily; however, since businesses are always revolving this data also will have some degree of unreliability (http://www.infogroup.com). Also, the job data was collected in 2012 while the rest of the data was either collected in 2009 or 2010, and since there had been a lot of change in the market between these years, the data may be slightly inaccurate.

There may be discrepancies in the data obtained from the *On Board Travel Surveys* and in the *2010 Bluebook*. Not everyone responds to all questions, not every person is counted, and ridership levels vary on different days of the week and times of the year. With every study there is a certain degree of error, but since care was taken, all of the variables were carefully examined, and the majority of factors considered by other researchers (plus some important extras like parking, line terminus and CBD distance) were included in the model, I am confident in the final results.

Further Research

This research project is narrow in scope and only provides analysis of a few variables out of hundreds. There are many more opportunities for further research within the MBTA service area, the Massachusetts Bay, Boston proper, and both in cities across the United States and globally.

It would be beneficial to do parallel studies to compare the results of other similar sized cities and transit systems to determine if Boston's results align with those of Atlanta, Georgia; Dallas, Texas; or Chicago, Illinois just to name a few. The density of the built environment, the quality of the service, and many other factors may produce dramatically different results.

This research also only utilized transportation data from rapid transit users. One could conduct a region-wide survey of the entire population to determine why citizens do or do not utilize rapid transit. Often, public transportation systems contain a certain amount of negative stigma, but since Boston's transit system has been employed for such a significant amount of time and is used by all demographics this stigma may be less prominent in the area. What then, are other reasons people do not utilize rapid transit systems, and what could easily be implemented to increase use?

Another research project concerning rapid transit in the region could look solely at the connection between transit ridership and on-the-ground zoning. The zoning special data can be collected from the State of Massachusetts's GIS database. This is a large task and may be best accomplished with the help of local jurisdictions and planning departments. In this study it might also be interesting to look at what has actually been developed and what developed areas attract the most amount of riders and why. Is there a certain ratio of residential square footage or commercial square footage development that is needed to attract transit riders?

As previously mentioned, it would be beneficial to see how the rapid transit system (and development in general) reacts to fare increases or decreases. Currently the MBTA predicts ridership to increase by twenty percent in the next decade. This will cause a considerable amount of stress on the system and riders may have to pay a growing premium to use the service. Thus far, fare increases have done little to deter riders, and the number of daily trips continues to rise (Byrne & Landergan, 2012). At what extent will fares be able to increase before ridership levels will begin to drop? If people have to pay an increased amount to park at stations will ridership levels decrease? How does service quality affect transit ridership? How does station cleanliness or the safety levels in and around that station influence people's decisions to use transit? There are many more questions to answer concerning rapid transit in the MBTA service area.

Finally, it may be interesting to perform this study with data a half-mile around each station. Boston's stations are located fairly densely, but since people are generally willing to walk further to rapid transit, it would be interesting to see how the results between the two studies compare (Walker, 2011).

CHAPTER EIGHT: CONCLUSIONS

The transportation and land use nexus could be researched by hundreds of people for decades. It was the intent of this project to provide a base of knowledge to determine which variables provide the most influence over transit ridership. As discussed in the previous chapters the built environment variables — the line (*destinations*), *distance from CBD*, *four-way intersections*, and *line terminus* — have the greatest influence over rapid transit ridership in the MBTA's sphere of influence.

This study only brushes the surface of the connection between transit ridership, the built environment, and land uses. Transportation influences nearly every decision people make on a daily basis, but so does land use. The two are (too) often regarded as completely separate entities with separate governing bodies making the decisions for each. Zoning and land use decisions are made at the local level and sometimes even at the neighborhood level, while transportation decisions and funding emanates from a regional planning organization such as a Metropolitan Planning Organization. In order to use or even collect data that can be used by both systems, these groups of government need to collaborate to develop an overarching plan for the region. In transit-oriented developments policy makers look at different scales of transit and patron capture areas. The same needs to be done with transit and land use. This is a complicated and time-consuming process, which will probably receive a lot of pushback from stakeholders from all over the region. In the Massachusetts Bay region alone there are over 150 cities and towns, five counties, and several larger policy making entities. Thus far the MBTA has done a great job of attracting riders within the region and is able to provide millions of efficient trips annually.

APPENDIX I

Blue Line Data

Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Bowdoin	BLUE	1	1454	0	34301	5577	30.2	107993	7	2	0
Government Center	BLUE	0	1556	0	73271	2423	31.1	110852	6	1	1
Aquarium	BLUE	0	4444	0	34189	3012	48.4	136373	14	1	0
Maverick	BLUE	0	8134	0	1208	5239	33.3	40819	13	2	0
Airport	BLUE	0	6901	0	3310	2748	31	49596	4	3	0
Wood Island	BLUE	0	1450	0	559	1411	33	57745	6	4	0
Orient Heights	BLUE	0	4121	434	884	1968	34.1	62216	7	5	0
Suffolk Downs	BLUE	0	794	110	748	523	38.4	60306	0	6	0
Beachmont	BLUE	0	1936	430	221	2435	37	57608	3	7	0
Revere Beach	BLUE	0	2693	0	581	3147	32.6	45640	6	8	0
Wonderland	BLUE	1	5520	1862	504	1488	38.2	64280	1	9	0
State	BLUE	0	5230	0	83017	1951	32.9	108079	20	0	1

Red Line Data

Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Harvard	RED	0	21868	0	15590	4517	21.5	92307	14	5	0
Kendall/MIT	RED	0	13975	0	18987	1656	27.4	99100	7	3	0
Davis	RED	0	11628	0	2768	3794	32	95764	12	7	0
South Station	RED	0	20647	226	37457	1115	37.1	139580	17	1	1
Alewife	RED	1	10657	2733	653	3600	33.6	50312	3	8	0
Porter	RED	0	8552	0	2259	4154	32.9	115170	3	6	0
Charles/MGH	RED	0	10615	0	9928	5411	30.5	126086	17	2	0
Broadway	RED	0	4200	0	2288	844	34.9	112231	10	2	0
Andrew	RED	0	5586	0	1780	2437	32.6	44369	8	3	0
Savin Hill	RED	0	1863	18	678	2476	37.1	63490	7	5	0
Fields Corner	RED	0	4152	0	3272	3662	34.8	49947	4	6	0
Shawmut	RED	0	2241	0	653	4034	35.2	68431	2	7	0
Central Avenue	RED	0	363	0	491	1773	38.6	105054	1	12	0
North Quincy	RED	0	7132	1206	1181	1342	36	68690	3	5	0
Wollaston	RED	0	4347	550	1220	3137	38.3	68945	16	6	0
Quincy Center	RED	0	7913	0	4307	1722	36.3	75066	5	7	0
Quincy Adams	RED	0	4383	2538	401	366	36	87643	6	8	0
Braintree	RED	1	4387	1322	621	353	41.4	98038	3	9	0
Downtown Crossing	RED	0	11746	0	51291	4511	32	53012	13	0	1
Park Street	RED	0	8237	0	45889	4232	32.4	77568	5	1	1
JFK/UMass	RED	0	7834	0	1732	1805	33.1	78231	5	4	0

Mattapan Line Data

Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Ashmont	MATTAPAN	1	6019	0	794	2825	37	66031	4	8	0
Capen Street	MATTAPAN	0	67	0	67	988	43.5	109629	2	14	0
Valley Road	MATTAPAN	0	48	0	97	1423	42.3	119684	3	13	0
Central	MATTAPAN	0	14531	0	5565	5879	30.3	81275	23	4	0
Milton	MATTAPAN	0	398	41	1167	1395	40.3	87341	3	11	0
Cedar Grove	MATTAPAN	0	82	0	1035	843	42.9	79495	0	9	0
Butler	MATTAPAN	0	139	40	836	1234	45.1	76200	1	10	0
Mattapan	MATTAPAN	1	3489	100	1432	1405	40.4	76139	3	15	0

Orange Line Data

Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Tufts Medical Center	ORANGE	0	5684	0	29502	8133	28.7	57240	24	2	1
Chinatown	ORANGE	0	5822	0	37864	7904	28	53283	6	1	1
Haymarket	ORANGE	0	6019	0	30750	4081	29.9	69781	15	2	1
North Station	ORANGE	0	8210	1275	11557	2498	29.6	67742	17	3	1
Oak Grove	ORANGE	1	5994	788	333	2325	37.1	64349	3	8	0
Malden Center	ORANGE	0	11258	188	2583	3698	33.3	64496	4	7	0
Wellington	ORANGE	0	7464	1316	1079	2189	33.2	89382	1	6	0
Sullivan Square	ORANGE	0	9004	222	3789	1084	32.5	82961	5	5	0
Community College	ORANGE	0	3695	0	3204	3741	35	117569	0	4	0
Forest Hills	ORANGE	1	13568	206	1376	1922	33.7	72581	2	10	0
Green Street	ORANGE	0	3229	0	1100	2811	34.8	77009	4	9	0
Stony Brook	ORANGE	0	3163	0	931	2933	33.3	75892	10	8	0
Jackson Square	ORANGE	0	4968	0	1616	4287	27.5	38481	4	7	0
Ruggles	ORANGE	0	8378	0	5990	6508	21.7	36948	4	5	0
Massachusetts Ave	ORANGE	0	5248	0	4496	9225	26.4	48299	16	4	0
Back Bay	ORANGE	0	16769	0	29767	5570	35.5	125875	17	3	0
Downtown Crossing	ORANGE	0	11563	0	51291	4511	32	53012	13	0	1
State	ORANGE	0	7323	0	83017	1951	32.9	108079	20	1	1
Roxbury Crossing	ORANGE	0	3693	0	2211	2654	24.8	47133	9	6	0

The Green Line

Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Waban	GREEN	0	427	74	525	574	47.5	201753	4	16	0
Kenmore	GREEN	0	8653	0	10531	5905	22.7	68244	12	5	0
Arlington	GREEN	0	8378	0	33226	3918	31	132281	9	2	0
Copley	GREEN	0	13500	0	29902	3469	34	145064	25	3	0
Boylston	GREEN	0	7618	0	30007	7058	27.5	55506	6	1	1
Haymarket	GREEN	0	5204	0	30750	4081	29.9	69781	15	2	1
North Station	GREEN	0	8491	1275	11557	2498	29.6	67742	17	3	1
Lechmere	GREEN	1	6645	347	4730	2308	31.9	87312	7	5	0
Science Park	GREEN	0	1179	0	1315	3583	34.7	110755	1	4	0
Government Center	GREEN	0	10072	0	73271	2423	31.1	110852	6	1	1
Prudential	GREEN	0	3732	0	24212	6582	32.5	113885	16	4	0
Symphony	GREEN	0	1993	0	6767	9661	25	77755	7	5	0
Northeastern	GREEN	0	3007	0	4243	9231	21.6	54907	5	6	0
Museum Of Fine Arts	GREEN	0	1676	0	2144	7095	21.3	39490	3	7	0
Longwood Medical Area	GREEN	0	3800	0	13985	6068	22.6	46197	3	8	0
Brigham Circle	GREEN	0	2535	0	13964	5303	24.7	50466	6	9	0
Fenwood Road	GREEN	0	343	0	11771	6513	26	46355	7	10	0
Mission Park	GREEN	0	462	0	3418	6130	29.5	44695	4	11	0
Riverway	GREEN	0	664	0	1988	7009	33.6	50719	1	12	0
Back Of The Hill	GREEN	0	86	0	2353	4430	32.4	58419	0	13	0
Heath Street	GREEN	1	622	0	1623	3214	29.8	48042	0	14	0
Hynes Convention Ctr/ICA	GREEN	0	9525	0	19237	9511	27.6	99025	21	4	0
Blandford Street	GREEN	0	2840	0	11412	6627	21	48211	5	6	0
Boston University East	GREEN	0	2892	0	8455	7088	21.1	49265	4	7	0
Boston University Central	GREEN	0	2524	0	1954	4918	21.6	80163	6	8	0
Boston University West	GREEN	0	899	0	342	681	30.9	136593	7	9	0
Saint Paul Street	GREEN	0	814	0	977	5584	21.3	72997	5	10	0
Pleasant Street	GREEN	0	1014	0	1153	6623	21.7	79087	4	11	0
Babcock Street	GREEN	0	1824	0	1597	6781	22	88330	4	12	0
Packards Corner	GREEN	0	1571	0	1799	6299	24.3	67038	9	13	0
Harvard Avenue	GREEN	0	4077	0	2106	7448	25.7	55245	5	14	0

The Green Line (continued)

Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Griggs Street	GREEN	0	1260	0	1505	8765	26.6	57469	5	15	0
Allston Street	GREEN	0	1115	0	1125	8427	26.9	56310	7	16	0
Warren Street	GREEN	0	1650	0	1285	6284	27.3	58395	4	17	0
Washington Street	GREEN	0	1723	0	1090	7010	28.1	54575		18	0
Sutherland Road	GREEN	0	923	0	449	7470	28.8	66166	3	19	0
Chiswick Road	GREEN	0	735	0	420	6894	29.2	61971	8	20	0
Chestnut Hill Avenue	GREEN	0	861	0	1646	4827	29	66496	7	21	0
South Street	GREEN	0	237	0	250	4272	27.5	77096	3	22	0
Boston College	GREEN	1	1042	0	171	3832	22.2	126858	1	23	0
Cleveland Circle	GREEN	1	1557	0	830	3845	28.9	91755	9	18	0
Englewood Avenue	GREEN	0	585	0	945	4867	29.3	98017	7	17	0
Dean Road	GREEN	0	316	0	737	4310	31.6	121249	12	16	0
Tappan Street	GREEN	0	837	0	1070	4160	32.7	132332	7	15	0
Washington Square	GREEN	0	1217	0	1034	3723	32.6	122921	5	14	0
Fairbanks Street	GREEN	0	585	0	712	4927	32.9	112234	3	13	0
Brandon Hall	GREEN	0	316	0	728	5494	33.4	110238	3	12	0
Summit Ave/Winchester St	GREEN	0	1175	0	3230	6529	34.7	107948	3	11	0
Coolidge Corner	GREEN	0	4150	0	5304	5466	35	115208	3	10	0
Saint Paul Street	GREEN	0	935	0	4077	5761	33.9	127454	11	9	0
Kent Street	GREEN	0	510	0	1390	4279	33.6	130688	6	8	0
Hawes Street	GREEN	0	426	0	1568	2837	32.1	120513	7	7	0
Saint Marys Street	GREEN	0	1970	0	2313	5377	24	83271	13	6	0
Fenway Park	GREEN	0	3041	0	3785	7395	23.4	56150	10	6	0
Longwood	GREEN	0	2749	0	4440	1189	33.1	122542	6	7	0
Brookline Village	GREEN	0	3512	0	3314	4369	35.8	89308	5	8	0
Brookline Hills	GREEN	0	1654	0	1149	2380	34.1	139006	10	9	0
Beaconsfield	GREEN	0	896	0	558	2796	34	142390	6	10	0
Reservoir	GREEN	0	3395	0	837	2814	29.2	108989	13	11	0
Chestnut Hill	GREEN	0	778	70	909	386	22.9	206045	1	12	0
Newton Centre	GREEN	0	1487	0	2066	1148	43.6	150260	3	13	0
Newton Highlands	GREEN	0	1052	0	604	1198	41.6	142630	3	14	0
Eliot	GREEN	0	595	55	84	1304	42.9	167172	4	15	0
Woodland	GREEN	0	1044	548	2430	266	44.7	218110	0	17	0
Riverside	GREEN	1	2158	925	383	599	25	168499	0	18	0
Park Street	GREEN	0	11169	0	45889	4232	32.4	77568	5	0	1

The Silver Line

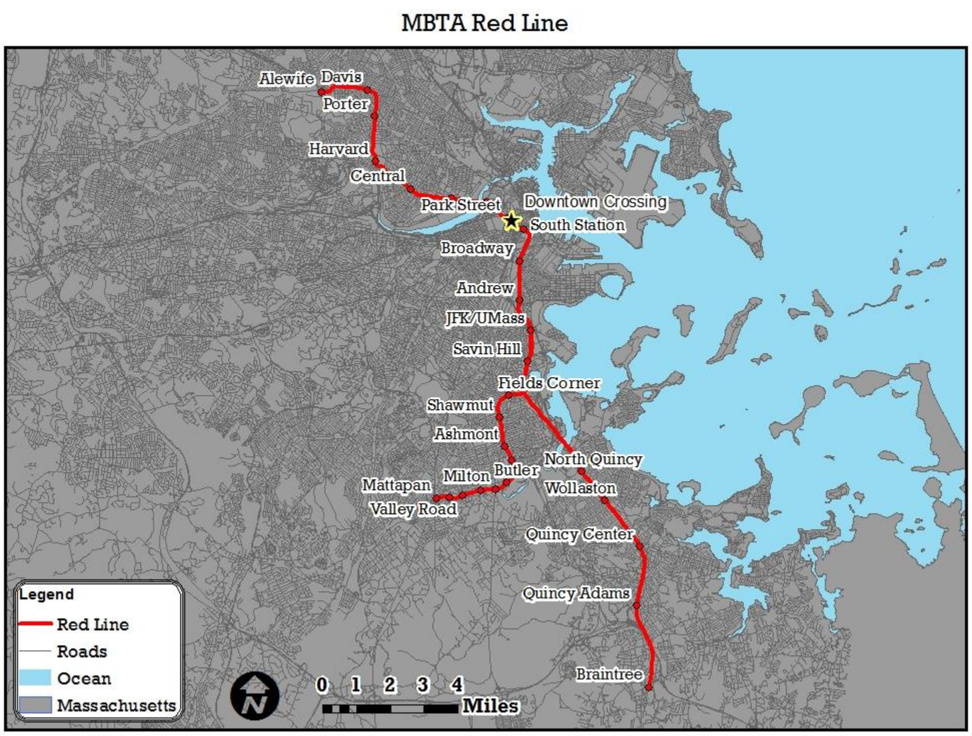
Station	Line	Terminus	Riders	Parking Spaces	Job Density	Population Density	Age	Income	4-way	CBD	Transfer
Airport Terminal B2	SILVER	0	442	0	1161	0			0	7	0
Dry Dock Ave at Design Ctr Pl,	SILVER	0	25	0	4173	207			2	9	0
Lenox Street	SILVER	0	414	0	3297	6924	32.1	60794	17	9	0
Massachusetts Ave	SILVER	0	546	0	6961	8381	33.1	69637	26	8	0
Newton Street	SILVER	0	1334	0	9997	8019	34.9	74446	23	6	0
Union Park Street	SILVER	0	1163	0	5450	7389	37	98867	12	5	0
E.Berkeley Street	SILVER	0	904	0	4198	5229	40.2	92494	10	4	0
Herald Street	SILVER	0	216	0	7972	5837	36.6	72072	15	3	0
Worcester Square	SILVER	0	618	0	7970	8514	33.6	72315	28	7	0
Melnea Cass Blvd	SILVER	0	324	0	1927	3017	31.4	39507	12	10	0
Tuffs Medical Center	SILVER	0	5684	0	17580	7710	29.8	63691	23	2	1
Northern Avenue at Tide Street	SILVER	0	278	0	3819	207	24.4		2	6	0
Northern Avenue at Harbor Street	SILVER	0	278	0	2300	704	32	78719	3	5	0
Airport Terminal B1	SILVER	0	454	0	1161	0			1	6	0
Airport Terminal A	SILVER	0	588	0	523	0			0	5	0
Airport Terminal C	SILVER	0	789	0	0	0			0	8	0
Airport Terminal E	SILVER	1	353	0	116	0			0	9	0
Silver Line Way	SILVER	0	253	0	6302	704	32	78719	6	3	0
World Trade Center	SILVER	0	610	0	8044	702	32.1	78722	11	2	0
Court House	SILVER	0	240	0	10516	590	33.7	100407	5	1	0
South Station	SILVER	0	2664	0	33788	963	37.1	140347	12	0	1
88 Black Falcon	SILVER	0	75	0	3130	207	24.4		2	9	0
21 Dry Dock Avenue	SILVER	0	7	0	2989	207	24.2		1	7	0
25 Dry Dock Avenue	SILVER	0	106	0	3130	207	24.2		2	8	0
Black Falcon at Design Center	SILVER	0	79	0	4193	207	24.2		1	10	0
Boylston	SILVER	0	7618	0	36636	7014	27.5	58278	9	1	1
Downtown Crossing	SILVER	0	2590	0	66705	5576	31.8	67644	13	0	1
Chinatown	SILVER	0	5822	0	37592	7399	27.7	50120	8	1	1
Dudley Square	SILVER	1	3585	0	2535	2033	33.8	36972	12	11	0
South Station Essex St.	SILVER	0	1069	226	39161	963	37.1	140347	17	1	1
306 Northern Avenue	SILVER	0	48	0	2300	704	32	78719	4	4	0

APPENDIX II

The Red Line

The Red Line runs from the northwest to the southeast of central Boston, with the furthest northwest station terminating at Alewife and the southeastern most station being terminating at Braintree station. The Red Line bisects downtown with three major transfer points at Government Center, where riders can transfer to or from the Green Line, Downtown Crossing, which connects to the Orange Line, and South Station, where passengers can board the bus rapid transit on the Silver Line.

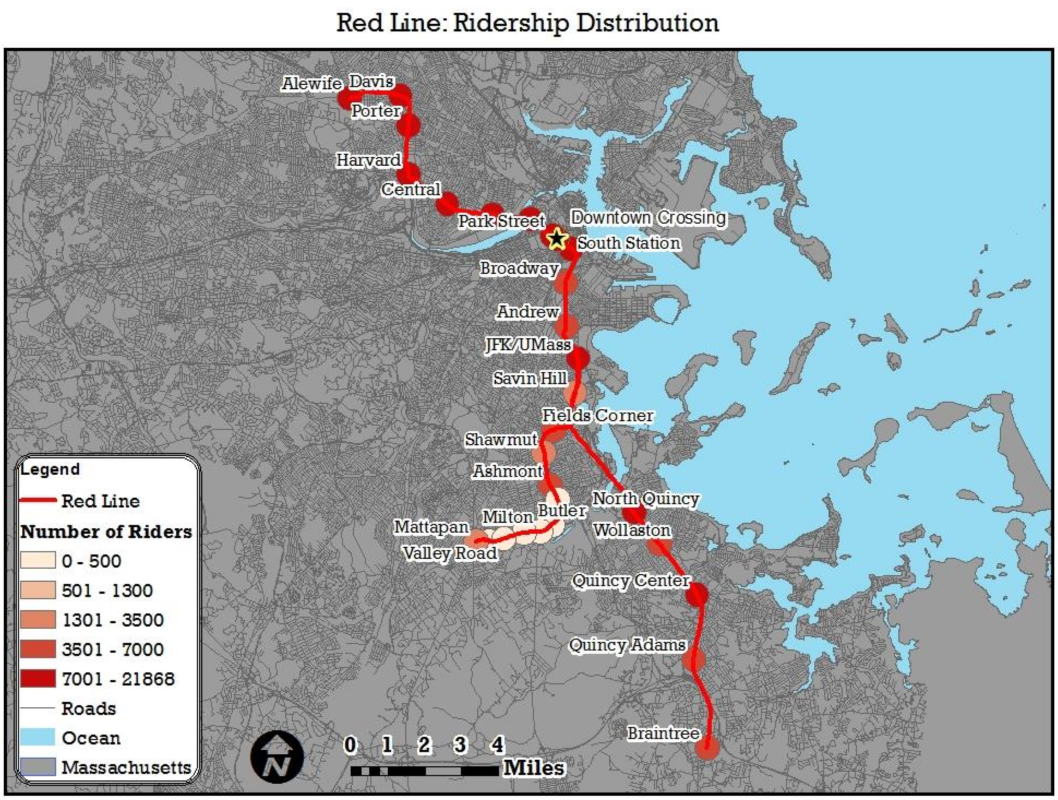
Figure 45: The MBTA Red Line



There are a total of twenty-nine stations located along the Red Line; of these, twenty-one are rapid transit subway stations and eight are Mattapan Trolley stops. Ridership data from the *2010 Bluebook* shows that, including the trolley, the Red Line transports approximately 197,099 riders on an average weekday, with the Harvard T-station serving the largest number of patrons with an average daily ridership of 21,868 people (Massachusetts Bay Transportation Authority, 2010). The Mattapan Trolley initiates at the Ashmont T-station, where the Red Line subway terminates and the trolley begins. In 2009, the Mattapan Line served approximately 4,586 riders on a typical weekday, with the majority of the riders boarding at either the Ashmont Station (1,985 riders) the beginning of the line, or at the Mattapan Station (1,504 riders) which is where the trolley line terminates (Central Transportation Planning Staff, 2009). (Massachusetts Bay Transportation Authority, 2010). To help planners and researchers better understand the ridership patterns on the Red Line, the MBTA divides the Red Line into five segments (northern segment, central segment, Dorchester branch, South Shore branch, and Mattapan High-Speed Line).

As shown by the ridership numbers described above, the Red Line serves a number of important areas in the Massachusetts Bay, including Harvard University, Massachusetts Institute of Technology (MIT), South Station (a major transportation hub), the University of Massachusetts at Boston, and the John F. Kennedy Library. Due to the higher concentration of jobs near these areas as shown in Figure 48 it is no surprise that the majority of the Red Line's trips were "home-based work" trips. The 2009 Systemwide On Board Travel Survey found that sixty-seven percent of Red Line trips were "home-based work". Forty percent of the riders using the Red Line had destinations within Boston proper; of these, fifteen percent were traveling to the Financial/Retail District. The majority of destinations outside Boston proper were at the Kendall/MIT T-station (fourteen percent) and Harvard T-station (ten percent) (Central Transportation Planning Staff, 2009).

Figure 46: Red Line Ridership Distribution



The CTPS Onboard Survey also examined the reasons why people chose to ride the Red Line and sixty-six percent of those surveyed cited "convenience" while sixty-four percent said it was to avoid driving/traffic. Fifty-seven percent of respondents said they used the Red Line to "avoid parking at destination."

As of 2012 there are 8,774 parking spaces available at T-station stops on the Red Line. The largest numbers of parking spaces are found at the Alewife T-station and on the South Shore Branch of the line at Quincy Adams, Braintree, and North Quincy stations. Alewife and Quincy Adams boast the highest number of parking spaces on the entire rapid transit system.

