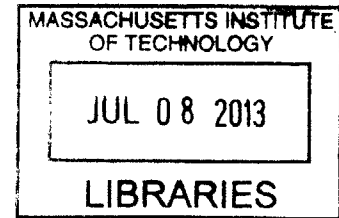


Exploring The Relationship Between Destination Accessibility, Cluster Formation and Employment Growth in Kendall Square ARCHIVES

by

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Bachelor of Arts in Applied Mathematics
Harvard University, 2011



Submitted to the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degree of

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at the

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Abstract

The exploration of the links between transportation and land use highlights the cyclical relation of accessibility, activities and transit demand. Agglomeration theory focuses on the benefits in productivity that arise from high employment density areas when companies operate in the same sector; while cluster theory examines these centers more closely and stresses the importance of relationships among companies, as well as links to input services and employment. Previous research (Pushkarev & Zupan 1977) demonstrated that high trip density is unsustainable without an efficient public transportation system.

This high employment density center fosters a unique kind of industry, focusing on the cutting edge of technology and research, bio-tech and technology start-ups. The location of Kendall Square, next to the Massachusetts Institute of Technology (MIT), and supporting transportation infrastructure make it highly accessible.

This thesis explores Kendall Square, as well as other employment centers in the Greater Boston Area, in order to determine if Kendall may be considered an employment cluster. Utilizing census data, this thesis looks at employment changes, industries and worker types to explore Kendall's uniqueness. The study of the area also includes the evolution of commuting patterns (trip length distribution, trip origins, modal splits) in the last 30 years. In order to better understand current trends, it also utilizes employee interviews and MBTA service usage.

Three transportation models for the Greater Boston Area that replicate socio-economic and transportation infrastructure conditions of 1990, 2000 and 2010, created using modeling software packages, TransCAD and Cube Voyager, are used to analyze the modal accessibility of each destination for those time periods. Accessibility measures are then utilized to develop a series of linear regression models that explore the relative importance of each modal accessibility measure on employment density and employment changes. The results suggest that transit accessibility is the most important modal measure to support high employment density areas. In order to continue fostering employment growth planners must provide a transit service capable of sustaining the employment changes for the region.

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My friends and family, thank you for your support throughout this journey and reminding me that:

Not everything that can be counted counts, and not everything that counts can be counted.

Pura vida!

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Chapter 1 – Introduction

In the search to foster employment centers and job growth, local governments have used a number of incentives to attract economic activity. Promoting areas of high employment density tend to bring higher than proportional increases in economic productivity due to the benefits of collaboration and interaction among local corporations. In order to promote and sustain these kinds of developments, local governments must first explore the importance of infrastructure on employment growth.

Boston has historically been a city of economic prosperity, a thriving urban life and high levels of innovation. This long tradition of being in the forefront of business, education and politics, has led to a unique environment all over the Greater Boston area. Boston's main employment center, the Central Business District has long been the center of employment for banking and financial services in the area. In recent years, Kendall Square has come to be a major employment center and a national hub for innovation, biotech companies, research and technological advancement.

Kendall Square attracts companies due to the unique environment offered in its proximity. The Massachusetts Institute of Technology (MIT) brings in the latest technology and research, as well as highly trained individuals; flexible office space provides adaptable locations for new companies; venture capital provides access to the capital needed to grow; while long-standing companies such as Microsoft foster a sustainable business environment. Growth in recent years has brought an increase of commuters to the square that is supported by Kendall's Square transportation infrastructure.

Transportation infrastructure impacts land use decisions. A better understanding of this relationship between land use and transportation infrastructure highlights the many unexplored externalities that come from an accessible city. Exploring this relationship empowers local governments to make informed decisions as to what kind of infrastructure will promote high employment density areas.

This thesis aims to provide further understanding about the relationship between transit accessibility and growth of employment centers in an urban setting. Through the exploration of recent growth patterns in Kendall Square, we will propose a framework with which to define the benefits, uniqueness and sustainability of Kendall Square; a method to estimate the modal accessibility of Kendall Square; and its correlation with

recent employment density increases. This approach should lead to a better understanding of the importance of different types of transportation accessibility (auto, transit and walking) on employment growth.

1.1 Research Objectives & Research Questions

The specific objective of this research is to gain a better understanding of the accessibility, employment and commuter pattern changes that have taken place in Kendall Square over the last twenty years (1990-2010).

To this end, the specific research questions defined to guide the thesis are the following:

- What is accessibility? How is accessibility theoretically defined and how has it been numerically estimated in the past? What are the benefits that come from understanding and measuring accessibility?
- How do we identify the accessibility to a destination? What are the potential benefits from increases in destination accessibility?
- How do firms decide to locate in a certain area? What are the differences between agglomerations and clusters, and what are the advantages resulting from higher job density areas?
- What is the relationship between density, accessibility and modal split?
- How has Kendall Square managed to become a main center for employment in the last 20 years? What is unique about this employment center that attracts companies and manages to sustain high employment density patterns?
- How is the modal split changing in Kendall Square?
- What is the relationship between destination accessibility and areas of high-density employment?
- Can the argument for investing in new transit infrastructure project be strengthened by considering accessibility and employment density impacts and benefits?

1.3 Contribution to Kendall Square

In recent years, Kendall Square has grown to become one of the mayor employment centers in the Greater Boston Area. Due to its strategic location, Kendall Square has been a main transportation hub since the 18th Century. After years of slow growth and neglect, Kendall Square has recently thrived by a collection of new office and research businesses, housing more than 150 biotechnology and information technology firms as of 2011. Firms are attracted to the unique environment provided in Kendall Square, high employment density, proximity to the Massachusetts Institute of Technology (MIT) campus, venture capital investment opportunities and transit infrastructure that serves Kendall Square directly.

In order to continue this revival and employment growth pattern that has taken place, it is most important to examine the infrastructure that supported this development process. Previous research on employment density suggests that without adequate transit service (Pushkarev & Zupan, 1977), locations may not achieve job increases above a certain density. The main transit access to Kendall Square continues to be the Massachusetts Bay Transportation Authority (MBTA) Red Line. This research aims to explore the importance of transit in supporting the employment growth that has occurred over the last decades.

As Kendall Square looks into the future, it expects to continue growing and adding more firms. Microsoft and Google recently announced that they would be expanding their offices, and Amazon also plans to move in to the area as well. With the current expected employment growth, understanding the relationship between accessibility, commuter patterns and employment becomes crucial.

This thesis will examine the history of Kendall Square in order to better understand the changes that brought this employment increase. By analyzing what makes Kendall Square unique and which infrastructure types are critical to sustain its employment growth, local officials will have a better understanding of what is needed to foster future growth.

1.4 Thesis Structure

This thesis contains eleven chapters, including this introductory chapter. The second chapter presents a literature review of previous research conducted on

transportation investments and accessibility. It also presents the concepts of corporate localization theory, including agglomeration and cluster theory; as well as the relationship among areas of high employment density, transportation investment and modal split.

The third chapter provides an overview of Kendall Square, the study area for this thesis. It provides historical understanding of the area, as well as a theoretical approach to understand current employment increases. This chapter also provides an overview of the transportation infrastructure in the area.

Chapter four deepens the study of Kendall Square by utilizing data from the Census Transportation Planning Products (CTPP) to provide a quantitative and geographical analysis of the area, in order to compare it to the rest of Boston.

Similarly, chapter five utilizes other data sets, including employer surveys, MBTA ridership data and results from the American Community Survey to explore the most recent employment and commuting patterns in Kendall Square.

Chapter six presents the variables and approaches that have been utilized to estimate accessibility: the isochrone, gravity-based, utility-based and person-based accessibility models. It also outlines a regression model to explore the relationship between accessibility and employment density.

In chapter seven the four step academic model utilized to reproduce transportation patterns of the Greater Boston Area is presented and explained.

Chapter eight utilizes data from the model as well as surveys to calculate the deterrence functions utilized in the accessibility calculations.

Chapter nine presents the results for the accessibility calculation methodologies for different trip types and modes. This data is later utilized in chapter ten to create scatter plots, and a number of regressions analysis that further explore the correlation between accessibility and employment density.

The final chapter presents the conclusions of the research as well as limitations and areas of potential further exploration.

Chapter 2 - Literature review

This chapter examines the existing research on the relationship between transportation and land use, specifically high employment areas. Initially this connection between transportation projects and land use is explored to understand the quantifiable transit externalities that result from higher accessibility.

Through a deeper understanding of corporate strategy and localization theory, we can explore the decisions that lead a company to place its offices in a specific area. This understanding of individual company choice will provide a better comprehension of the benefits of high employment density areas, specifically the benefits of agglomeration and clusters.

Lastly this chapter will cover previous research that has looked at the relationship between accessibility and employment densities. This will allow us to create a framework with which to study the employment patterns in Kendall Square and the potential relationship between different kinds of accessibility and its employment growth.

2.1 Transportation Benefits

Elaborating on the effects and benefits of transportation projects has been the subject of much research. Most studies conclude that transportation benefits can be categorized into the following:

- Direct Benefits,
- Environmental Benefits,
- Regional & local economic growth,
- Increase Social Welfare and,
- Quality of life and Marketing of a city as a world-class city.

Direct benefits relate to those associated to the construction and operation phase of any transportation project. During the construction phase these effects include the employment needed to build the project. Once the project starts operations, direct benefits include the time and cost savings that the transportation project provides to the people it serves. Direct benefits are easily captured and quantified; however, direct

benefits are rarely the main reason to establish the feasibility of transportation investments.

Transit projects are associated with more environmentally friendly alternative modes. Transit investments typically reduce emissions and road congestion by shifting people's travel patterns to transit. It should be noted that not all transportation projects result in environmental benefits; some investments that promote automobile use have an adverse effect on the environment.

The relationship between transportation projects and land use has led to many transportation infrastructure investments, such as the Red Line subway extension in Boston that aimed to revitalize the central parts of the city thanks to its new connectivity. Since calculating the actual benefits of transit projects in terms of regional and local economic growth is highly contested, it is quite hard to determine which are the direct benefits of a single project (Covarrubias 2004) since many of the effects are evident years after the projects completion and it is hard to isolate the results from other circumstances.

Transportation projects may improve the overall mobility of a city. By providing links and mobility access to different city sectors, transportation investments may provide new opportunities to many. Since public transportation projects may offer low cost alternatives to marginalized sectors, "Transit provides services to transportation-disadvantaged groups and fosters transport equity. It reduces the social discrepancy between the poor and the rich through mobility provision and improvement" (Zhang, Shen & Sussman 1998)

Amongst the other unquantifiable benefits of transportation infrastructure creation, some projects serve to improve the quality of life of city residents, and market the city as a world-class city. There has been much scholarly research pertaining to the theory and the estimation of these benefits.

Although transportation projects do have a large number of direct quantifiable benefits, most of the contributions of public transportation projects are externalities. Externalities are all the costs and benefits that affect people that are not direct participants of the use of a product. The externalities are often a matter of scholarly research and theoretical discussion, but they are still underused for the economic assessment of transportation project. One of the explanations is that there are no clear

methods or guidelines to estimate such externalities. Nevertheless, there is no doubt that some transportation projects create these potential benefits and therefore research that quantifies such effects and sheds light on the potential contribution of transportation projects is deemed necessary.

2.2 Land Use & Transportation Investments

Although the direct causality link between land use and transportation has not been well established, the relationship between the two is uncontested. Travel is considered to be an intermediate good, meaning that users travel to engage in some activity or reach an opportunity. (Warade 2007) Therefore, the demand for transportation alternatives is derived from the need to reach a certain location offering a specific set of services. Thus, land patterns directly influence the demand for transportation.

Transportation access however also influences the development of land in a certain area. (Guiliano 2004) Research to map the relationship between land use and transportation projects has focused on using proxies such as land values and land use patterns. Having a destination with better accessibility than others encourages development in that area; the shifting land patterns fill the destination with opportunities that consequently raises the demand for transportation services. Therefore the relationship between land patterns and transportation infrastructure is best represented as a cyclical connection as displayed in figure 2.1.

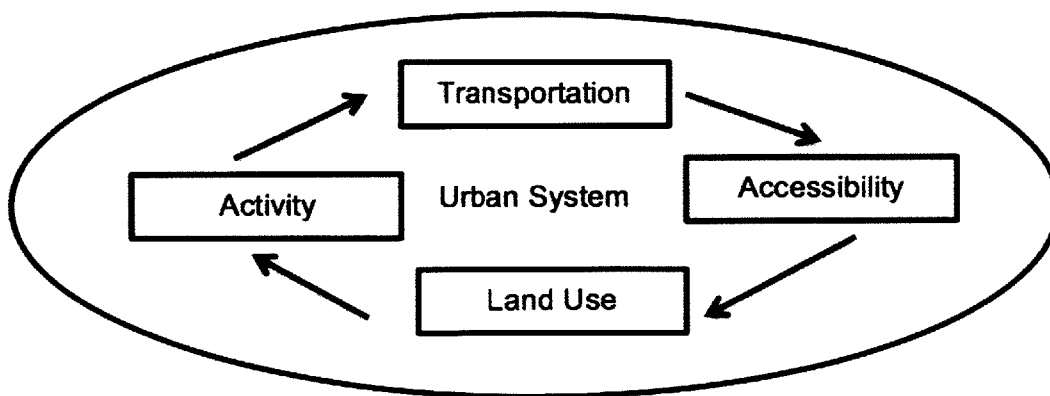


Figure 2.1 Land use and Transportation cycle. Source: Giuliano 2004; El-Geneidy & Levinson, 2006)

This research shows how a transportation project will improve the accessibility to an area. Higher accessibility will attract new opportunities, changing the land use patterns and value of the area. These patterns change and increase in land value will

attract new activity. The increase in activity in turn increases the opportunities at a destination that further increases the travel demand.

Although we are not able to quantify the effects of transportation projects along a timeline (as there may be other economic and infrastructure factors at play), there is enough research to suggest that this cyclical change in transportation and land use hinders on the accessibility changes that the project brings.

2.3 Accessibility

As suggested by previous research understanding accessibility becomes an essential part of attempting to evaluate the impacts of transportation projects. Nevertheless, accessibility is a “misunderstood, poorly defined and poorly measured concept” (Geurs & van Wee, 2004)

Initial attempts to define accessibility were led by Hansen (1959) who defined accessibility as “the potential of opportunities for interaction.” Attempting to make a clear definition of accessibility has continued to be a subject of academic research. Although we still lack a clear definition for this concept, research has greatly advanced our understanding and evaluation of accessibility.

Research at MIT by Busby (2004), Warade (2007) and Ducas (2011) has attempted to aggregate the research done by previous scholars. The understanding of accessibility that began as a simple notion of a link between transportation and land use has grown in complexity and to provide an accurate representation of urban relations. The research on accessibility is best summarized by the details it includes:

There are four major elements affecting accessibility: the spatial distribution of opportunities, the mobility provided by the transportation system, the temporal constraints of individuals and activities, and the individual characteristics of people. (Ducas, 2011)

This new understanding of accessibility includes the complexities of urban mobility and transportation choices as critical factors of the accessibility of a certain region.

Although the study of accessibility has focused on the opportunities that are available to individuals, the same concept can be applied to the accessibility to a business venture. Hypothetically we expect that, in the same way in which having

opportunities available to individuals will change the land patterns of a place, so too will be the case for the improved accessibility for businesses.

2.4 Localization Theory & Agglomeration

The links among geography, trade and economic growth has been the topic of great interest for many years. Many seem to believe that the proximity of businesses to similar ventures fosters the further development and success of a region or city. Therefore, as a city is made more accessible for its residents by the proximity of employment opportunities and other services, so too a city is made more attractive to employers by the presence of these similar ventures. "Firms in the same industry may be drawn to the same locations because proximity generates positive externalities or 'agglomeration effects'" (Head et al, 1994)

Several economists and theorists have attempted to quantify the effects of agglomerations. Most notably Graham (2007) did so by calculating the benefits in productivity gains by the agglomeration of industries. Henderson (1986) in a study that examined the data for the United States and Brazil found a positive relationship between factor productivity of a company and its proximity to similar institutions.

E. Glaeser, H. Kallal, and J. Scheinkman (1992) arrived at similar conclusions after a study on the growth of large industries in 170 U.S. cities between 1956 and 1987. The researchers came to the conclusion that city growth was a product of industry diversity and competition. They added however, that this might be a product of the selection bias in their sample, but the stress on competition amongst neighboring industries seemed to correlate with larger city growth across the board. Nevertheless, they still provided evidence that a group of industries would attract other similar firms.

As technology advances, some hypothesized that this would diminish the need for personal interactions. Telecommunications would breach the need to communicate with peers personally, however, this has not been established. Rather, information technology and face-to-face contact are behaving with each other more like complements than as substitutes for each other. (McCann & Schefer 2005)

The theory and research produced on agglomeration benefits is widely accepted nowadays. There seems to be consensus on the fact that dense areas attract further industrial development, and that these bring intangible benefits but quantifying these

benefits is difficult. Agglomeration effects therefore are by definition an externality, which implies that they cannot easily be directly measured. Therefore indirect approaches have been adopted such as observing the spatial patterns of patent cogitations (Jaffe et al 1993; Aces 2002); joint ventures (Aria and McCann 2000); joint-lobbying activities (Bennet 1998); telephone usage (Gaspar and Glaser 1998); or real estate price movements (Gordon and McCann 2000) to quantify the value of agglomeration effects.

Another branch of agglomeration theory has focused on attempting to find evidence the increase of agglomeration through a firm's decision to operate in one place or another. The study of this decision is called localization theory. Localization theory analyzes each firm's decisions and corporate strategy to place its offices in a certain region. Utilizing localization theory, benefits of agglomeration effects are described as a cycle feedback loop on three levels:

- Inter-firm technological spillovers: useful technical information seems to flow among entrepreneurs, designers and engineers
- Agglomeration effects mitigate the hold up problem (concerns over a loss of bargaining power) and secures a constant stream of specialized labor to the region
- Intermediate outputs. Reduction in the need for intermediate good expenditures on auto and auto use may be a contributing factor as suggested by Tejus Kothari(2007). This frees up purchasing power to contribute to economic wellbeing.

The consensus is that agglomeration of industries tends to increase the productivity, particularly of labor. Furthermore, modern location theorists agree that agglomeration economies play a role in the expansion of cites (Gordon & McCann 2005; McCann & Schefer 2004; Schefer & Aviram 2005)

2.5 Applying Corporate Strategy to Urban Growth

A city and its transportation system therefore act as an enabler of links among people, resources, services and locations. A city's employment and central business district's success is dependent on how well it competes with other regions and neighboring cities. We can therefore study the city under the lens of Michael Porter's

cooperate strategy theory (2002) in order to determine why certain zones become more prosperous than others.

Using corporate theory, we find that certain principles apply directly to urban growth. Central to Porter's argument is that successful business enterprises have the following common denominators:

- *Value Creation*: successful business do not compete at being the best (as maximizing market share); rather they focus on creating value and promoting a specific niche that has not yet been exploited
- *Competitive Advantage*: Competitive advantage is not about beating rivals; it's about creating unique value for customers. This leads to the conclusion that a distinctive value proposition and a diverse environment that fosters this type of thinking are essential for corporate strategy. As technology reduced communication lags, regional advantages for companies become more essential. Competitive advantage therefore lies in making a more efficient use of inputs
- *Continuity*: a business enterprise must have a long-standing vision of the value that it is trying to create. This allows a company to be flexible with changing and advancing technologies while keeping true to the value creation proposal

Therefore, we can theorize that successful and sustainable businesses fostering locations are those that promote and provide a readily accessible platform for this kind of venture.

2.6 Cluster Theory

Agglomeration theory provides compelling evidence that industries seem to attract similar industries to the region. Nevertheless, agglomeration theorists have yet to capitalize and discuss the benefits of industry diversity and the advantages of resource and labor agglomerations, as well as industry agglomerations.

Utilizing Porter's corporate theory, it would not seem that a particular business would be able to increase its competitive advantage by the presence of similar industries. Rather, traditional theory would seem to suggest that the proximity to quite similar industries would lead to competition on 'being the best' instead of focusing on the particular value creation of a company. Furthermore, the simple concentration of similar

industries does not necessarily contribute to the company's own continuity and commitment to its own mission since it would have to be constantly strategizing on competing for labor and resources. The combination of these factors has led to the theoretical hypothesis that instead of groupings of similar industries, sustainable city growth is achieved by the presence of clusters. Clusters are geographical concentrations of related companies and institutions in a particular field.

Unlike agglomerations, clusters do not conform to the standard industrial classification system. Furthermore, their existence is not a hindrance to similar industries, but rather a catalyst for diverse, but interconnected companies and resources. Cluster theory suggests that the advantages that agglomeration theory postulates are in fact true. However, it suggests that agglomerations are only sustainable when there is a combination of interconnected companies, rather than companies competing with each other to 'be the best'. Porter (1998) argues that indeed, the enduring competitive advantages in a global economy lie increasingly in the local sphere, knowledge, proximity relationships, and motivation – that a distant rival cannot match.