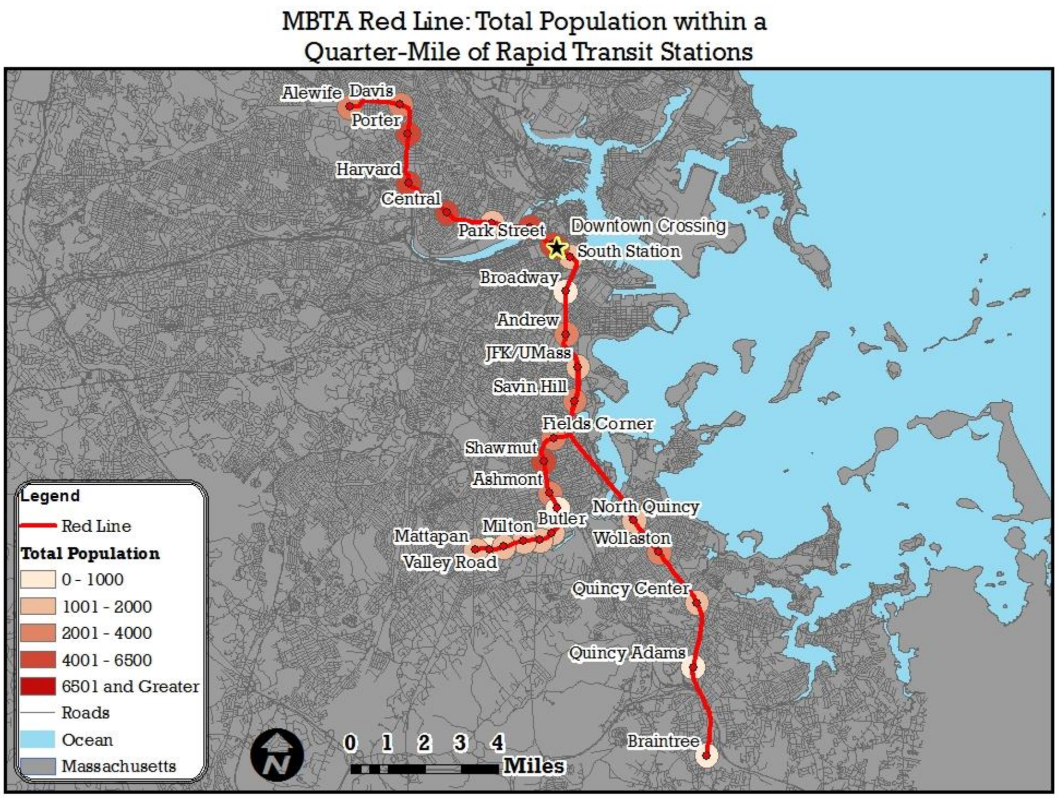
Table 42: The Red Line Parking Spaces

Red Line Parking Spaces	
Butler	40
Alewife	2733
Milton	41
Savin Hill	18
Braintree	1322
Quincy Adams	2538
Wollaston	550
North Quincy	1206
Mattapan	100
South Station	226
Total Spaces	**8774**

Source: The MBTA

According to the United States 2010 Census 72,933 people in 31,862 households live within a quarter-mile of T-stations on the Red Line. Central Station boasts the largest number of nearby residents and Charles/MGH boasts the second largest number of residents living within a quarter-mile radius of each T-station with 5,879 and 5,411 respectively.

Figure 47: MBTA Red Line: Population Density



The average median income along the Red Line is $84,994.00 according to the American Community Survey 2005-2009. South Station, Charles/MGH, and Valley Road boast the highest income levels while Alewife, Fields Corner, and Andrew T-station contain the residents with lower incomes on average within a quarter-mile radius. However, this data might be slightly skewed because it does not account for population density within this area, only total average earnings. South Station has far fewer residents within a quarter-mile radius than Alewife.

According to the CTPS Travel Survey sixty-three percent of the riders on the Red Line reported incomes of $60,000 or more. Thirty-four percent of those respondents claimed their household income was $100,000 or more. However, this number is most likely inaccurate to some degree due to the sensitivity of asking survey respondents about income. The MBTA staff note that many participants left this question unanswered either intentionally or unintentionally. The 2005-2009 American Community Survey from the U.S. Census shows that only twenty percent of people living within a quarter-mile of stations on the Red Line have a median income of $100,000 or more, however this information reflects the entire population, not just transit rider.

The average age of residents living near the Red Line is 35.7 years of age according to the 2010 U.S. Census. The average age varies greatly across the board with the lower average ages located near the major universities and downtown with higher average ages located on the periphery of the system, especially near the Mattapan Trolley line. However, the CPTS Travel Survey demonstrates that a large portion of the people utilizing the stations near major universities reported they were between 25-34 years of age.

Four-way intersections in the quarter-mile radius around each station to determine the walkability of an area around each transit station. The Red Line stations near downtown have a higher number of four-way intersections than the rest of the line and stations serving areas with high student populations also have a high number of four-way intersections.

Red Line Top Ten Stations with High Number of 4-Way Intersections	
Station	***4-Way Intersections***
Central	23
Charles/MGH	17
South Station	17
Wollaston	16
Harvard	14
Downtown Crossing	13
Davis	12
Broadway	10
Andrew	8
Savin Hill	7

Source: Author

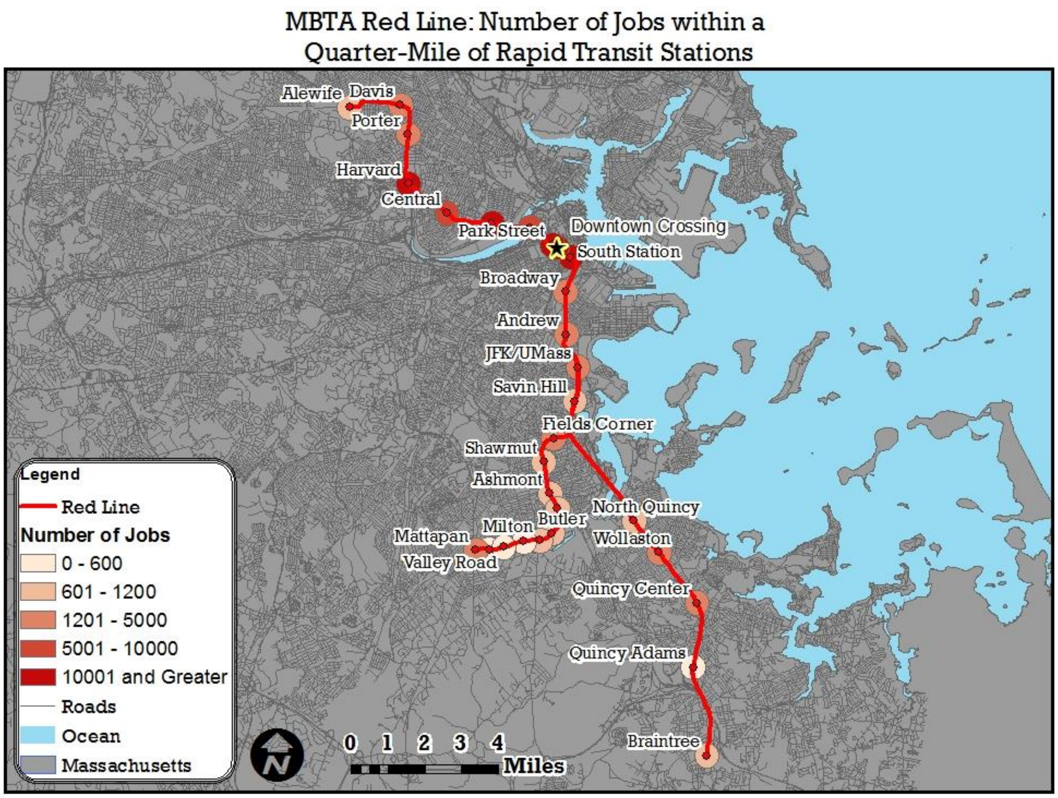
The number of four-way intersections also directly relates to the number of jobs located nearby, as shown in the correlation table on page 97. There are 214,439 jobs located within a quarter-mile around Red Line transit stations. Of these, the stations located near the CBD boast the highest number of jobs, followed by Kendall/MIT and Harvard, which are some of the region's largest employers.

Table 43: Red Line Job Concentration

Red Line Job Concentration	
Station	***Jobs***
Downtown Crossing	51,291
Park Street	45,889
South Station	37,457
Kendall/MIT	18,987
Harvard	15,590

Source: ESRI Business Analyst Online

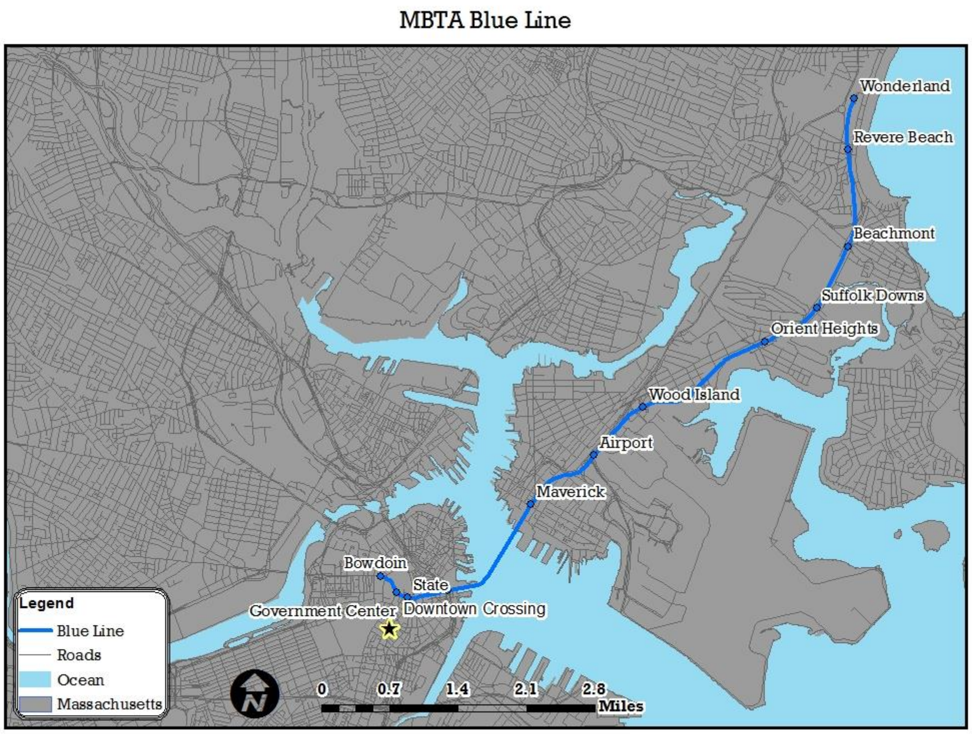
Figure 48: MBTA Red Line Job Density



The Blue Line

The Blue Line serves the northeastern portion of the Massachusetts Bay area. It originates at the Bowdoin T-station and serves the CBD, then veers to the northeast and travels through East Boston and Orient Heights, with a stop at Logan Airport, terminating on Ocean Avenue at the Wonderland T-station. There are two transfer points on the Blue Line, both located near the CBD at Park Street T-station, with connections to the Green Line, and State T-station with transfers to the Orange Line.

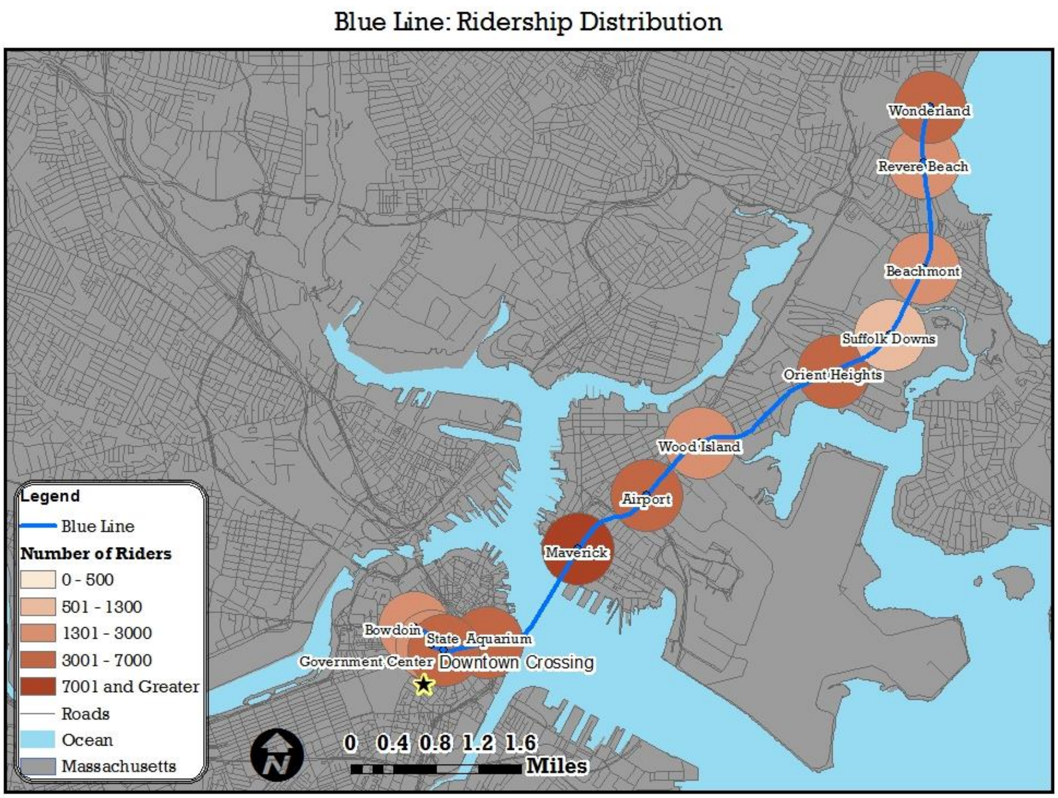
Figure 49: The MBTA Blue Line



The Blue Line consists of twelve stations, all rapid transit subway stations. The *2010 Bluebook* indicates a total of 44,233 average weekday riders. The largest numbers of riders originate at the Maverick T-station with 8,134 riders, followed by the Airport T-station and the Wonderland T-station with 6,901 and 5,520 riders respectfully (Central Transportation Planning Staff, 2009). Both the Maverick T-station and Airport T-station are near Boston's Logan airport and are located adjacent to airport shuttles, which help account for the high rider data for these stations. The Wonderland T-station receives the third highest number of riders most likely because it is located at the route terminus where there is a large number of parking spaces. In fact, the Wonderland T-station has sixty-five percent of the Blue Line's available parking and ranks third system-wide with a total of 1,862 parking spots.