Evidence from a study by Berry and Glaeser (2005) suggests that cities with initially higher skill levels have become relatively more skilled over time. This tendency appears to be driven by shifts in the demand for skilled labor, as there is an increasing wage premium for such labor. This would suggest therefore, that their growth was not an externality of the agglomerating firms, but rather a product of the continuous skillful labor force that could diversify and adapt to work in any corporate environment. Similarly, McCann & Scheffer (2005) suggest that the geographical proximity of firms and people within individual urban areas is becoming relatively more important over time. Therefore, the cluster is dependent on inputs and outputs, rather than only outputs, as agglomeration theory suggests.

A cluster encourages and develops new linkages broader than the traditional industry categorization. This creation of new connections among industries captures spillovers of technology, skills, information, marketing, and customers that cut across firms and industries. Therefore such diversity encourages the unique value creation and fosters the industry success.

Such connections across firms and industries are fundamental to competition, to productivity, and to the direction and pace of new business formation and

innovation. Most cluster participants are not direct competitors but rather serve different segments of industries. Yet they share many common needs, opportunities, constraints, and obstacles to productivity. The cluster provides a constructive and efficient forum for dialogue among related companies, their suppliers, government, and other institutions. Because of externalities, public and private investments to improve cluster circumstances benefit many firms. Seeing a group of companies and institutions as a cluster also highlights opportunities for coordination and mutual improvement in areas of common concern with less of a risk of distorting competition or limiting the intensity of rivalry. (Porter, 2000)

Clusters create this paradoxical arena where companies are encouraged to compete and cooperate with each other. This relationship improves company's competitive advantage by increasing the productivity of companies based in the area.

Porter (1999) uses the example of the wine cluster in California to highlight the contribution of grouping several industries in a cluster, depicted in Figure 2.2. The cluster arises from the inputs as from the well as outputs of the industry.

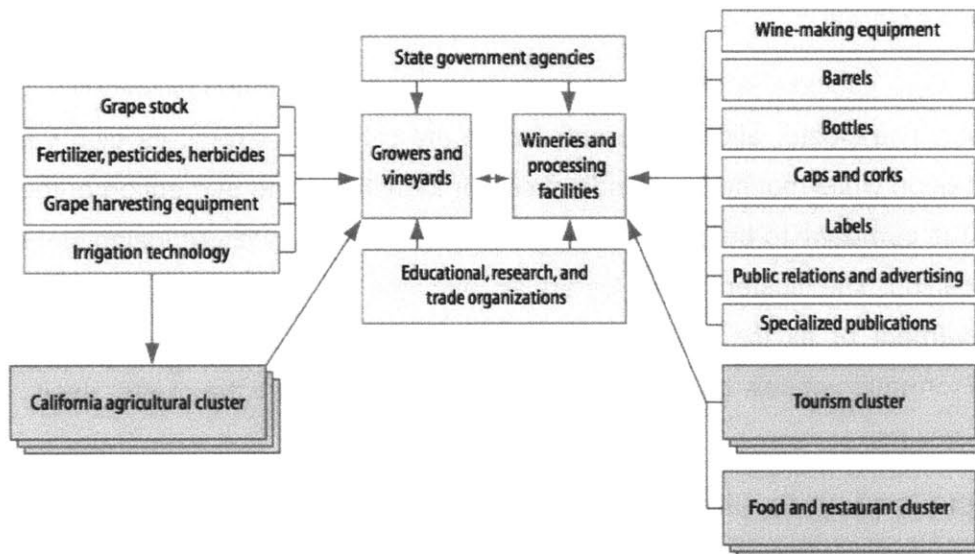


Figure 2. 2 Example of the interactions in the California Wine Cluster. Porter (1999)

The existence of clusters provides a competitive advantage to industries through the following paths:

- *Access to specialized inputs and employees:* clusters provide a better access to superior or lower costs product and specialized inputs such as components, machinery, business services and labor markets;

- *Access to information:* the accumulation of specialized information in the cluster is more easily accessible. Because of this, companies may improve current productivity;
- *Complementarities:* the complementary activities of companies in the same cluster reduces the information asymmetry of the market;
- *Access to institutions and public goods:* The increased demand of public goods and infrastructure to sustain the market encourages the companies to demand better public services.
- *Incentives and performance measurement:* competitive pressure amongst the companies incentivizes more productive performance. (Porter, 2000)

This research implies that that the locational decisions of a company must be based on both total system costs and innovation potential, and not on the existence of industry rivals in an area.

The clusters success is derived from the links created by industry diversity and resource inputs. The cluster allows for each firm in the cluster to exploit its own value creation proposition while monitoring trends of similar industries. The perception of these trends allows the company to be in the avant-garde of technology, without losing sight of its value proposition. The cluster ideally fosters an amicable competition and cooperation for the improvement of all the companies nearby. This feeds back into a loop that stimulates the formation of new businesses that expand and strength the cluster itself.

2.7 Aspects leading to Cluster Formation

A cluster at its most basic level is a set of “groups of industries with high level of co-location in terms of employment” (Porter, 1998). Using this definition, we can easily identify a number of clusters of varying size and scope.

Using this definition of a cluster and corporate theory on location decisions, we can easily identify the following features that lead to the creation and expansion of a cluster:

- Presence of complementary economic activity;
- Specialized suppliers;

- A large or advanced local customer base;
- Producers of complementary products and services;
- Specialized research institutions & labor force;
- Increase the pool of available inputs in a location while giving rise to externalities of various sorts.

2.8 Accessibility, Clusters & Economic Growth

Good transportation infrastructure has long been linked to economic growth and prosperity. This is due to the fact that a “developed transportation system provides adequate access to the region, which in turn is a necessary condition for the efficient operation of manufacturing, retail, labor and housing markets” (Ozabay et al, 2002). Transportation infrastructure provides the accessibility to suppliers and labor markets needed to make a venture expand and grow.

The benefits of transportation projects have focused largely on time and cost savings for travelers. The evidence from the research that focuses on the relationship between infrastructure and economic development shows by and large a positive effect. The studies have focused on highway developments to rural areas showing by and large high economic growth (Isserman et al, 1989; Boarnet 1996; Clay et al 1988). The relationship between highway investment and local economic growth in cities that already had an existing transportation network however, did not exhibit this general positive relationship. (Stephaneades et al 1986). This suggests that economic development is a product of the connectivity and accessibility that transportation provides and not an intrinsic benefit of the infrastructure itself.

The evidence from agglomeration effects has led to attempt to quantify the large externalities of transportation investment projects. Most of these attempts were made by economists utilizing available data to quantify transportation effects.

Most notably Daniel Graham (2007) utilized such data on the London area to quantify the benefits of transportation investments as a requirement for increasing these effects. His findings supported the notion that transportation projects in the London area, where the study was conducted, would bring an increase in the effective densities and could lead to associated productivity benefits via agglomeration.

Utilizing the proposed light rail project in the Tel-Aviv Metropolitan area, Shefer et al (2005) likewise proposed a method, which would quantify the agglomeration benefits to the city. By estimating the increased number of employees in the Central Business District due to the increased capacity of the light rail system, and their contribution to the transactions of the CBD, they calculated that the agglomeration economies could add a significant amount of additional benefits.

Although we still lack a formal way to quantify the benefits of transport infrastructure, the consensus seems to be that amongst the many externalities of transportation projects a critical one is to foster agglomeration. According to Graham et al (2012) showed that doubling accessibility to jobs leads to an increase in real average wages of 6.5%.

As previously stated, cluster theory derives all of its benefits from the creation of these linkages between interconnected industries and inputs. Transportation projects in its most basic nature do just that: to provide links among people, industries, services and resources. Therefore, any transportation project providing additional connections in a city has the potential to spur cluster effects.

Krugman (1991) argues that lower transportation costs will encourage the users and suppliers of intermediate inputs to cluster near each other. Furthermore, Graham (2007) implied the notion of clustering effects as he stated that transport investments affect different types of journeys in different ways, and that these different types of journeys were needed to spur externalities in the city.

Although the focus has only been made on the links that transportation provide to similar industries (agglomerations); sustainable city growth and the benefits of transportation projects might in addition be explained by the provision of linkages among interconnected resources and labor markets from different types of industries.

Subsequently, investments in transportation infrastructure improve accessibility thus connecting more opportunities and increasing potential agglomeration and cluster benefits. We are able to measure economic growth as the longitudinal change in total earnings or income; or simply as employment growth. Using an index for accessibility we are able to measure the potential effect of accessibility on economic growth. Agglomeration benefits would indicate that a corporation's accessibility to similar companies would be the sole cause of economic development. While cluster theory

would suggest that it is rather accessibility to a diverse set of complementary industries and inputs that has a significant relationship with economic growth in the area.

2.9 Expanding urban clusters

Given that clusters seems to be more productive and efficient, companies will look to converge into these rapidly growing areas. However, the advantages from clusters are derived from the efficient links it creates between resources, labor forces and employers. Clusters that occur in an urban environment, such as financial clusters in many downtown business districts, tend to increase densities in that area, and to improve the cities connectivity. As densities increase, congestion limits the automobile mobility of the area. Therefore, cluster locations, in order to continue expanding must offer different types of connectivity to labor and resources. As a company looks for a place to locate, it should search for clusters that are capable of handling a higher mobility load.

According to research done by Boris Pushkarev and Jeffrey Zupan (1977) when an area is accessible solely by automobile, there is a limit of 150,000 end trips per square mile. Therefore in order to continue expanding and provide accessibility to a larger number of end trips, a city must provide public transportation access modes.

Accessibility appears to correlate with lower commuting times and higher transit usage. A 1-percentage increase in accessibility to jobs reduces average metropolitan commute times by about 90 seconds each way and results in a 0.0575-percent drop in auto mode share (Levinson 2012; Levinson 2013)

Clusters rely on a location's accessibility to resources and employees. Providing only automobile transportation to an urban cluster therefore will highly limit its development since it will never be able to handle very high trip density patterns. In order to further understand the benefit of public transportation modes, we should explore the role of transit links in the creation and expansion of urban clusters.

2.10 Transit Investment & Urban Densities

Transit investments are always capital-intensive projects. Ridership and capital costs typically rise with job and population densities, but these high densities are needed

to achieve the ridership increases necessary to produce cost-effective systems. Researchers have consistently found that rail, “with its high up-front capital costs and increasing economies of scale, needs to attain a threshold density of trips in order to cost less than providing the same trips by car or bus” (Keeler, Small, & Associates, 1975; Meyer et al., 1965; Pickrell, 1985; Pushkarev, Zupan, & Cumella, 1982).

In high-density cities, these researchers found that rail was more cost-effective than bus at all passenger volumes and corridor lengths.

Pushkarev and Zupan (1977) estimated land use thresholds for different types of transit. Under the right circumstances—downtowns with substantial office and commercial floor space and linear travel corridors of densely developed multi-family or attached housing—they hypothesized that rail would improve mobility, save energy, and conserve land. According to their calculations, the high costs of a heavy-rail investment would require a net-residential corridor density of at least 12 households per acre leading to a minimum of 50-million non-residential square-foot CBD. A minimal light-rail investment, by comparison, would require a corridor of 9 households per acre to a CBD of 20 to 50 million non-residential square feet.

In an extensive study of 59 capital transit investment projects in 29 metropolitan cities in the U.S., Cervero & Guerra (2011) explored the thresholds necessary to offset the costs of transit investments. They found that transit expansions into residential neighborhoods tended to be a less cost-effective way of increasing ridership than fare reductions or service increases. Furthermore and more importantly, residential extensions needed to be coordinated with concurrent increases in jobs around existing system stations.

The thresholds that were found by Cervero & Guerra (2011) were similar to those of Pushkarev and Zupan’s (1977). Their calculations showed that on average, light rail systems need around 30 people per gross acre (134 per square mile) around stations while heavy rail systems need 50 percent higher densities for such a project to be cost-effective. Their results provided the minimum thresholds to achieve cost-effective transit systems:

The study also adjusted capital cost to city densities in order to determine if light rail systems could be more cost-effective than heavy rail. The study appeared to demonstrate that reaching a 28 job per gross acre limit, heavy rail becomes more cost-effective.

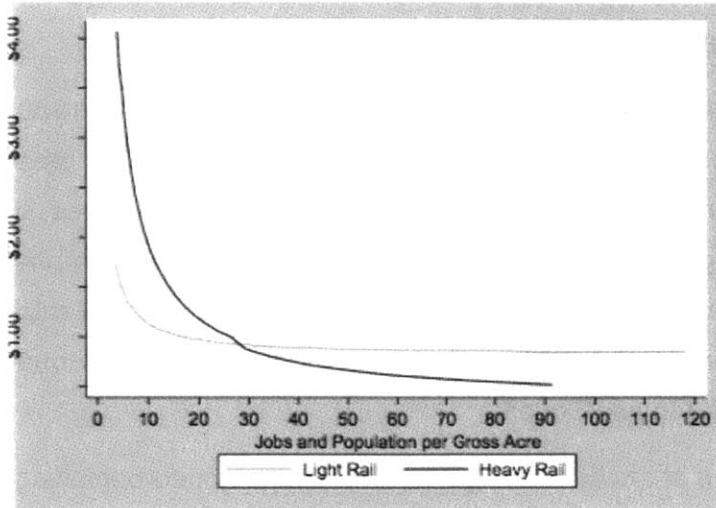


Figure 2. 3 Net cost per passenger mile by jobs and population in average light and heavy-rail dominated cities

Looking at the results from this study, it is evident that increasing the number of jobs around stations appears to have a stronger impact on ridership than increasing population, particularly when comparing figures across systems.

Chapter 3 –Kendall Square as the Study Area

Boston was founded in 1630 by John Winthrop and became a city in 1822. It grew by filling in sections of the Charles River (Block-Schachter 2012). The greater Boston area includes the main dense center, as well as the smaller cities that surrounded it, including Cambridge, Somerville, Quincy and Charleston. The Cambridge area expands north of the Charles River to Somerville and Arlington. It covers 18 square kilometers of land. The largest neighborhoods include: Harvard Square, Kendall Square, Central Square, Porter Square and Inman Square.

Urban mass transportation in the Greater Boston area was provided beginning in the mid 1820's, when hourly coaches crossed the Charles. In 1834 the city provided an omnibus that covered a route that connected Cambridge and Boston and had a capacity of 20 people. [Cheape, 1980]. Charlestown ran omnibuses that ran every 15 minutes into Boston, with half hour service to Cambridge by the 1840s. These agencies were the predecessors of the current Massachusetts Bay Transportation Authority (MBTA).

3.1 Kendall Square

Just over the Longfellow Bridge from Boston, Kendall Square proper refers to the intersection of Main Street, Broadway, Wadsworth Street and Third Street. The Kendall Square area also comprises to the broader business district east of Portland, northwest of the Charles, north of MIT and south of Binney Street.

Originally this area was simply a salt marsh between Boston and Cambridge. The West Boston Bridge, completed in 1793 provided the first direct wagon route between these two cities; immediately converting Kendall square into a transportation hub. (Block-Schachter 2012). It grew to become a major industrial center hosting a number of distilleries, electric power plants, soap and hosiery factories, and the Kendall Boiler and Tank Company. In 1907, the Longfellow Bridge replaced the West Boston Bridge and included the structure to extend the Red Line of the Subway Station to Kendall Square continuing to reach Harvard Square. In 1915, MIT moved its campus to Cambridge, locating between Main Street and Massachusetts Avenue.

3.2 Boston's Innovation Drivers

Boston has been well established, over the last four centuries as a hub for innovation, creative thinking and progress. Throughout many eras, it has been able to maintain this legacy of achievement by fostering an environment that is conducive to this growth. In a qualitative historical analysis of the last four centuries in Boston, a group of researchers from the Boston History and Innovation Collaborative (BHIC, 2006), found the key drivers that have fueled this innovation machine.

In order to identify these drivers, BHIC conducted an eight-year study that looked at more than three hundred innovations produced in Greater Boston. These projects included those listed in the National Inventors Hall of Fame. Using these innovations as examples, and using the help of consultants and scholars, it distilled which drivers had been fundamental for the creation of each innovative technology. The BHIC study was able to find twenty-four “drivers” that had been influential in many projects. Using this long list of drivers, it highlighted the five key drivers. These five key drivers have played a critical role throughout Boston's history. In their findings, the main five drivers for innovation over the last four centuries were determined to be:

- *A dynamic local **Entrepreneur** or team of leaders:* people who have creative problem solving skills and who have the drive to use any resources available to release the potential success that comes with implementing their ideas
- *A local **Network** of people and businesses/organizations:* Boston provides the benefits of collaborating and clustering, which brings in many people from diverse backgrounds to the same working area. Instead of focusing on a specific industry, Boston has capitalized on new learnt information, ideas and services.
- *Local **Funders**:* The availability of Local Funding has been critical in Boston's past, providing the resources and the will to invest in risky ventures.
- ***Local Demand**, which the entrepreneur can use to support a new idea or product:* MIT innovation expert Eric Von Hippel found that “most innovation initially comes from someone who wants to solve a problem that is bugging them”. The diversity in Boston provides a stage to tackle many diverse problems, making demand local and drive personal.

- *Swift access to **National or Global Demand***: Since colonial times, Boston has been viewed as a port for ideas from the international sphere. This allows global problems to be present on the local scope, and once innovative ideas are produced, they are easily spread to other parts of the globe.

There is another major component, 'The Bump Rate', that is not mentioned as a driver, since it responds and reinforces the other key drivers. The Bump Rate was a term first used by Harvard Provost Stephen Hyman and is best described as:

"The potential for people to meet, often serendipitously, due to their proximity. It has been identified as a factor affecting innovations in the areas of idea sharing (abolitionists, Suffragettes), service trading (during the lucrative salt cod trade, where merchants, sailors and farmers all traded services), and the innovation potential of nearby cultures, as seen in the decision Novartis made for their research labs and headquarters. Novartis, a global healthcare products company, chose to move their international research labs and headquarters to Central Square in Cambridge (vs. Burlington/MA, San Diego, or several other places they looked at) so that their researchers would be able to grab a cup of coffee with colleagues, teach at Harvard Medical School or MIT, or come over to the lab to talk. So [...] innovations are dependent on the same local network, a network which often crosses silos."

This degree of interaction is only achieved in places with high density, vibrant streets and urban spaces that encourage the interaction among residents.

Historically, the interactions among shoe manufactures, inventors and risk finance made Massachusetts a major center of shoe manufacture. Today, as this study also showed that Boston's research universities and teaching hospitals, fueled by federal research dollars, were also one of the drivers for innovation. However, it was not just the universities alone that created this innovation and economic potential. Indeed, if this was the only driving factor, other cities such as, Cambridge, England, would have had the same growth patterns that are present in Boston. Universities, research institutions and teaching hospitals are part of a larger innovation environment in the greater Boston area.

Similarly, the interplay among social, political and technological innovation was a motivating factor in a most of the cases studied in this research. This stresses the belief that it is not one single factor that leads Boston's progress, but the interaction between global and local forces.

It is important to note that even as the world becomes increasingly more globalized, the driving factors in Boston's growth are mostly local. This reflects, among others, the importance, once again, of the Bump rate. As virtual distances are shortened

and the ease of company relocation and specialization increases, Boston contributes to cross-fertilization by random encounters of people and ideas under different perspectives. This continues to be one of the unique assets that Boston provides thanks to the combination of an immigrant population, port city status, and identity as a multi-university and multi-business city, ensuring the continuous presence of a diverse culture. “The task is to figure out how to nourish, and replenish, the *HIGH Five* mix, and with it, the bump rate which both responds to and re-enforces the five drivers.” (BHIC, 2006)

BHIC also provides an analysis of each era in Boston’s development. For the most current era, from the 1970s until today, in a globalized economy, these are the factors that found to be most important in sustaining current growth trends. Besides highlighting the importance of **entrepreneurship** and **national/global demand**, as in previous decades, the most important driving factors for driving innovation in the future are also:

- **Local Collaboration and Research Universities:** More so than in previous eras, the city’s universities and foundations play a key role in fostering collaboration between scholars and private ventures;
- **Inter-regional Collaboration:** Innovation that is happening at Boston does not work in a vacuum of other regions, rather it fosters the interaction between entities in various places;
- **Social and Science Interplay:** Boston has worked to improve people’s lives and health through the combination of health care and high tech. The biotech revolution in Boston is integrating the sphere of healthcare and technology to solve societal issues with science.

The study also attributes Boston’s newest innovation surge to the progressive policies including the appreciation for racial and ethnic diversity, inclusion of gay men and women, and religious integration. Furthermore, it notes the importance of transportation infrastructure and accessibility improvements. The expansion of transit services of the Red and Orange Lines, the improvements in commuter rail and the construction of the Silver Line and the Big Dig, which has moved Boston’s six-lane Central Artery highway underground, improved regional access to the CDB, South Boston, Innovation District and airport and created the new Kennedy Greenway as a key

public space, changed the mobility patterns in the city. Furthermore, the city's population is undergoing rapid physical, social, and technological change.