As noted above, the Blue Line serves the CBD, Logan Airport, and residential districts located in the northeastern portion of Massachusetts Bay. According to the CTPS Onboard Rider Survey from 2009, almost ninety percent of trips were "home-based", meaning that most trips originated from the home. Of these "home-based" trips, seventy-two percent of the trips on the Blue Line were "home-based work trips". The report also shows that eight percent of all trips were "work-based" trips, meaning the trips originated at work. This eight percent could account for people using transit for work errands or lunch breaks. This means that almost eighty-two percent of trips pertain to work related activities as one trip end (Central Transportation Planning Staff, 2009).

Figure 50: Blue Line Ridership Distribution



The CTPS Onboard Survey also examined the reasons why people chose to ride the Blue Line. Sixty-two percent of those surveyed cited “convenience” while fifty-three percent said it was to avoid driving/traffic and fifty-two percent of people said they chose transit because of parking cost and availability at trip end. Only twenty-four percent of riders named “only transportation available” as the reason they rode transit, which was also the least common reason cited.

The Blue Line has only fifteen percent of the system-wide parking with the majority located at the Wonderland T-station as previously mentioned. The only other stations on the Blue Line with parking available are Suffolk Downs, Beachmont, and Orient Heights for a total of 2,836 spaces.

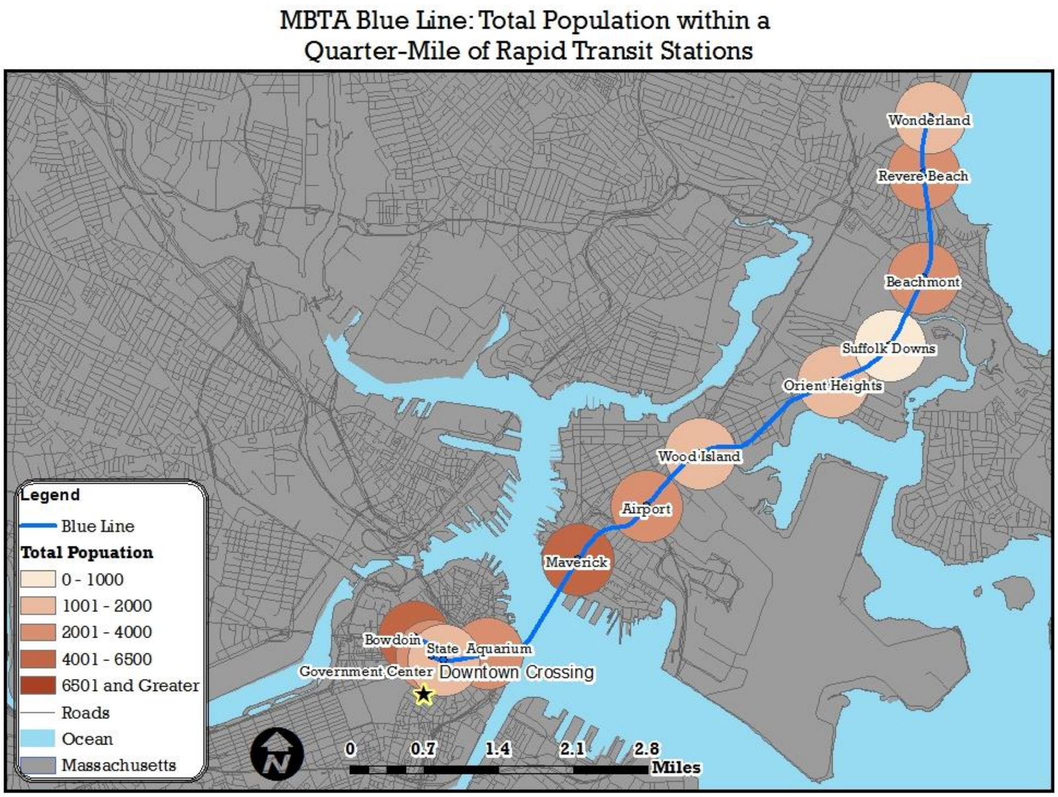
Table 44: Blue Line Parking Spaces

Blue Line Parking Spaces	
Suffolk Downs	110
Wonderland	1862
Beachmont	430
Orient Heights	434
Total Spaces	**2836**

Source: The MBTA

According to the United States 2010 Census 31,922 people in 14,132 households live within a quarter-mile of T-stations on the Blue Line. T-station boasts the largest number of nearby residents and Airport T-station boasts the second largest number of residents living within a quarter-mile radius of each T-station, with 5,239 and 2,748 people respectively.

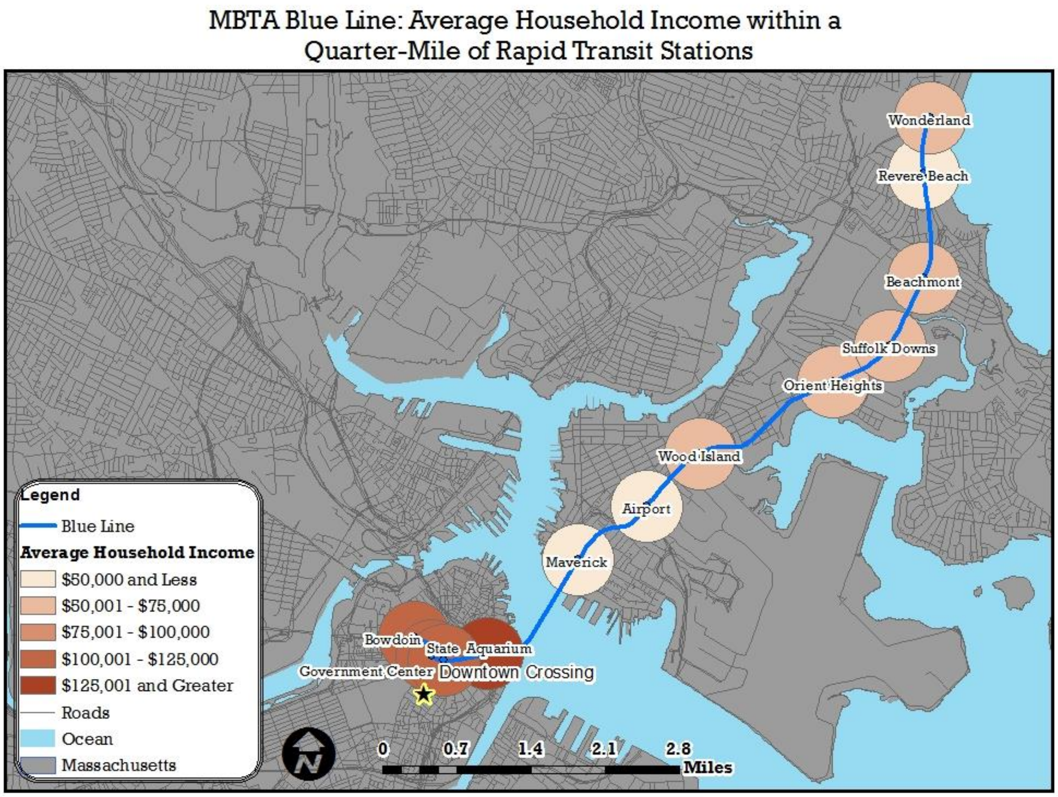
Figure 51: The MBTA Blue Line Population Density



The average median income along the Blue Line is $75,125.00 according to the American Community Survey 2005-2009. Aquarium, Government, and State boast the highest income levels while the Maverick, Revere Beach, and Airport T-stations contain the residents with lower incomes on average within a quarter-mile radius. This data seems relatively accurate since it is generally more expensive to live in the CBD and less expensive to live in a first or second ring suburb, including areas surrounding airports due to heavy noise and air pollution.

According to the CTPS Travel Survey over half of Blue Line respondents reported incomes of $60,000 or more, this number seems to be accurately represented with the 2005-2009 American Community Survey income collected within a quarter-mile of each station shows that fifty-two percent earn greater than $60,000 annually. CTPS staff reports that the most common income variable checked on the survey was $100,000 or greater (Central Transportation Planning Staff, 2009). As with the Red Line, they note that many participants may have inflated their income for this survey as 2005-2009 American Community Survey from the U.S. Census shows that twenty-eight percent of people living within a quarter-mile of stations of the Blue Line have a median income of $100,000 or more.

Figure 52: The MBTA Blue Line Average Median Income



The average age of residents living near the Blue Line is 35.15 years of age according to the 2010 U.S. Census. There is an approximate twenty-year median age gap between stations on the Blue Line. The median age around Aquarium T-station is 48.4 years of age, while the youngest median age at 30.2 years old is near the Bowdoin T-station. The CTPS Onboard Rider Survey states that over eighty percent of Blue Line riders are between 25 and 64 years of age, nine percent are between the ages of 19 to 24, or college age, and eight percent are 65 years or older.

The Blue Line stations near downtown such as the State T-station have a higher number of four-way intersections.

Table 45: Blue Line Stations with High Number of 4-way Intersections

Blue Line Top Ten Stations with High Number of 4-Way Intersections	
Station	***4-Way Intersections***
State	20
Aquarium	14
Maverick	13
Orient Heights	7
Bowdoin	7
Wood Island	6
Revere Beach	6
Government	6
Airport	4
Beachmont	3

Source: Author

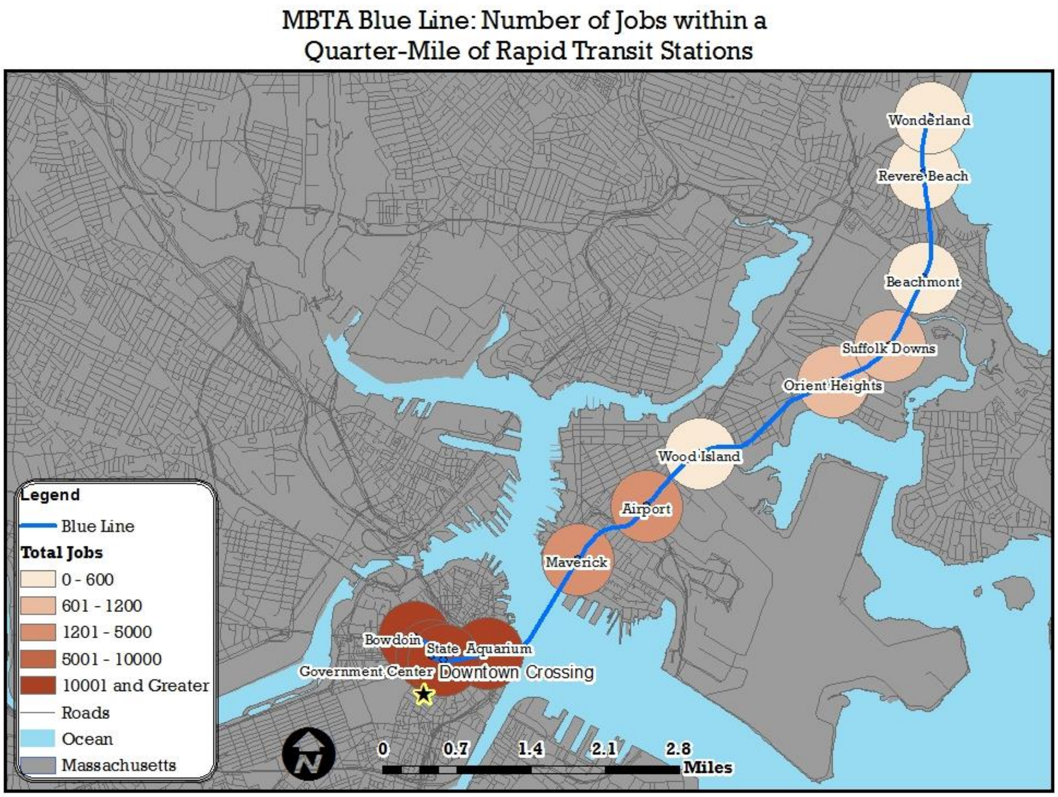
There are 232,793 jobs located a quarter-mile around Blue Line transit stations. Of these, the stations located near the CBD boast the highest number of jobs, and include State, Government, Bowdoin, and Aquarium.