This change has brought new ventures to the city, and builds upon the collaborative nature of a city's culture. Bostonians now lead in developing collaborative ventures that address national and international issues. The universities fuel these movements by providing a world-class education, access to research laboratories, and a highly educated pool of potential employees. Perhaps the universities' most significant role in this period comes in their ability to foster collaboration by attracting talented people, and potential innovators into the region, some of whom remain and contribute to the economy; but more of whom relocate but stay connected contributors.

3.3 Businesses in Kendall Square

Nowadays, Kendall Square is also known as Technology Square, since it has become a hub for technology start-ups. The area has also seen the flourish of the biotech industry. In 2011, this area provided offices for more than 150 biotechnology and information technology firms.

MIT has taken a proactive role in the re-urbanization of the Kendall Square area. It now owns a significant percentage of commercial real estate in the Square and continues construction of space for high-tech tenants. The area houses a number of high-leveled complex parks: One Kendall Square, Technology Square and Cambridge Innovation Center. Furthermore, the increasing number of flexible office spaces allows for short term renting of office space. Cambridge Innovation Center houses about 400 businesses within this type of flexible space. Similarly One Broadway offers housing to a large number of businesses in flexible spaces. Kendall Square also houses a number of venture capital firms that allows for easy access to potential capital for new businesses.

The existing companies in Kendall Square include:

- Akamai Technologies
- Amgen
- AT&T
- Bitstream Inc.
- Cambridge Innovation Center
- Charles Stark Draper Laboratory
- EMC Corporation
- Amazon.com
- Art Technology Group
- Biogen Idec
- Broad Institute
- Computer Sciences Corp.
- Equity Residential
- Endeca Technologies

- Forrester Research
- Google
- IRBNet
- Volpe National Transportation Center
- Kendall Square Association
- MIT
- Millennium Pharmaceuticals
- The MIT Press Bookstore
- Nokia
- Pegasystems
- Sermo
- Vertex Pharmaceuticals
- Whitehead Biomedical Research
- Yahoo
- Genzyme
- HubSpot
- ITA Software
- Kendall Square Association
- KlingStubbins
- Microsoft
- The MIT Press
- Moshe Safdie and Associates, Inc.
- Novartis
- Schlumberger
- Verizon
- VMware
- World Wide Web Consortium
-

3.4 Transportation Infrastructure in Boston

The MBTA began operations in 1897 with light rail operations. It is now one of the most expansive and busiest transit systems in the United States. The served network is composed of 12 commuter rail lines, 4 rapid transit lines, 5 light rail lines, 4 trolleybus lines, 4 ferryboat lines and 187 bus lines. Its fleet is composed of 1,065 vehicles serving a 1,193-mile network. Average ridership is 1.3 million unlinked trips each weekday [Massachusetts Bay Transportation Authority, 2012]. Fares were increased in July 2012. Using the Charlie Card (smart card) fares are \$1.50 for bus service, \$2.00 for rail service and \$70 for a monthly pass. Without a Charlie Card the fares are \$2.00 for bus service and \$2.50 for rail service.

The Red Line runs from Cambridge to Boston and then branches out to Ashmont and Braintree. This line originally ran from Harvard Square in Cambridge to Park St in Boston.

Planning for an extension of the Red Line from Harvard Square to the northwest began as early as 1930. Proposed routes included using Memorial Drive to Watertown, skipping both Porter and Davis Squares and routing beneath Garden Street, skipping Davis Square and going straight to Alewife from Porter Square along the Fitchburg rail corridor, and going farther north to Arlington Heights [Harriman, 1926, Boston Elevated Railway Company, 1938, Metropolitan Transit Recess Commission, 1945, Massachusetts Bay Transportation Authority, 1966, 1969]. The alignment through

Porter and Davis Squares is partially a product of Cambridge reticence and successful Somerville advocacy in the Red Line planning process during the 1970's.



Figure 3. 1 MBTA Map

The Red Line has been extended on numerous times, to Andrew in 1918; Ashmont in 1928 and Quincy Center 1971. The stations of Porter and Davis Square opened for service in December 1984. Most recently the Red Line was extended in the northeast to Alewife, and was in full operation by March 1985. The capacity of the Red Line was expanded by 50% in the late 1980s, by expanding stations to accommodate 6 car trains.

Since that period, the MBTA has also added the Silver Line to its existing network of rapid transit. The Silver Line operates as a Bus Rapid Transit that serves two routes. The first phase opened in 2002 serving the Dudley-Downtown via Washington St. The second phase started operations in 2004 and now uses a bus only tunnel that connects South Station to the South Boston innovation district, before emerging into surface road to continue into the Ted Williams tunnel to serve Boston Logan International Airport trips.

In terms of auto infrastructure, the cities biggest undertaking in recent years was the Central Artery/Tunnel Project. This mega-project, commonly known as the Big Dig, rerouted Boston's most utilized road, the Central Artery (Interstate 93), into a 3.5mile tunnel. Included in this project was also the Ted Williams tunnel that connected Interstate 90 to Logan International Airport, the Leonard P. Zakim Bunker Hill Memorial

Bridge over the Charles River, and the Rose Kennedy Greenway. Planning for the project started in 1982, and construction was done from 1991 and 2006; concluding on December 31, 2007.



Figure 3. 2 Picture of the Boston Greenway prior and after the Big Dig completion.

As part of the mitigation plan for the Central Artery/Tunnel (Big Dig) the state of Massachusetts is legally obligated to extend the Green Line from its current terminus at Lechmere through Somerville to Route 16 in Medford. It was originally scheduled to open by 2011, but it has been delayed and it is currently planned to start operations by 2016-2020. Also planned but suspended because of the current transit finance crisis are plans to expand the capacity of the center of the network, such as the extension of the Blue Line from Government Center to the Red Line Park Street station; the extension of the Silver Line from South Station to the Chinatown station on the Orange Line, to Boylston Station on the Green Line and the Silver Line to Dudley; the Urban Ring Circumferential Service; and the expansion of South and North Station.; and introduction of DMU Service on the Grand Junction linking North Station to Kendall to a new West Station in Allston and the western corridor.

Chapter 4 - Kendall Uniqueness

Kendall Square provides a unique combination of accessibility to people employment opportunities. This distinctiveness is evidenced by its the employment densities, its industries types and its commuter patterns. Trying to compare Kendall Square with other employment areas brings to light the intricacies that in fact make it a unique place of employment.

The Census Transportation Planning Products (CTPP) administers an extensive survey of transportation Home Based Work (HBW) commuter patterns every ten years. This comprehensive data gathering effort provides information of Home Based Work trips from an origin and destination point of view, thus facilitating a better understanding of the unique patterns of Kendall Square. Since the CTPP provides detailed information on the entire Greater Boston area, we may also utilize this data to display the differences between Kendall Square and other employment areas.

Boston's Central Business District (CBD) is considered to be a business agglomeration, and used an example of a business cluster by Michael Porter (2000); therefore we choose to utilize this area in order to compare the commuter patterns of such an agglomeration.

The aim of this analysis being to identify the intricacies that makes Kendall different than other Boston employment areas. And, by comparison to the CBD an other employment areas, explore if the patterns of Kendall indicate its potential as the second city cluster. This hypothesis about the uniqueness of Kendall Square is explored from different perspectives including:

- Rate of employment growth;
- Location of industry types;
- Worker skills and income;
- Commuting travel times and mode share &
- Commuting trip lengths.

4.1 Employment Changes

Employment in the Greater Boston area has been concentrated largely in the downtown and neighboring areas. As seen in Figure 4.1, most of the areas outside the city have actually experienced job losses from 1990 to 2000. At this same time, the city center was gaining jobs. In Figure 4.2, the employment differences in the city center demonstrate an overwhelming job increase in Boston proper as well as Cambridge.



Figure 4.1. Employment changes in the Greater Boston Area from 1990 to 2000. CTPP 1990, 2000



Figure 4.2. Employment changes from 1990 to 2000. CTPP 1990, 2000

If we are to focus on the areas of the city that only experienced job growth in the area, and increase the granularity of the scale, we are able to visualize which parts of the city where those that experienced the highest jobs growth in that time period. The areas that can be highlighted for job growth are:

- The Central Business District
- Kendall Square
- Innovation District / The Harbor
- Longwood Medical Center

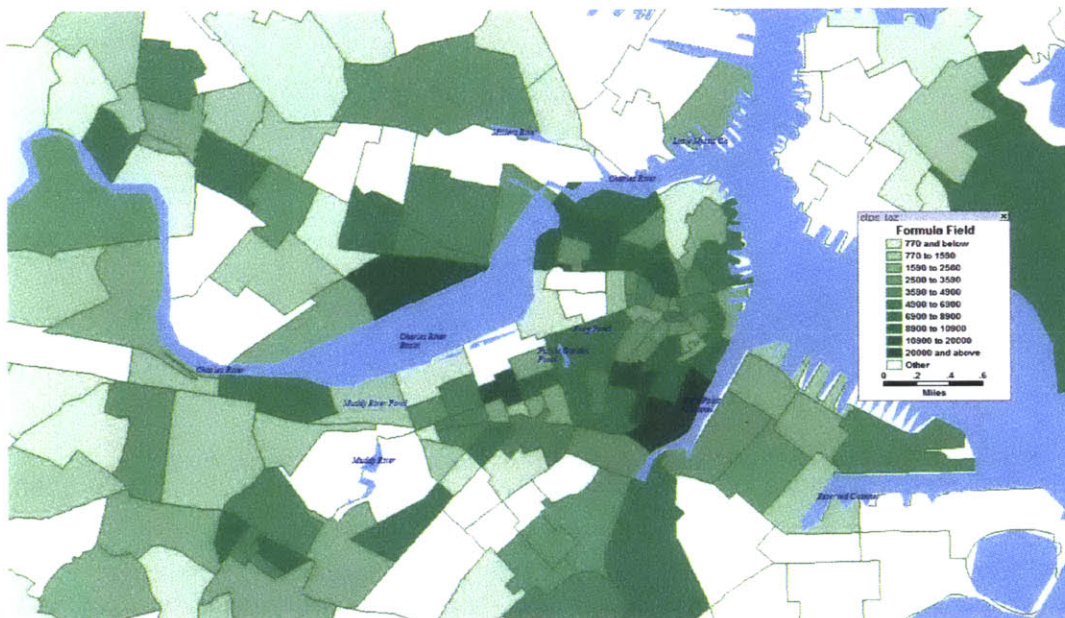


Figure 4.3. Employment Increases from 1990 to 2000. CTPP 1990, 2000

Kendall Square does appear to be unique in its overwhelming job growth in this period, only comparable to the Central Business District (CBD). Kendall Square and the adjacent regions, near Mass General Hospital, appear to have the highest job increases from 1990 to 2000. The waterfront Innovation District, which is being advertised as another mayor employment center did experience job growth, but its increase was not as large as that experienced in either the Kendall Square region or the CBD.

4.2 Industry Types

One of the main claims that supports the idea that Kendall is unique as a sustainable employment center is that it houses a distinctive industry combination that is not similar to any other. Kendall's proximity to MIT would suggest that the industries present in the Kendall area would rely heavily on research and innovation. A closer look at the overall employment opportunities in the Greater Boston Area, displayed that industry type serves as a stark contrast to the job mix in other places.

For the purposes of this research, we have aggregated employment into four mayor industry types: Information technologies; Finance, Insurance, real estate & rental & leasing; Scientific, professional, management, administrative and waste management; and Educational, health and social services. Aggregating industries into these subcategories allows us to visualize the industry diversity in the Boston Area.

Kendall appears to have a unique industry combination, as displayed in Figures 4.4 and 4.5 corresponding to CTPP 2000. The identity of Kendall area appears to be distinctively focused on a diverse environment of Scientific and Educational industries, with a smaller subset of information and Finance jobs.

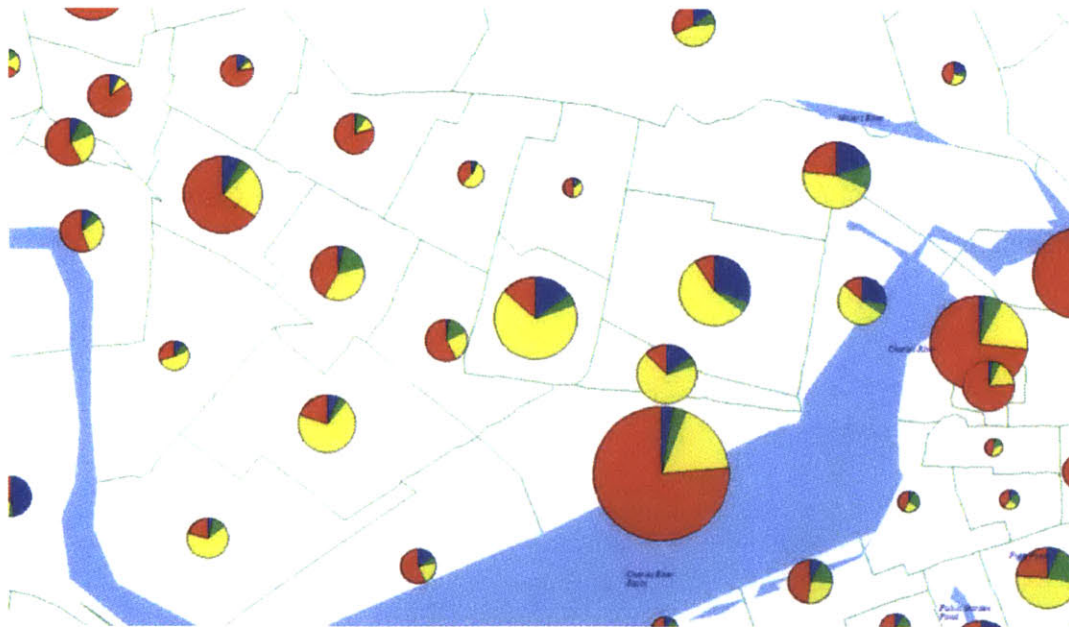


Figure 4.4. Jobs in the area displayed by industry type as Information (Blue), Finance(Green), Scientific(Yellow) and Educational(Red). CTPP 2000

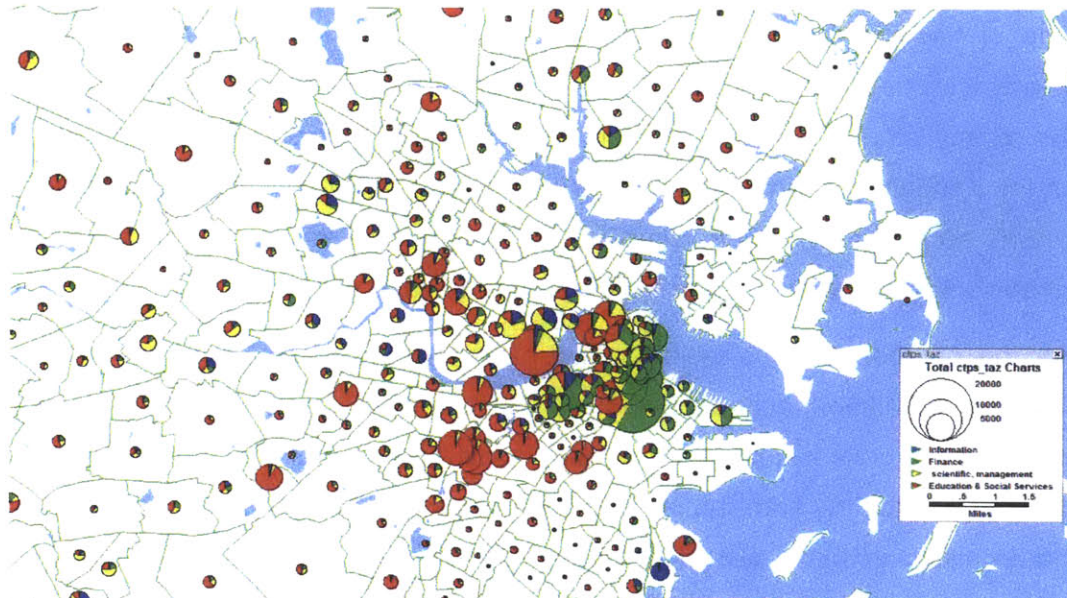


Figure 4.5. Jobs in the area displayed by industry type as Information, Finance, Scientific and Educational. CTPP 2000

The focus of the selected four employment areas appears to be (Figure 4.6):

- The Central Business District identity: Finance and some scientific
- Kendall Square identity: Scientific and Educational
- Longwood Medical Center identity: Educational
- Innovation District / The Harbor identity: Similar to that of the Central Business district, that is Finance and Scientific

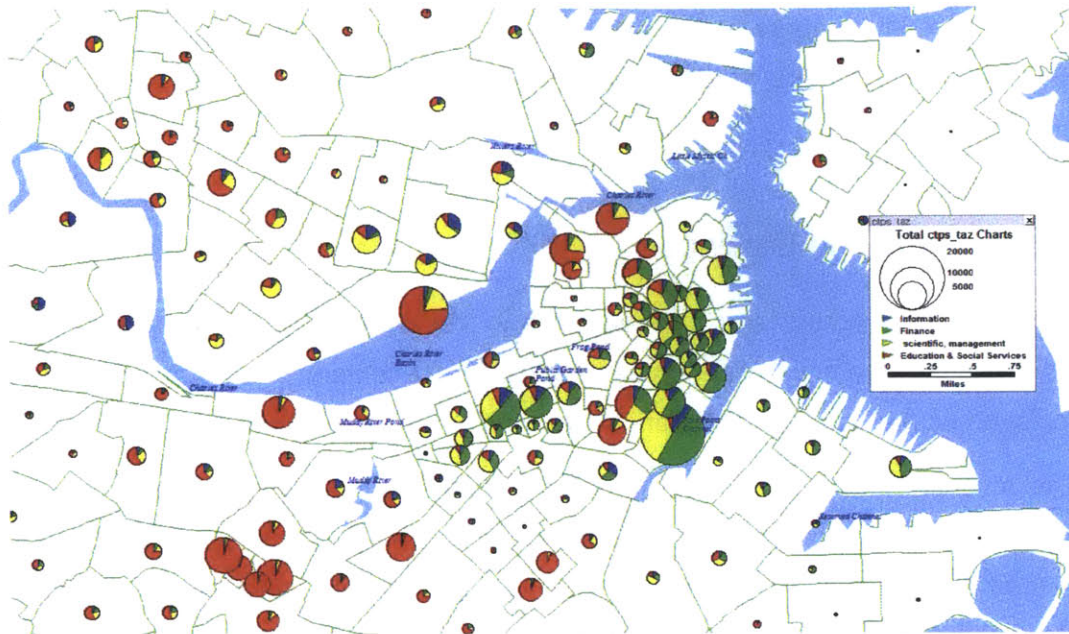


Figure 4.6. Jobs in the area displayed by industry type. Information, Finance, Scientific and Educational. CTPP 2000

From the 2000 CTPP data, we gather that the Central Business district focuses on Finance and Scientific industries and provides a diverse environment for these. The Innovation Center seems to mimic the industry type displayed in the Central Business District, but is unable to provide the substantial employment opportunities provided in the CBD. Therefore, the Innovation Center seems to compete with the CBD to provide a work environment that is quite similar to the one in the city's downtown area.

The Longwood Medical Center does not provide significant industry diversity, but rather concentrates just on Educational and Research facilities. This seems reasonable given number of teaching hospitals and medical educational facilities in the area.

Kendall appears as a unique combination of research facilities and educational centers (MIT) with scientific industries. Therefore, Kendall Square does not compete with other strong employment centers, such as the CBD, but rather offers a unique work and educational environment that is only found in this area.

The industry employment combination appears to be indicative of Michael Porter's Cluster Theory. The Boston CBD, which has been used by Prof. Porter as an example of a financial cluster (1999), provides a strong focus on financial industries, while still providing a diverse work environment. In the same manner, Kendall Square provides a cluster for technology and scientific industries. By combining industries that are complementary, yet competing with each other, Kendall Square becomes a unique

in this sector. The environment becomes attractive to other companies in those fields, since the environment fosters a collaborative and innovative environment that is only found in Kendall Square.

4.3 Worker Type and Earnings

Exploring the workers and their earnings in the Greater Boston area provides further information on potential differences in employment centers. As is common, most of the employed workers appear to be private for profit and non-profit salaried workers.

The diversity that was found in industry type is once again present in worker types. The most diverse worker type environments are in the central business district as well as in the Kendall Square area. Figures 4.7 and 4.8 display the different worker types in the Boston Area, broken down in: Private salaried workers; Non-Profit salaried workers; Local government workers; State government workers; Federal government workers; Self-employed & Unpaid workers.