Table 46: Blue Line Job Density

Blue Line Job Density	
Station	***Jobs***
State	83,017
Government	73,271
Bowdoin	34,301
Aquarium	34,189
Airport	3,210

Source: ESRI Business Analyst Online

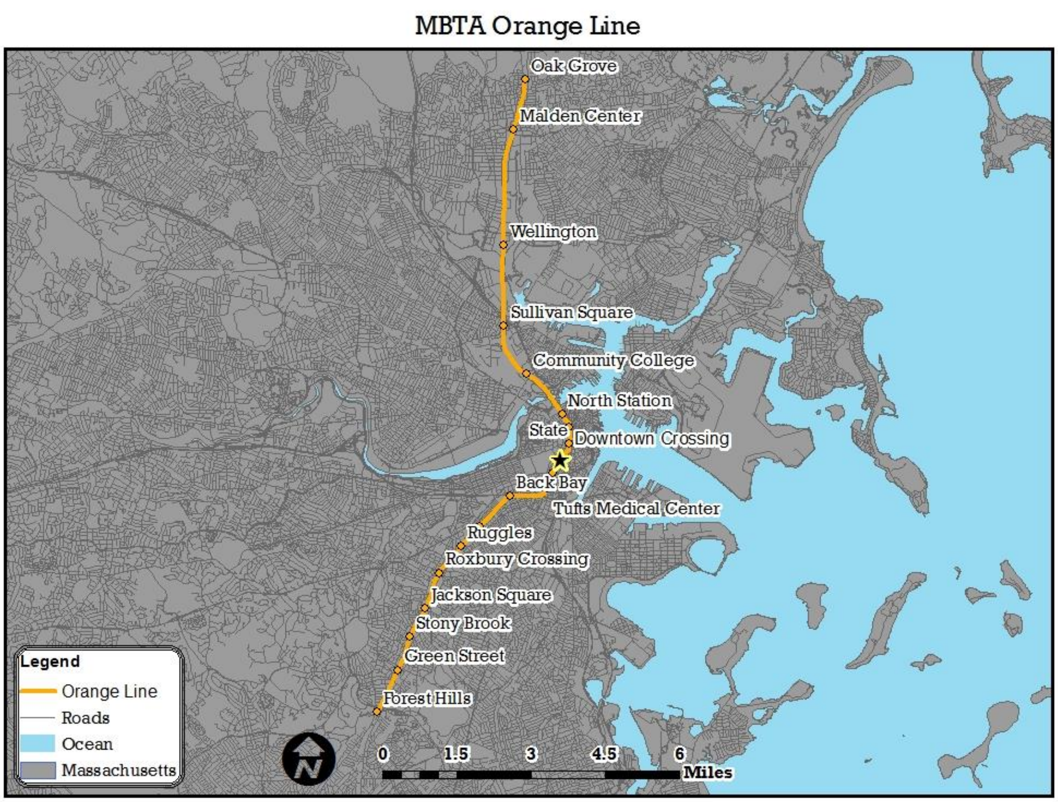
Figure 53: The MBTA Blue Line Job Density



The Orange Line

The Orange Line originates in the north at the Oak Grove T-station, primarily a park and ride located near residential communities, travels south toward downtown where there are six transfer points to other rapid transit lines, and then cuts through the southwestern portion of the Massachusetts Bay, terminating at the Forest Hills T-station in the southern section of the Jamaica Plain neighborhood. The Forest Hills T-station is also primarily a park and ride and a major bus transfer station with connections to fourteen routes.

Figure 54: The MBTA Orange Line

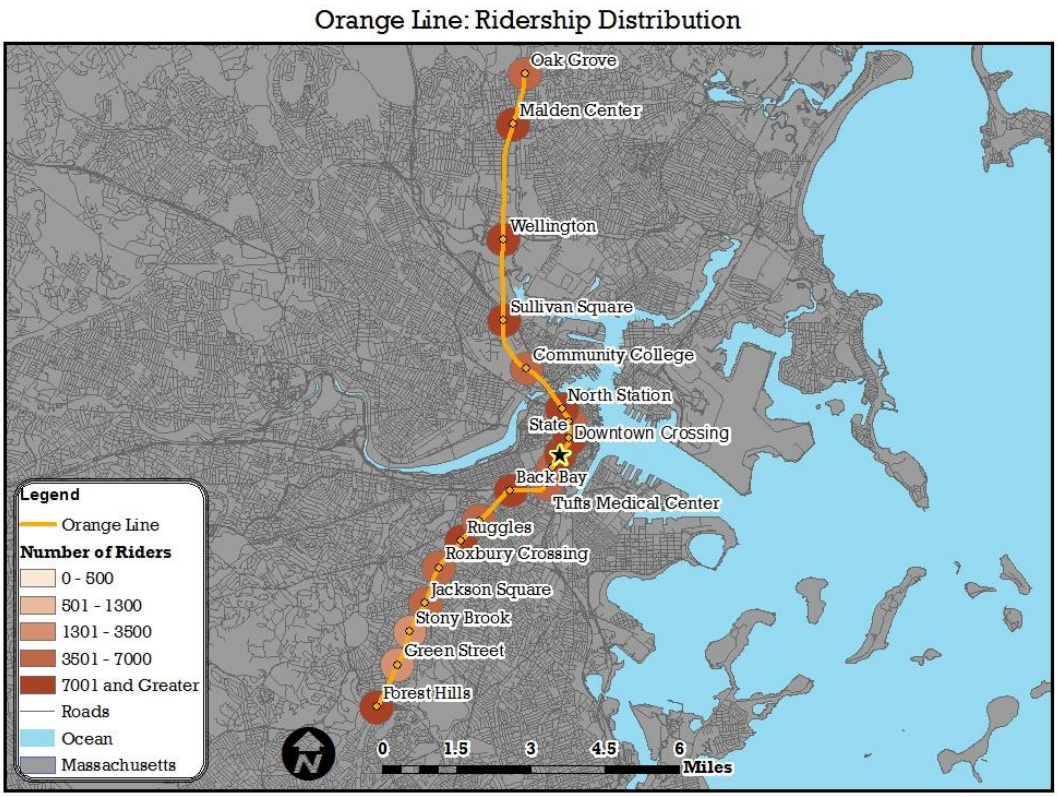


The Orange Line has a total of nineteen rapid transit T-stations and carries approximately 141,052 riders on a typical weekday. The Back Bay T-station provides access to the highest number of riders (16,769) daily on the Orange Line; this station is served by numerous transit providers other than the MBTA, including Northeast Corridor and Amtrak which provide regional and nationwide train service. The Orange Line actually has several stations that provide daily access to over 10,000 riders. Other than the Back Bay T-station the busiest stations are Forest Hills T-station with 14,568 riders, Downtown Crossing T-station with 11,563 riders, and the Malden Center T-station that serves 11,285 riders daily (Massachusetts Bay Transportation Authority, 2010). With six transfer stations and numerous bus access points, as well as regional train access, the high ridership on the Orange Line can partially be attributed to its high degree of connectivity. Parking may also play a role in the high number of riders utilizing the Orange Line from the north, since ninety-five percent of the line's parking spaces are located north of the CBD.

Outside of the CBD there are few major developments served by the Orange Line, unlike the Red and Blue Lines. The largest single development serving the Orange Line is Tufts Medical Center, which is still located within the Boston city limits. The majority of the Orange Line's ridership comes from residential neighborhoods using park and rides and the Orange Line at trip origin rather than gaining access from transfer points. According to the CTPS Onboard Travel Survey eighty-four percent of riders on the north side of the Orange Line entered the rapid transit system on the Orange Line, the majority (sixty-five percent) gaining access from Oak Grove or Community College. Survey data also shows that eighty-eight percent of riders exiting the Orange Line on the south side also entered the Orange Line at trip origin (Central Transportation Planning Staff, 2009). For those passengers who did transfer to or from other lines, the majority transferred to the Red Line, including ten percent from the north and seven percent from the south (Central Transportation Planning Staff, 2009). The type of trip on the Orange Line varied across the board. The four stations furthest north reported ninety- to ninety-seven percent of trips were "home-based" trips, but only fifty-five percent of trips originating at "Community College" were "home-based". Home-based means a trip either begins or ends at the user's home. The north side of the Orange Line also had a high percentage of respondents citing "school" as their trip end according to the Onboard Survey.

Transit staff also had hoped to better understand the reasons why people chose the Orange Line over other modes and found that sixty-six percent of Orange Line riders choose rapid transit due to "convenience" while fifty-nine cited "avoid driving/traffic and fifty-two said it was to "avoid parking at destination". The least cited reason, at twenty-three percent, said they used the Orange Line because it was the "only transportation available" (Central Transportation Planning Staff, 2009).

Figure 55: The MBTA Orange Line Ridership Distribution



Despite the fact that the Orange Line serves a large residential population and has many transfer stations, the line only has a total of 3,995 parking spaces. This accounts for only fourteen percent of the total parking on the entire MBTA rapid transit system. The majority of these spaces are located at the Wellington T-station and North Station. Thirteen Orange Line stations have no parking whatsoever since many are located downtown where parking space is less necessary. Moreover, only one station on the southern half of the Orange Line has parking, Forest Hills, with less than five percent of the line's total parking spaces.

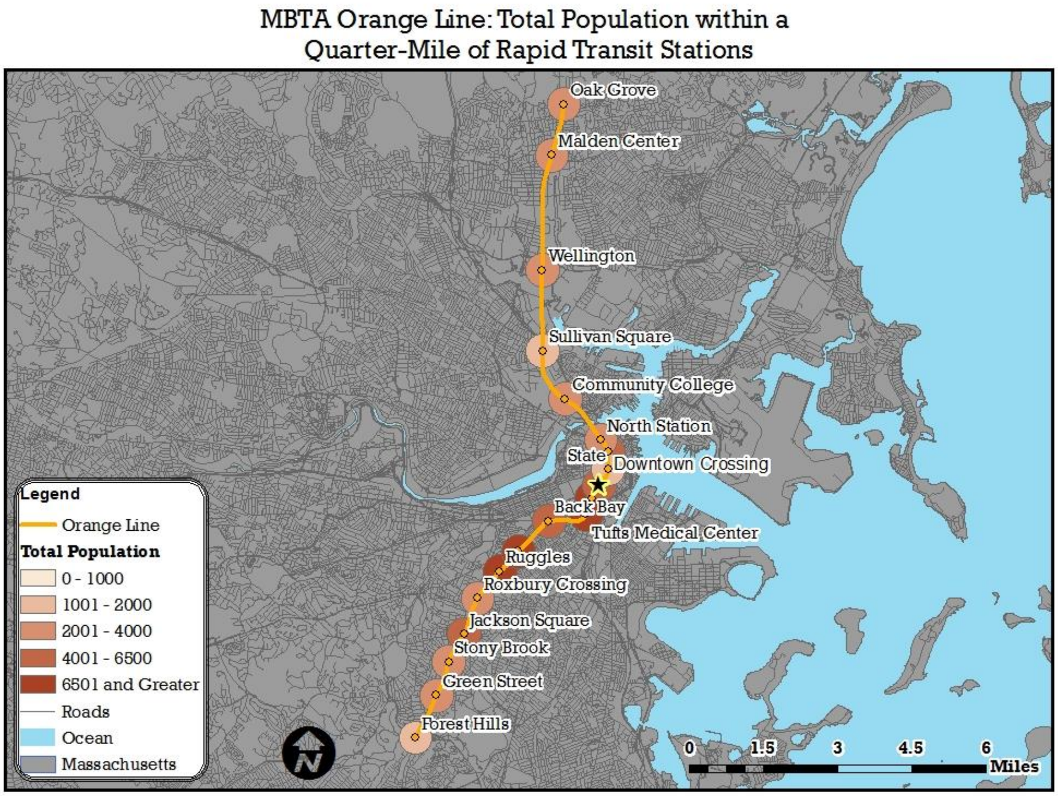
Table 47: The Orange Line Parking Spaces

Orange Line Parking Spaces	
Wellington	1,216
North Station	1,275
Oak Grove	788
Sullivan Square	222
Forest Hills	206
Malden Center	188
Total Spaces	**3,995**

Source: The MBTA

According to the United States 2010 Census, 78,025 people in 33,259 households live within a quarter-mile of T-stations on the Orange Line. Massachusetts Ave Station boasts the largest number of nearby residents and Tufts Medical Center T-Station boasts the second largest number of residents living within a quarter-mile radius of each T-station, with 9,225 and 8,133 respectively. The Orange Line serves a relatively high population around each station, with the least dense area containing 1,084 residents in 532 households (2010 United States Census Bureau).

Figure 56: The MBTA Orange Line Population Density



The average median income along the Orange Line is $67,742.00 according to the American Community Survey 2005-2009. Back Bay, Community College, and State boast the highest income levels while Roxbury Crossing, Jackson Square, and Ruggles contain the residents with lower incomes on average within a quarter-mile radius. According to the CTPS Travel Survey fifty-eight percent of people on the Orange Line reported incomes of $60,000 with twenty-nine percent of respondents citing incomes greater than $100,000 annually. According to the 2005-2009 American Community Survey from the U.S. Census Bureau, approximately sixty-eight percent of residents living within a quarter-mile radius from Orange Line T-stations earn over $60,000 annually, while twenty percent of residents earn over $100,000 annually. The income data for residents probably does not accurately represent the income data of riders and a transit station outside of the city proper most likely has a capture radius greater than a quarter-mile; however the data reported by both sources fall into somewhat similar ranges.

The average age of residents living near the Orange Line is 32.5 years of age according to the 2010 U.S. Census. The average age varies greatly across the board with the lower average ages located near the CBD and on the south side of the Orange Line. The CPTS Onboard Survey found that thirty-five percent of Orange Line respondents were between the ages of 45 and 64. When divided into north and south sections, eighty-five percent of north side respondents and eighty percent of south side respondents were between the ages of 25 to 64 years of age,

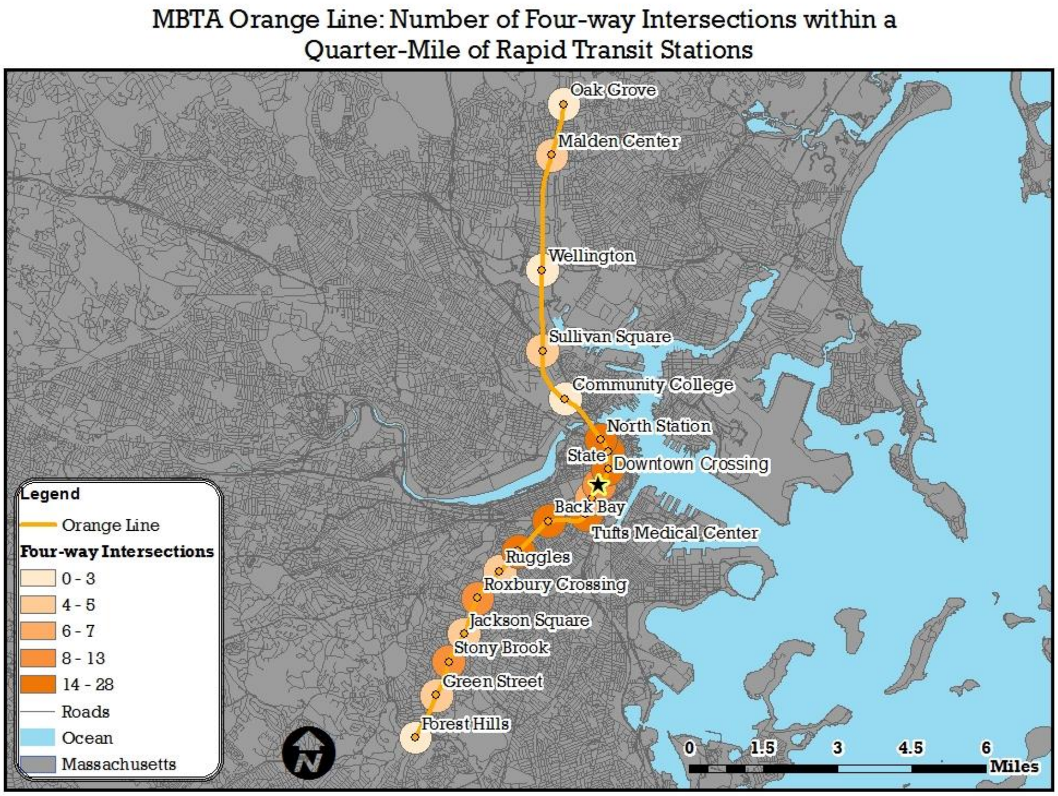
The Orange Line has a significant number of stations with low numbers of four-way intersections, and the stations with the highest number of four-way intersections are located in or in close proximity to the CBD.

Table 48: The MBTA Orange Line Top Ten Stations with 4-way Intersections

Orange Line Top Ten Stations with High Number of 4-Way Intersections	
Station	***4-Way Intersections***
Tufts Medical Center	24
State	20
Back Bay	17
North Station	17
Massachusetts Ave	16
Haymarket	15
Downtown Crossing	13
Stony Brook	10
Roxbury Crossing	9
Chinatown	6

Source: Author

Figure 57: The MBTA Orange Line Number of Four-way Intersections



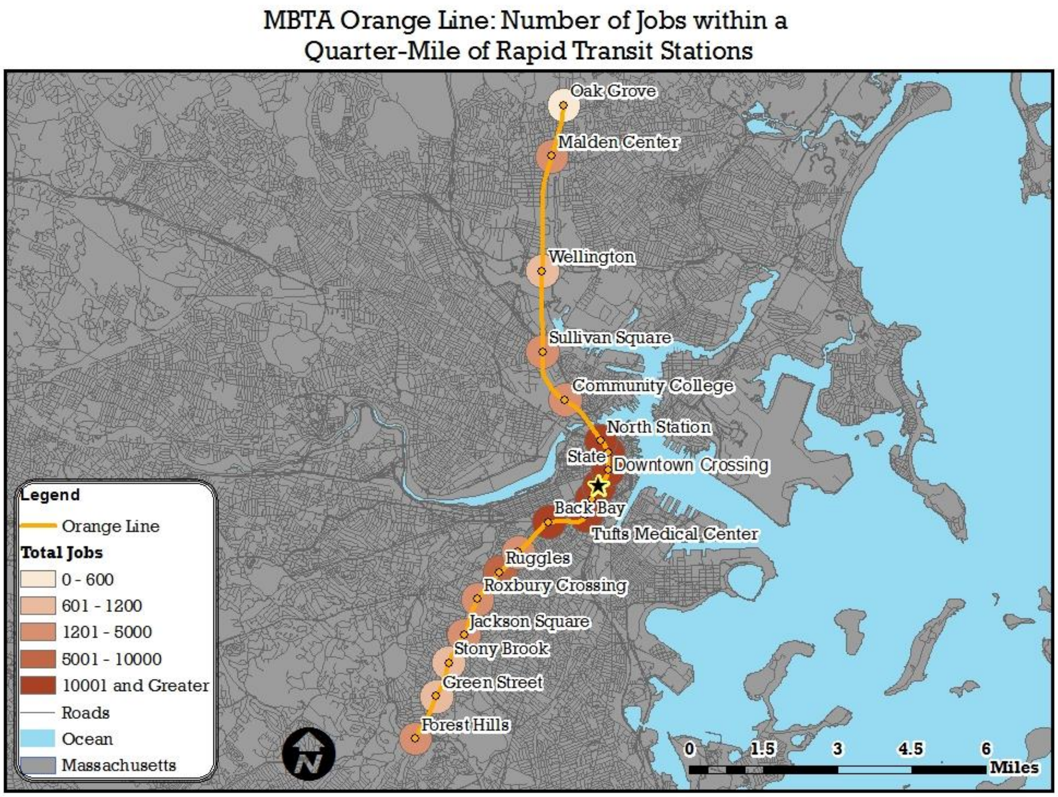
In older, gridded cities the number of four-way intersections generally relates to the number of jobs since most older CBDs were constructed using a gridded street pattern. On the Orange Line there are 302,456 jobs located within a quarter-mile around transit stations (ESRI Business Analyst). The majority of jobs are located in the CBD and in Boston Proper, with an average of 39,106 jobs located around Orange Line stations, while the average number of jobs around suburban Orange Line stops is only 2,609 (ESRI Business Analyst).

Table 49: The MBTA Orange Line Job Density

Orange Line Job Density	
Station	***Jobs***
State	83,017
Downtown Crossing	51,291
Chinatown	37,864
Haymarket	30750
Back Bay	29,767
Tufts Medical Center	19,502
North Station	11,557

Source: ESRI Business Analyst Online

Figure 58: The MBTA Orange Line Job Density

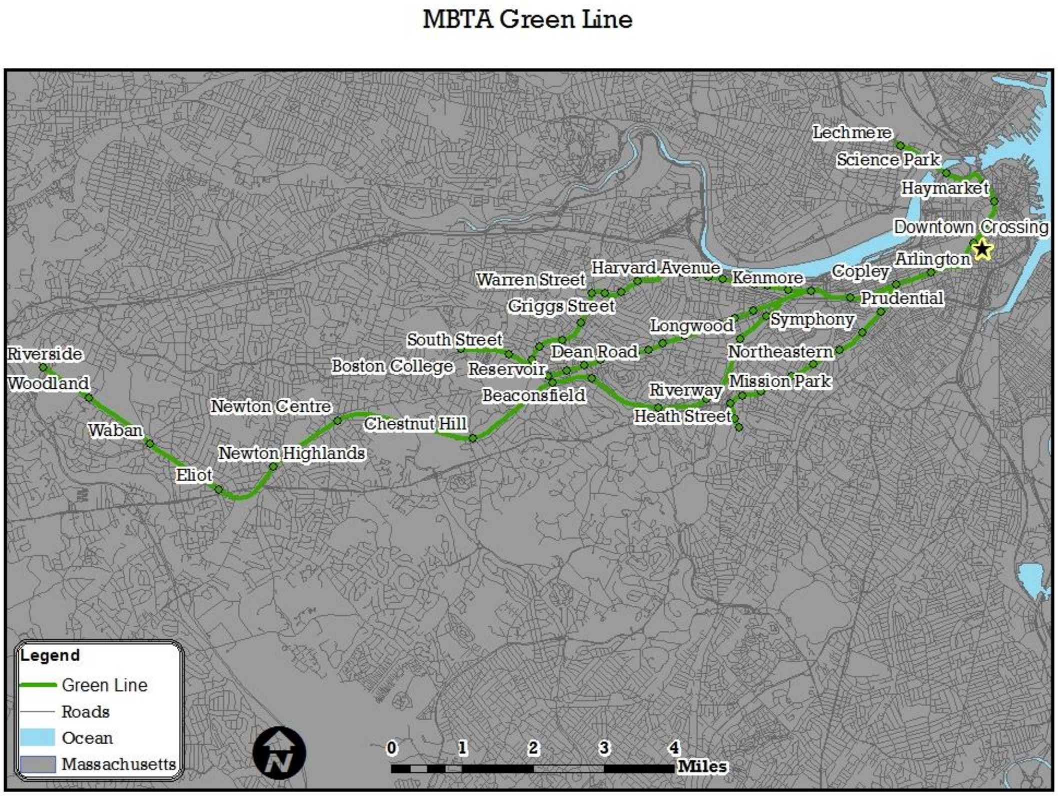


The Green Line

The Green Line is the longest rapid transit line in the MBTA service area and is a light rail system. It initiates northwest of the CBD in the East Cambridge neighborhood at the Lechmere Station and travels underground into the CBD going south. In downtown Boston, the Green Line veers west and divides into four separate branches serving the western portions of the Massachusetts Bay region, The "D Branch" reaches the furthest west boundary of the Brighton Neighborhood at Riverside Station. The Green Line "B Branch" terminates at the Boston College

Station, "Branch C" terminates at Cleveland Circle, and "Branch E" ends at Heath Station near the Longwood Medical Center.

Figure 59: The MBTA Green Line



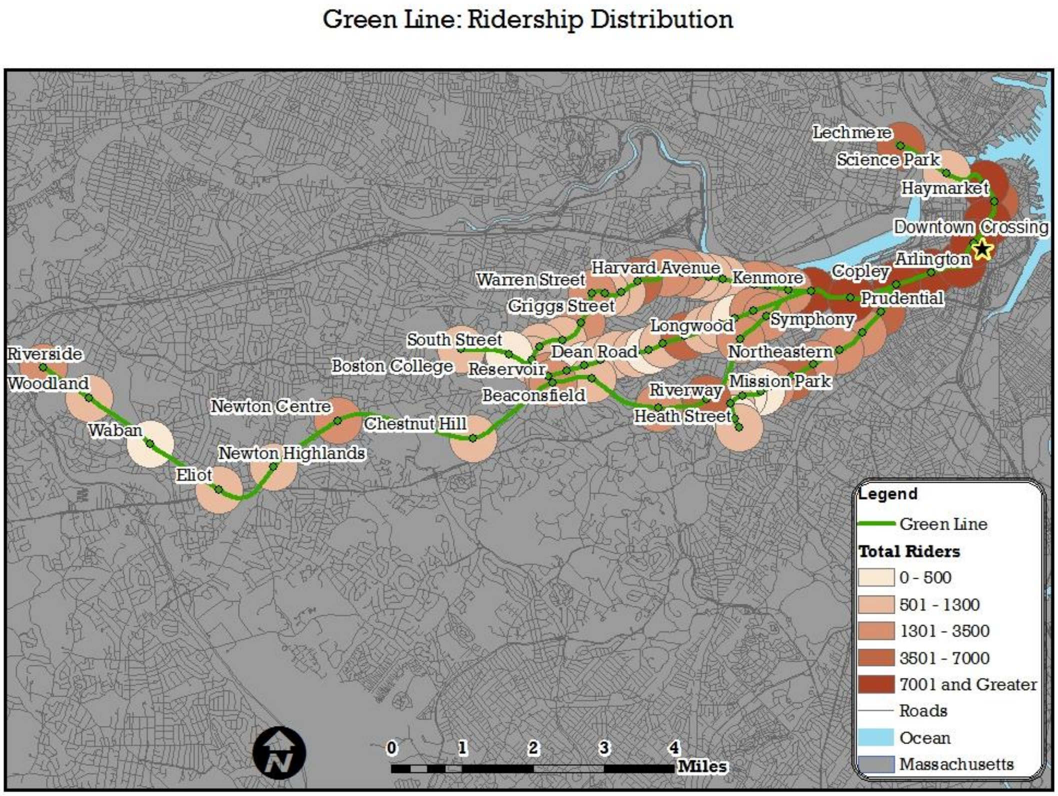
The Green Line is comprised of sixty-six rapid transit stations and transports roughly 174,722 riders every weekday. According to the *2010 Bluebook* the three busiest stations serve over ten thousand riders each: Copley Station is the highest and provides rapid transit access to 13,500 riders daily, followed by Park Street T-station and Government Center T-station which are the entry station for 11,169 riders and 10,072 riders, respectfully. The remainder of all stations serve anywhere from 9,525 riders at the Hynes Convention Center/ICA T-station to only eighty-six riders at the Back of the Hill station on "Branch E". The Green Line as a whole serves on average 2,647 riders per station each day. The majority of riders board the Green Line on the "A Branch", where all the lines converge, and which has a total of 90,434 riders daily equaling fifty-two percent of the Green Line's ridership. "Branch A" and "Branch E" are high system transfer lines with access to multiple modes of transit, especially bus routes. "Branch E" has bus connections at every stop whereas "Branch C" has bus connections at only four stations, with three only connecting to one bus route. The main rapid transfer stations on the Green Line take place on "Branch A" near the CBD at the Boylston T-station, Park Street Station, Government Center, Haymarket Station, and North Station with transfers to the Silver Line, the Red Line, the Blue Line, and the Orange Line, respectively.

Table 50: The MBTA Green Line Rider Data by Route

Green Line Rider Data by Route		
Line	***Riders***	***Percent of Total***
Branch A	90,434	52%
Branch B	28,122	16%
Branch C	14,458	8%
Branch D	22,788	13%
Branch E	18,920	11%
Total	**174,722**	**100%**

Source: The MBTA

Figure 60: The MBTA Green Line Ridership Distribution



The Green Line provides access to several major developments in the Massachusetts Bay area including Boston College, Boston University, Northeastern University, the Museum of Fine Arts, Longwood Medical Center, Fenway Park, and Hynes Convention Center. It also serves a large portion of the suburban communities on Boston's periphery. Fifty-three percent of all Green Line riders cited the most common trip purpose as "home-based work", however trip purpose varied by branch. According to the Onboard Travel Survey "the C and D Branches were more ‘home-based-work oriented (62% and 67% respectively) while only one-third of trips on the E Branch were ‘home-based-work.” On “Branch B” thirty percent of trips were “home-based school” trips, which can be attributed to the large number of educational facilities located on the branch. In general ridership is high at nearly all of “Branch A” stations with Copley, Park Street, and Government Center receiving the highest number of riders on the Green Line. The station with the highest number of riders on “Branch B” is Harvard Avenue Station which sees 4,077 entries daily. Coolidge Corner Station with 4,150 riders is the most highly used station on “Branch C” and Brookline Village with 3,512 riders is the most frequented station on “Branch D”. The Longwood Medical Area Station and the Prudential Station with 3,800 and 3,732 riders, respectively, are stations on “Branch E” with the highest number of daily entries.