While the CBD is clearly the main employment center, Kendall Square and the Longwood Medical Center have private worker numbers that are comparable in size. Furthermore, Kendall Square has private non-profit salaried employment in the same or larger proportion as of private for-profit workers. This is most likely a product of MITs workers since the same large number of private non-profit workers is seen in the Longwood Medical Center, given its nature as a large educational center.

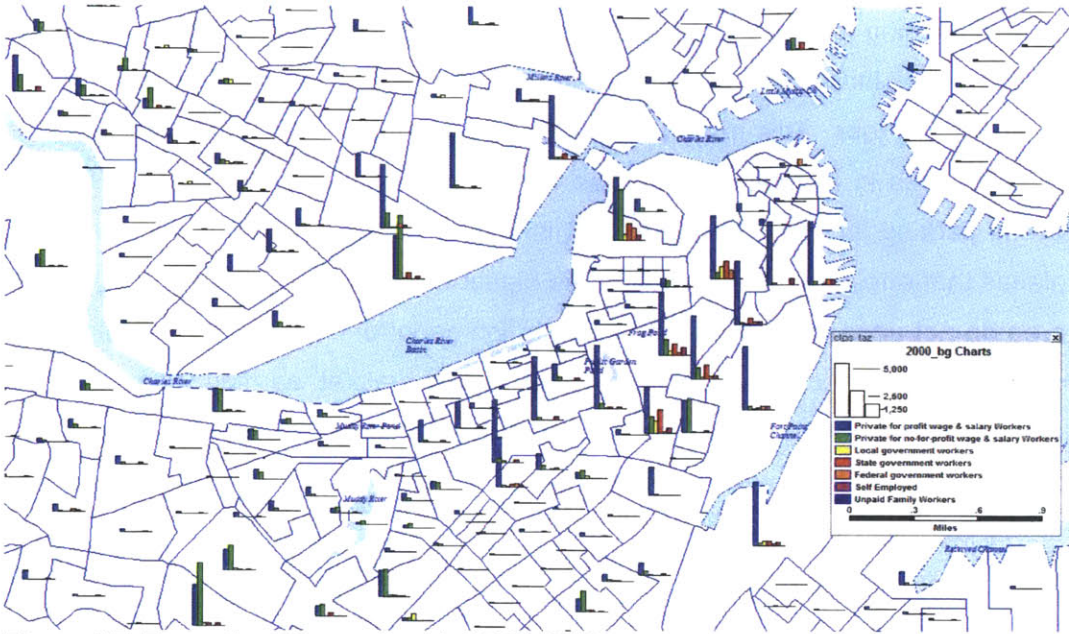


Figure 4.7. Type of worker employed. CTPP 2000

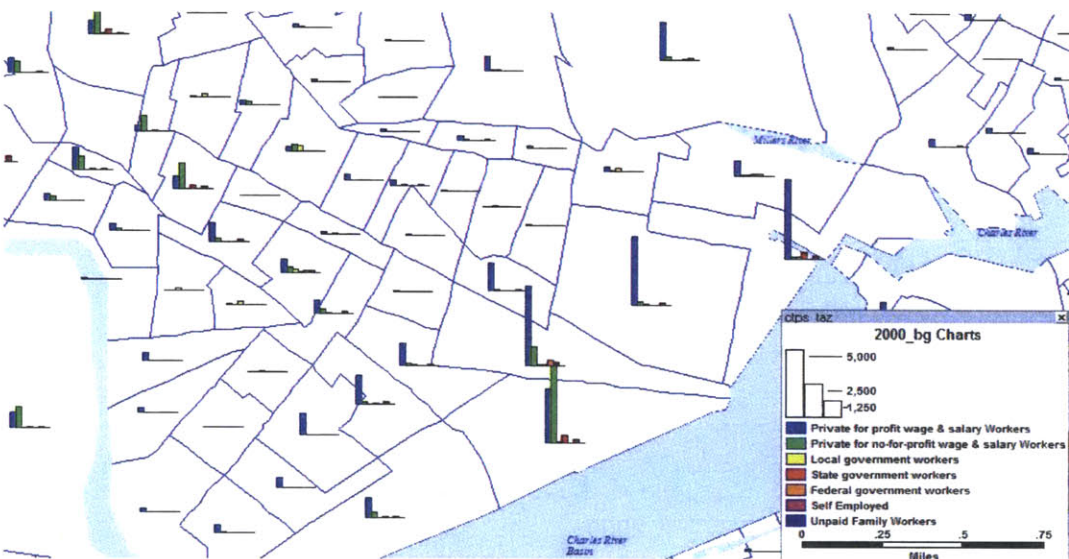


Figure 4.8. Type of worker Employed. CTPP 2000

Worker earnings also provide insights on to the type of jobs that are located in Kendall Square and other Boston areas. In the Greater Boston area, the average workers correspond to the lowest earning bracket. It must be noted that worker earnings correspond to annual earnings in 1999, from the CTPP 2000 survey. Although there is likely to be an omission bias by people who do not wish to disclose their earnings, using the recorded results we are able to notice once again a pattern of uniqueness in the Kendall and CBD area. The maps shown in Figures 4.8 and 4.9 describe worker earnings for Boston employment centers.

Highest earning jobs are located in the CBD, Kendall Square and the Longwood Medical Center. The Innovation District does not seem to employ many people in the highest-level earning jobs. This may represent a lag in employment densification as the densification process in Kendall Square has a head start. The Innovation District was dominated by parking lots ten years ago, but is now the site of substantial investment. Certain places that one would think would have higher worker earnings, such as Harvard Square area do not appear to offer those kinds of job opportunities. Kendall is unique by providing a combination of lower bracket and higher bracket earning opportunities. Although most high paying jobs appear to be in the CBD, the distribution in Kendall Square seems to be the most evenly distributed.

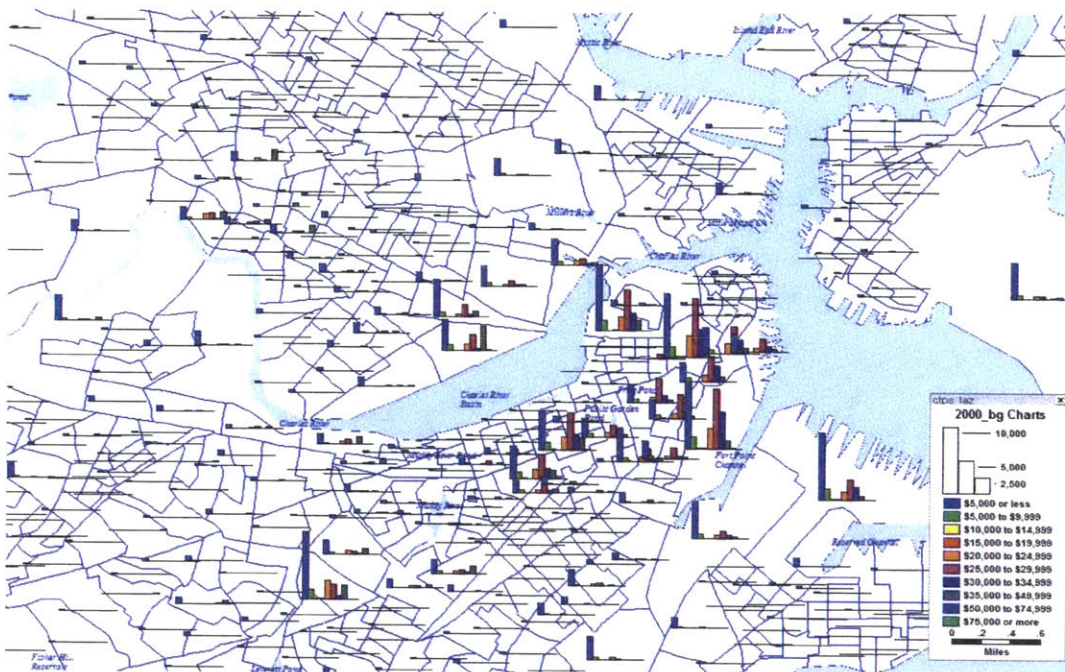


Figure 4.9. Worker earnings in 1999. CTPP 2000

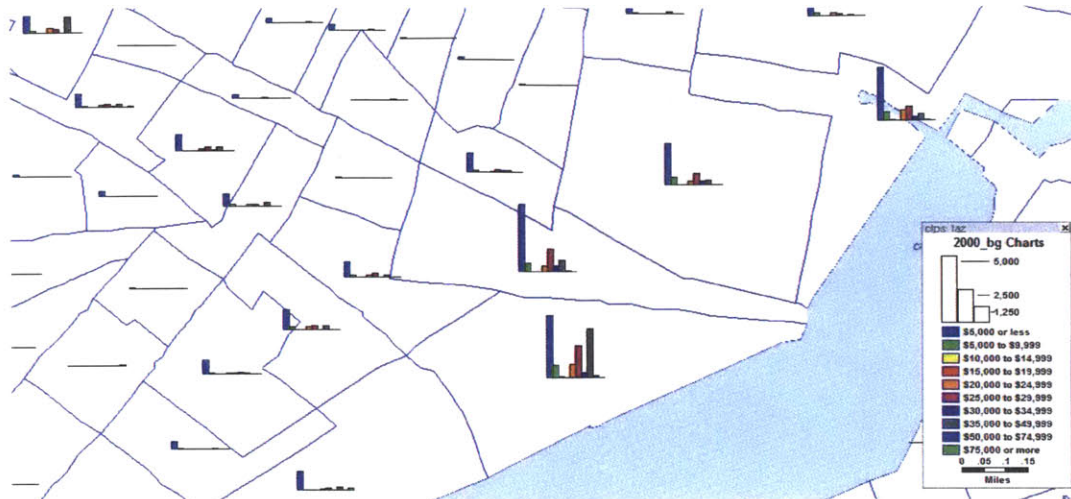


Figure 4.10. Worker earnings in 1999. CTPP 2000

4.4 Commuting Travel Times

Given the differences in job growth, industry types, as well as worker types and earnings in the Kendall Square area, we explored commuting patterns to determine if those predicted differences translated into differences in access commuting patterns. Figure 4.11 displays the mean travel time for trips on all modes, while 4.12 displays the median trip travel time for all trips. As seen from these figures. Kendall Square has average commuting times that are among the lowest of all employment centers. The CBD, although being the main employment center, has some of the longest average times.