Similar to the three previous lines discussed, sixty-four percent of Green Line patrons cited “convenience” as their number one reason for using rapid transit, followed by fifty-four percent saying it was to “avoid parking at destination”. Lack of access to other transportation modes was ranked higher compared to the other rapid transit lines. On the “B Branch” forty-two percent of riders said they had no other transportation available (Central Transportation Planning Staff, 2009).

Even though the Green Line has many more stations than any other rapid transit line, the parking available at stations is minimal. There are only 3,294 spots available and three lines have no parking available at any stations. The parking is distributed relatively evenly between "Branch A" and "Branch D" with forty-nine percent and fifty-one percent of the parking, respectively.

Table 51: The MBTA Green Line Parking Data by Route

Green Line Parking Data by Route		
Line	***Parking***	***Percent of Total***
Branch A	1,622	49%
Branch B	0	0%
Branch C	0	0%
Branch D	1,672	51%
Branch E	0	0%
Total	**3294**	**100%**

Source: The MBTA

Table 52: The MBTA Green Line Parking Spaces

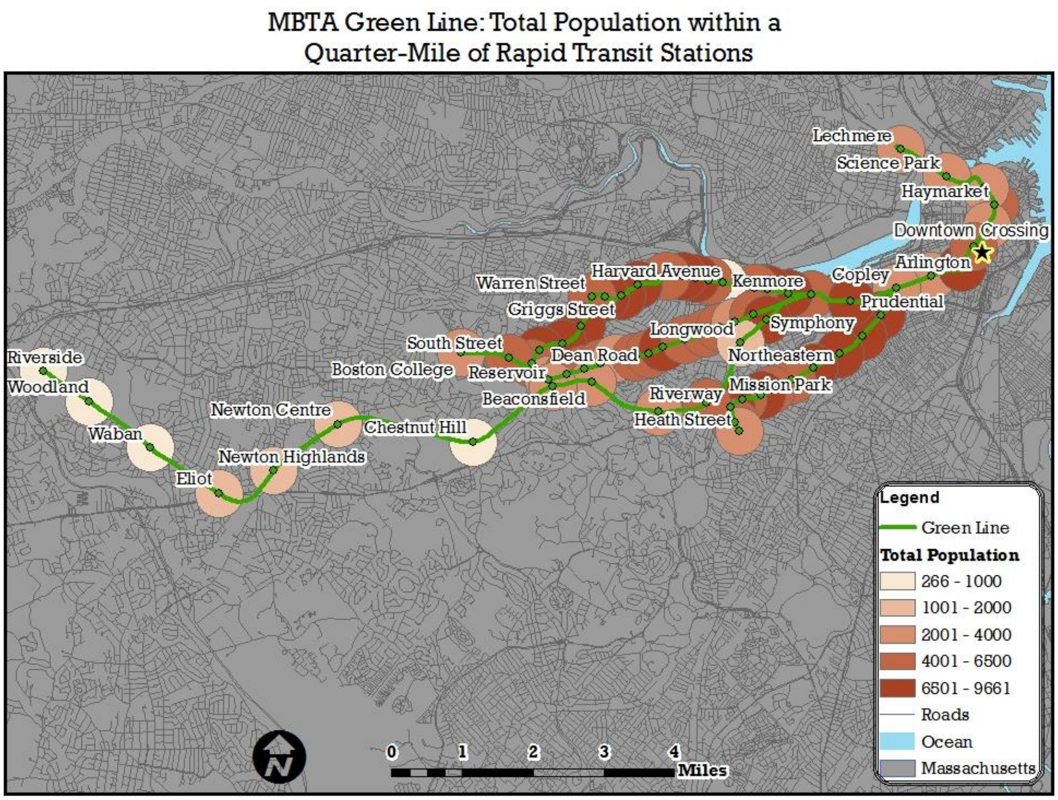
Green Line Parking Spaces	
North Station	1,275
Lechmere	347
Riverside	925
Woodland	548
Chestnut Hill	50
Elliot	55
Waban	74
Total Spaces	**3,294**

Source: The MBTA

According to the United States 2010 Census 318,045 people in 136,979 households live within a quarter-mile of T-stations on the Green Line. Symphony Station boasts the largest number of nearby residents and Hynes Convention Center/ICA T-station boasts the second largest number of residents with 9,661 and 9,511 respectively. The population varies greatly around Green Line stations, with generally less dense populations within the quarter-mile radius the further from the

CBD, especially on "Branch D", with the least dense area containing only 266 residents in 99 households (2010 United States Census Bureau).

Figure 61: The MBTA Green Line Population Density



The average median income along the Green Line is $96,121.00 according to the American Community Survey 2005-2009. Woodland, Chestnut Hill, and Waban boast the highest income levels and are all located in the Brighton neighborhood. The stations on the Green Line with the lowest average incomes within a quarter-mile of each station are Longwood Medical Area, Mission Park, and Museum of Fine Arts, and are all on Branch E and are in close proximity to each other. The CTPS

Onboard Survey measured the income level of Green Line riders in 2009 and found that fifty-five percent of respondents earn over $60,000 annually and thirty-one percent claimed that their annual income was greater than $100,000.

The average age of residents living near the Green Line is 29.7 years of age according to the 2010 U.S. Census, giving the Green Line the lowest average ages for the entire rapid transit system. The Green Line also boasts the largest difference in median ages around each transit station with the highest having a median age of 47.5 years of age at Waban Station and the lowest median age of 21 years at Blandford Street Station. The CPTS Onboard Survey found that twenty-five percent of Green Line respondents were between the ages of 45 and 64, and seventy percent of Green Line patrons fall between 25 to 64 years of age.

Table 53: The MBTA Green Line Data by Route

Green Line Age Data By Route	
Line	***Median Age (in years)***
Branch A	30.2
Branch B	26
Branch C	31.6
Branch D	35.2
Branch E	27.2

Source: The MBTA

Similar to the previously discussed lines, the stations on the Green Line located closest to the CBD boast the highest number of four-way intersections within a quarter-mile of each station. The Green Line has a significant number of stations with four-way intersections, which is beneficial since a majority of Green Line patrons accessed stations by walking. According to the Onboard Travel Survey from 2009, eighty-seven to one-hundred percent of people walked to the T-stations on “Branch A”. On “Branch B” ninety-seven percent of riders walked to the trains. CPTS staff noted the “high ‘walk’ shares…reflect the lack of parking and the lack of connecting bus routes for most of the branch,” (Central Transportation Planning Staff, 2009). Riders on “Branch C” accessed transit by walking ninety-six percent of the time and riders on “Branch D” walked to transit stations seventy-three percent of the time, while ninety-three percent of riders on “Branch E” accessed transit by walking to the station.

Table 54: The MBTA Green Line Top Stations with High Number of 4-way Intersections

Green Line Top Twelve Stations with High Number of 4-Way Intersections	
Station	***4-Way Intersections***
Copley	25
Hynes Convention Center	21
North Station	17
Prudential	16
Haymarket	15
Reservoir	13
Saint Mary’s Street	13
Dean Road	12
Kenmore	12
Saint Paul Street	11
Brookline Hills	10
Fenway Park	10

Source: Author

The Green Line has access to jobs in the CBD but serves a high portion of the less accessible suburban regions. The stations with the highest job density are Government Center, Park Street, Arlington, Haymarket, and Boylston, all of which boast more than thirty thousand jobs within a quarter-mile radius and are located on "Branch A" (ESRI Business Analyst). There is also a high concentration of jobs on "Branch E" at Prudential and Longwood Medical Area T-stations.

Table 55: The MBTA Green Line Job Data by Route

Green Line Job Data By Route		
Line	***Total Jobs***	***Percentage***
Branch A	290,415	63%
Branch B	40,836	9%
Branch C	20,838	5%
Branch D	21,084	5%
Branch E	86,468	19%
Total	459,641	100%

Source: ESRI Business Analyst Online

Table 56: The MBTA Green Line Job Density

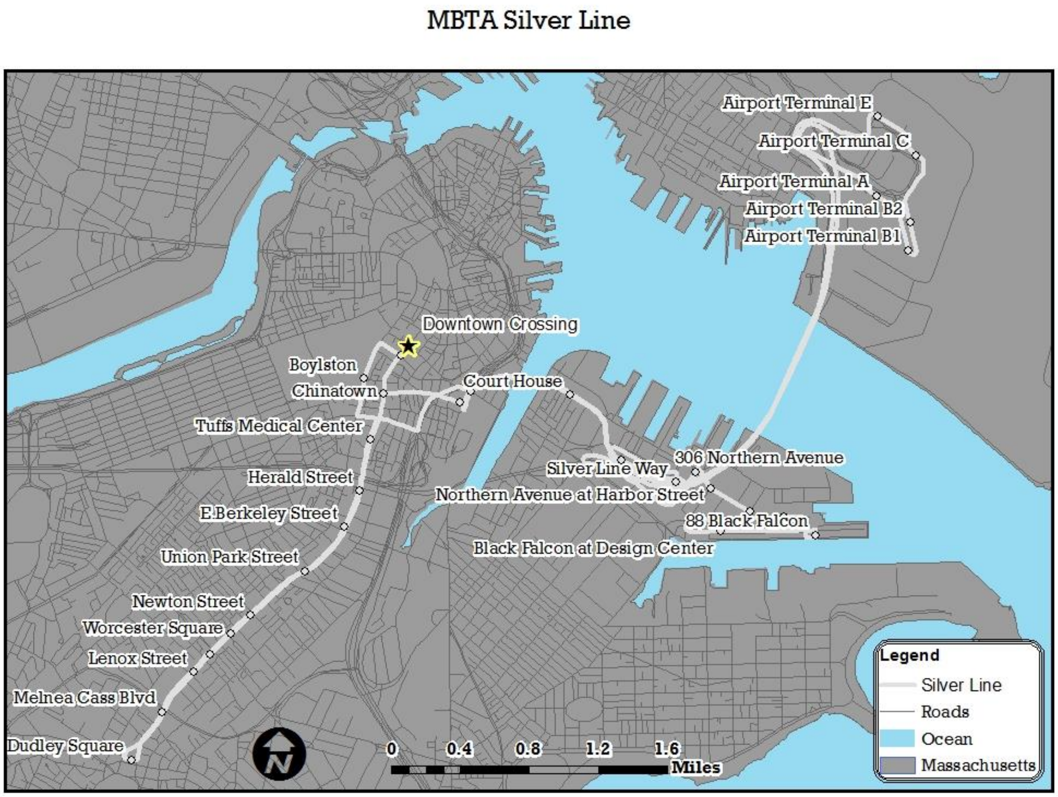
Green Line Job Concentration	
Station	***Jobs***
Government Center	73,271
Park Street	45,889
Arlington	33,226
Haymarket	30,750
Boylston	30,000
Copley	29,902
Prudential	24,212
Hynes Convention Center	19,237
Longwood Medical Area	13,985
Brigham Circle	13,964
Fenwood Road	11,771

Source: ESRI Business Analyst Online

The Silver Line

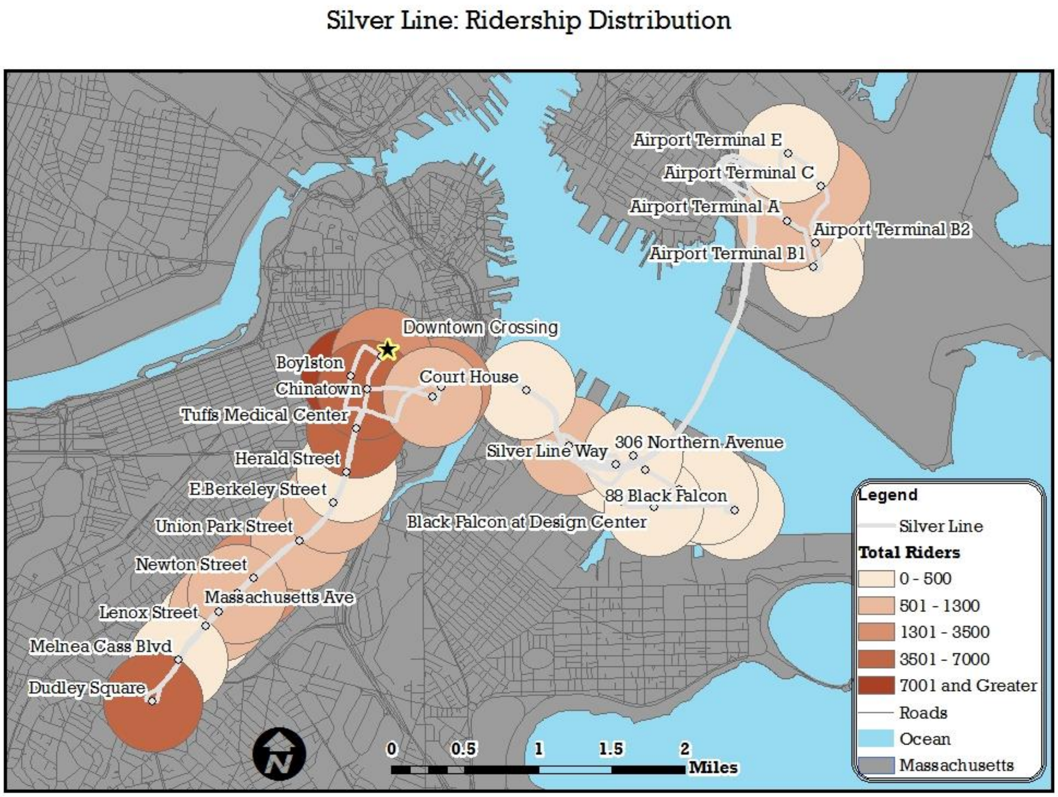
As of 2013 there is one bus rapid transit line serving the Massachusetts Bay, the Silver Line. The Silver Line has four routes (SL1, SL2, SL4, and SL5) providing access to two districts, with one branch serving the CBD and the South End on Washington Avenue (SL4 and SL5), and one branch serving Logan Airport and Boston's Design Center (SL1 and SL2). Bus Rapid Transit provides more flexibility for the MBTA to provide service where fixed rail rapid transit proves difficult. The Silver Line intersects with three of the major subway transfer points at Boylston Station, Downtown Crossing, Chinatown, South Station, and Tufts Medical Center. The Silver Line's "Branch A" begins at South Station and carries passengers south along Washington Avenue terminating at Dudley Square Station where it turns around and follows the same path north to South Station. "Branch B" starts at South Station and travels first to Silver Line Way where it splits and goes either to Logan Airport where it loops back to Silver Line Way, or continues onward to the Marine Industrial Park where the line terminates at Design Center.

Figure 62: The MBTA Silver Line



The Silver Line is comprised of thirty-one major bus rapid transit stations serving 39,176 passengers daily. Most of the Silver Line's ridership originates at Boylston with 7,618 riders, Chinatown with 5,822 riders, and Tufts Medical Center with 5,684 riders daily. The Silver Line operates both above ground in a dedicated lane, and below ground in tunnels, depending on the route. Passengers can transfer between "Branch A" and "Branch B" at South Station.

Figure 63: The MBTA Silver Line Ridership Distribution



The Silver Line provides the majority of its service in the CBD along route SL4 and SL5. It also services many people accessing Logan Airport, where the BRT travels in a circular pattern stopping at each of the four terminals, near the arrival gates.

In 2005-2006 Central Transportation Planning Staff conducted an online rider survey for the Silver Line. At the time only three routes were in operation (the fourth route previously described had not been constructed). During this analysis, staff found that “97% of the outbound boardings and 94% of the inbound alightings occurred at South Station,” (Central Transportation Planning Staff, 2006). The study found that on “Branch A” eighty-five percent of outbound trips were “home-based work” trips while “home-based work” accounted for only forty-three percent of inbound trips, which is most likely because the stations around the waterfront have little residential development. A majority of the “home-based work” trips actually originated in suburban Boston as people drove to the stations, parked nearby, and boarded the Silver Line to carry them the remainder of the way to work. The second largest category of inbound trips on “Branch A” was “work-based non-airport” trips, which accounted for thirty-five percent of inbound trips. On “Branch B”, or the Logan Airport Branch, thirty-nine percent of outbound trips were “home-based work”, followed by twenty-two percent of “non-home non-work-based”. CTPS reported that the majority of outbound trips to Logan Airport were mostly trips by visitors traveling to the airport for departure. “Home-based work” trips accounted for thirty-four percent of inbound trips from Logan Airport and were made by riders returning home from out of town via the airport while twenty-five percent were neither “home-based” or “work-based” trips.

Similar to the other four rapid transit lines, staff found that passengers utilize the Silver Line due to its high level of convenience, which was cited by eighty-four percent of inbound riders and sixty-nine percent of outbound riders. The second most common reason for using the Silver Line was also the same as the previous lines. Forty-nine percent of outbound riders and forty six percent of inbound riders said they chose the bus rapid transit line to “avoid driving/traffic” (Central

Transportation Planning Staff, 2006). Only twenty-one percent of outbound riders and seventeen percent of inbound riders cited "only transportation available" as the reason they chose transit, with the majority of these riders being outbound riders traveling toward South Boston stations.

The Silver Line has the lowest number of available parking spaces at rapid transit stations, with a mere 226 spots, or one percent of the total system parking. All of the 226 parking spaces are located at South Station at Essex. This does not include available parking at the airport or near the Marine Industrial Park, only parking at the stations.

Table 57: The MBTA Silver Line Parking Spaces

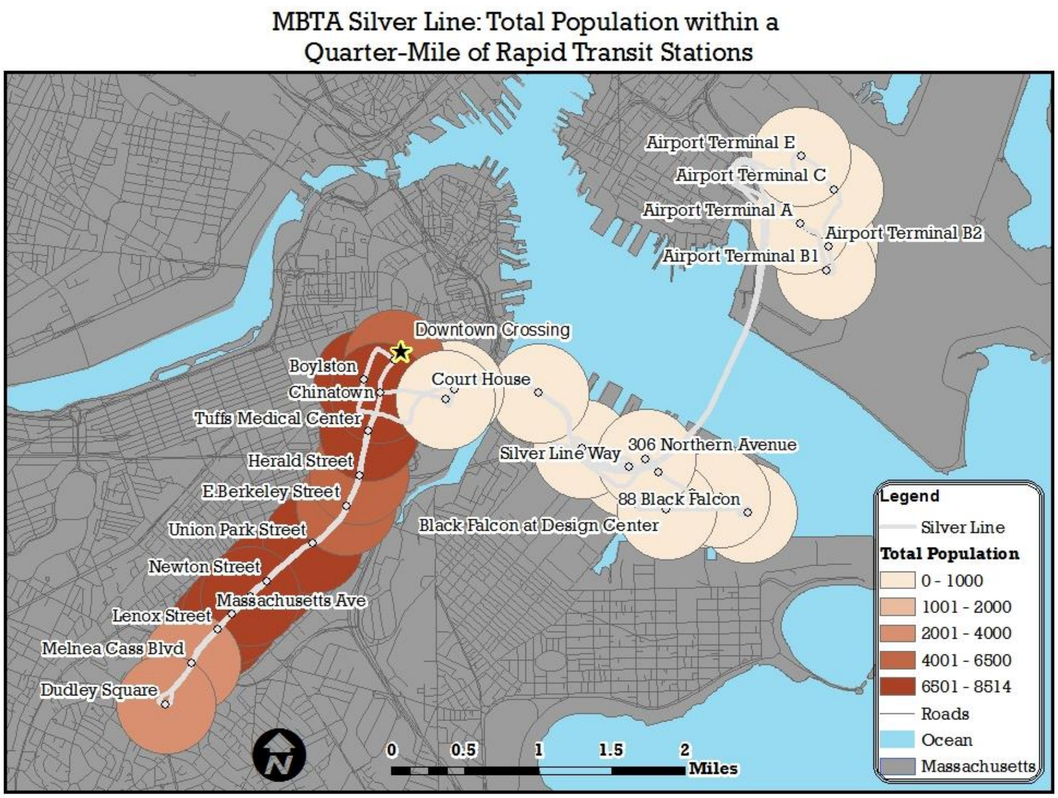
Silver Line Parking Spaces	
South Station at Essex	226
Total Spaces	**226**

Source: The MBTA

According to the United States 2010 Census, 89,614 people in 41,825 households live within a quarter-mile of T-stations on the Silver Line. Worcester Square Station boasts the largest number of nearby residents and Massachusetts Avenue Station boasts the second largest number of residents with 8,514 and 8,381 respectively. The Silver Line serves a relatively high population around each station near the CBD, but serves several areas without any or nearly any residents. There are no census recognized permanent residents within a quarter mile of the stations located at Logan Airport, and only 207 residents living near the Marine Industrial

Park near the Design Center and Dry Dock stations (2010 United States Census Bureau).

Figure 64: The MBTA Silver Line Population Density



According to the American Community Survey 2005-2009 the average median income a quarter-mile around transit stations on the Silver Line is $77,640. This does not take into consideration the stations that have no residents within a quarter-mile, which would significantly lower the average median income around stations with actual residents. South Station at Essex Street, South Station, and Court House stations boast the highest income levels while Dudley Square, Melnea Cass

Boulevard, and Chinatown are areas where residents have lower incomes within a quarter-mile radius of the stations.

When Silver Line riders were surveyed by CTPS in 2005-2006 the most common answer in regards to household income was $80,000 or more, excluding those passengers that did not answer the question. Fifty-seven percent of outbound passengers and sixty-one percent of inbound passengers on "Branch A" and forty-seven percent of outbound passengers and forty-six percent of inbound passengers reported this figure on "Branch B". The second most reported income level on "Branch A" was between $60,000 to $79,999 while the second, more common income level for "Branch B" was $40,000 to $59,999.

Residents living within a quarter-mile of the Silver Line have an average median age of 31.5 years of age according to the United States 2010 Census. Average median ages ranges anywhere from 40.2 years or age at East Berkeley Street Station to 27.5 years of age near the Boylston BRT-Station and 24.4 years of age near the Marine Industrial Park and the Design Center BRT-Station. Respondents of the Onboard Travel Survey for the Silver Line were of all ages, with the most common rider being between the ages of 45 to 64 years of age.

The Silver Line near the CBD has a high degree of four-way intersections that help with connectivity levels from transit stations to homes and jobs. It also allows for a greater number of people to easily access transit on foot. Conversely, the built environments around the airport and near the Marine Industrial Park have significant connectivity problems. The airport has no four-way intersections, which is beneficial for motorized traffic as it keeps traffic flowing (mostly) freely, however it is bad from a pedestrian standpoint. The same can be said for the Marine Industrial Park, which has very few four-way intersections. Here, there is actually a decent degree of connectivity, but the roads do not intersect at four-way intersections and there are many heavily traveled streets, creating dangerous pedestrian conditions. The stations located on Drydock Avenue and Black Falcon Avenue also have lower levels of connectivity because block lengths are longer than normal, making the pedestrian realm less attractive.

Table 58: The MBTA Silver Line Top Ten Stations with High Number of 4-way Intersections

Silver Line Top Ten Stations with High Number of 4-Way Intersections	
Station	***4-Way Intersections***
Worcester Square	28
Massachusetts Avenue	26
Tuffs Medical Center	23
Newton Street	23
South Station: Essex Street	17
Lenox Street	17
Herald Street	15
Downtown Crossing	13
South Station	12
Union Park Street	12

Source: Author

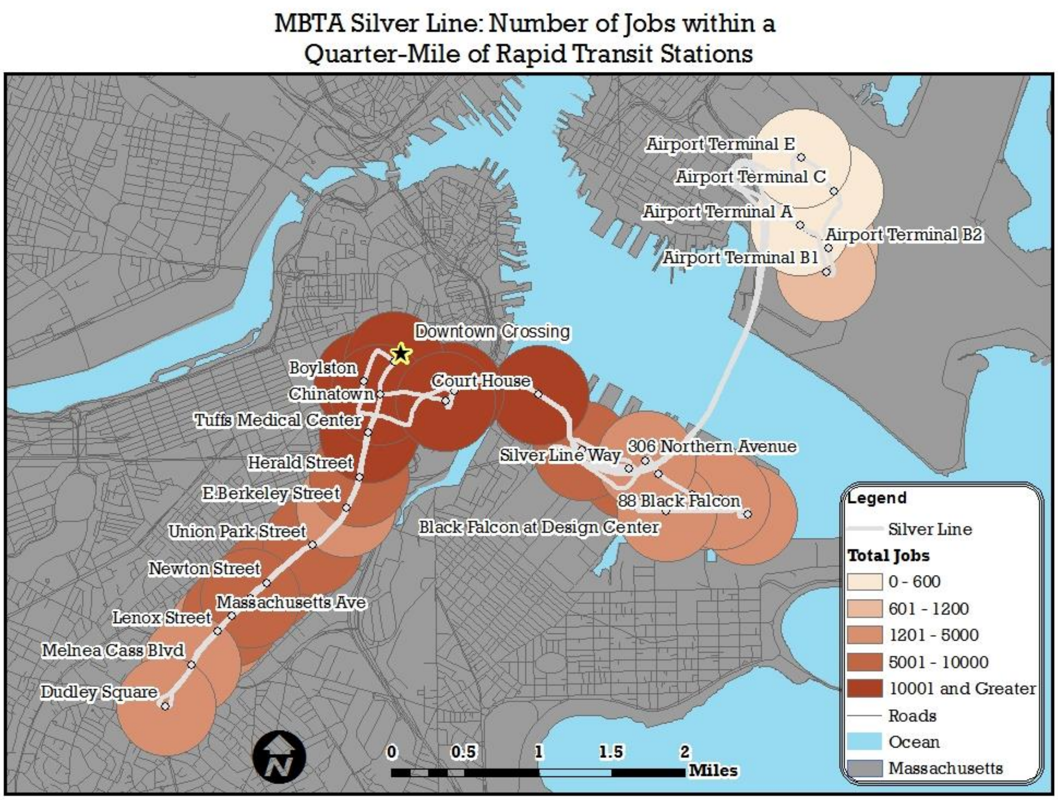
On the Silver Line there are 335,626 jobs located within a quarter-mile around transit stations (ESRI Business Analyst). The majority of jobs are located in the CBD and in Boston Proper, with an average of 10,826 jobs located around Silver Line stations (ESRI Business Analyst).

Table 59: The MBTA Silver Line Job Density

Silver Line Job Concentration	
Station	***Jobs***
Downtown Crossing	66,705
South Station: Essex St.	39,161
Chinatown	37,592
Boylston	36,636
South Station	33,788
Tuffs Medical Center	17,580
Court House	10,516

Source: ESRI Business Analyst Online

Figure 65: The MBTA Silver Line Job Density



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