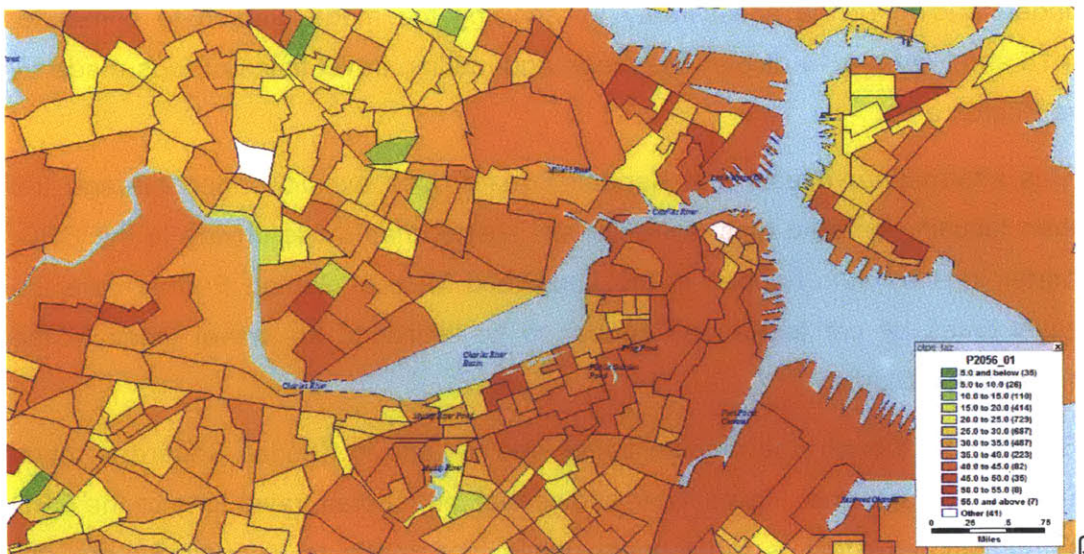


Figure 4.11. Mean Travel times for made trips on all modes, displayed by trip destination. CTPP 2000

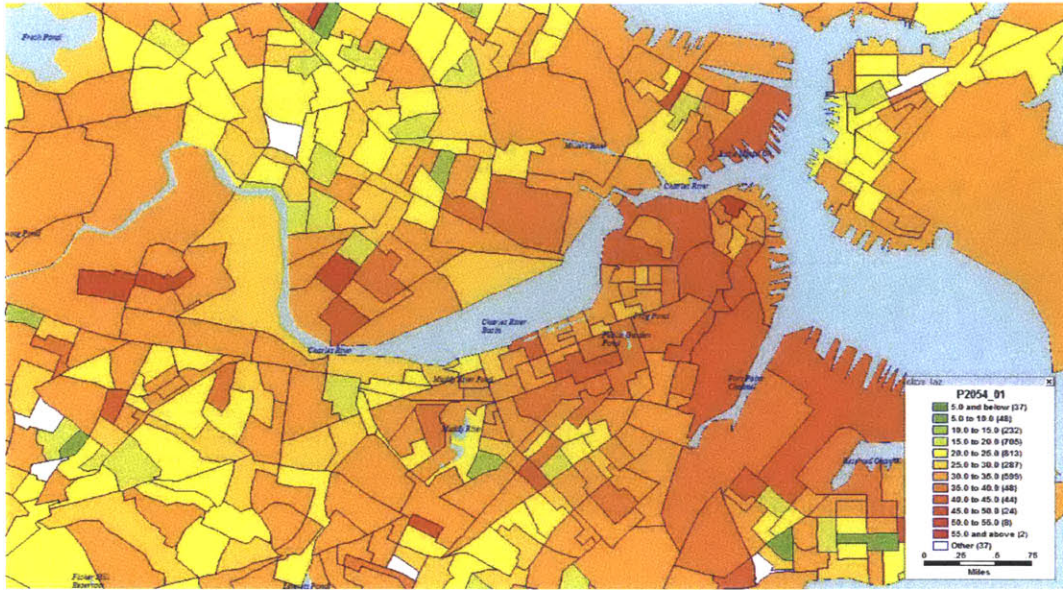


Figure 4.12. Median Travel times for made trips on all modes, displayed by trip destination. CTPP 2000

	Mean	Median
Kendall	35.22	29.14
Financial District	43.86	40.46
Longwood	32.25	27.50
Seaport	40.92	37.26
Bpark 93	36.78	29.75

Table 4. 1 Mean and Median Travel Times for HBW trips made on all modes. CTPP2000

4.4.1 Travel time – Drove Alone

The CTPP also provides information on trip times by mode. This provides a better understanding of the accessibility by showing the mode chosen to commute. Figure 4.13 and Figure 4.14 display the mean and median travel times of trips made by car in the Boston area.

This information reveals that Kendall Square does exhibit longer average trip times when focusing on auto trips, although still shorter than those driving to the CBD. Even shorter trips by auto happen in the Longwood Medical Center. Furthermore the mean travel times by car to Kendall appear to be similar to the travel times to the Seaport Innovation District.

Surprisingly though, the median travel time by auto to Kendall Square is much lower than the average one. Figure 4.14, shows that the median travel time to the CBD and the Innovation District is the longest, while trips made to Kendall Square are comparable to those made to Longwood Medical Center. This suggests that although

the mean travel time looks to be quite long, in fact most of the trips are of shorter length, but there are a number of very long trips made to the Kendall Square that raise the average trip length.

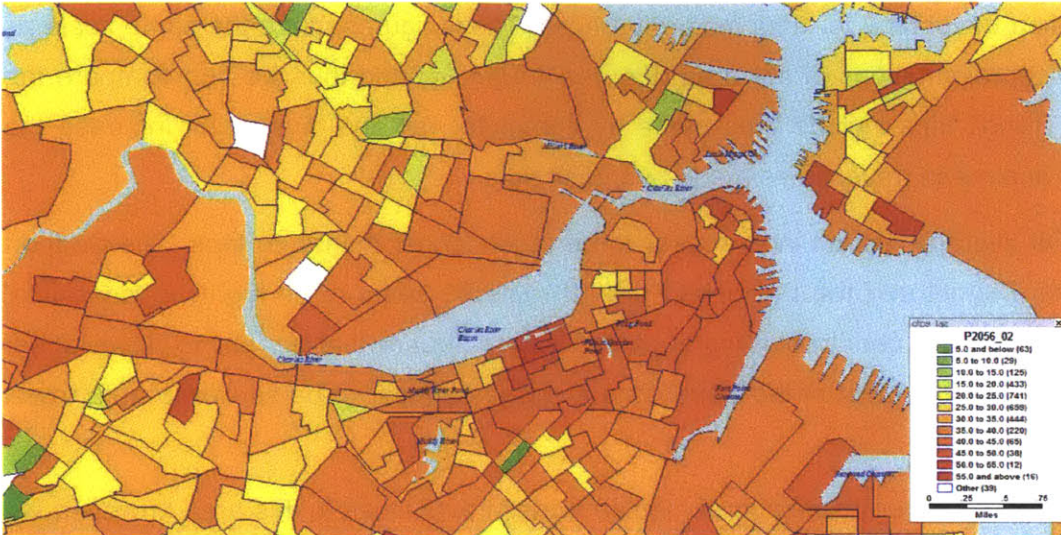


Figure 4.13. Mean Travel times for made trips by driving, displayed by trip destination. CTPP 2000

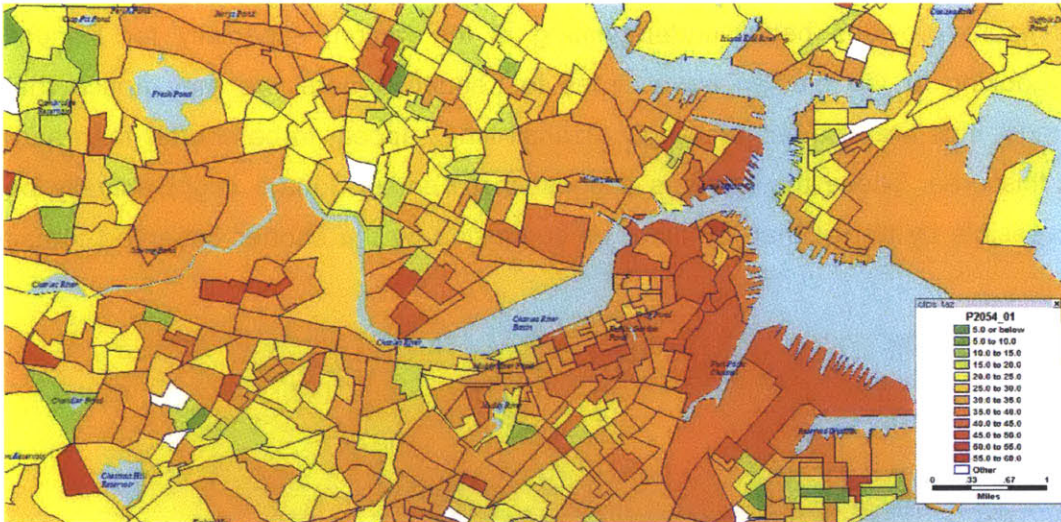


Figure 4.14. Median Travel times for made trips by driving, displayed by trip destination. CTPP 2000

	Drove Alone		Carpool	
	Mean	Median	Mean	Median
Kendall	36.70	31.20	43.15	44.39
Financial District	43.03	40.09	46.36	43.52
Longwood	35.32	29.49	29.41	26.38
Seaport	38.41	34.94	40.55	38.82
Bpark 93	31.16	28.76	29.22	29.71

Table 4. 2 Mean and Median Travel Times for HBW trips made by driving alone or carpooling. CTPP2000

4.4.2 Travel time by Transit

The trip length for trips made by transit is sparser, since not all block groups are transit accessible or have recorded transit trips. Figure 4.15 and 4.16 display the mean and median travel time for trips made by transit. These figures utilize the same scale as previous representations of the area (Figures 4.11-4.14) and thus we can compare the results. Transit trips include trips made by commuter rail and thus might increase the average and mean travel times made by transit trips.

On average, transit trips appear to be much longer than auto trips. The Seaport Innovation District and the Business Park off route 93 seem to be highly inaccessible. Although there are certain block groups at Kendall Square that appear to have longer transit travel times, most of the travel time averages appear to be similar to auto travel times.

Upon a further inspection of median transit travel times to this area however, we are able to notice that in fact, mean transit travel times might be skewed by longer commuter rail trips. Figure 4.16 displays the median travel times of trips made by transit, and this figure provides better understanding of the region, especially for Kendall Square. Looking at the median travel times to Kendall Square, we may notice that indeed, most trips are of a shorter length. Transit times appear to be shorter than auto times to this area. These trip patterns suggest that Kendall Square might actually be more accessible by transit than by auto, as suggested by the shorter observed transit times.

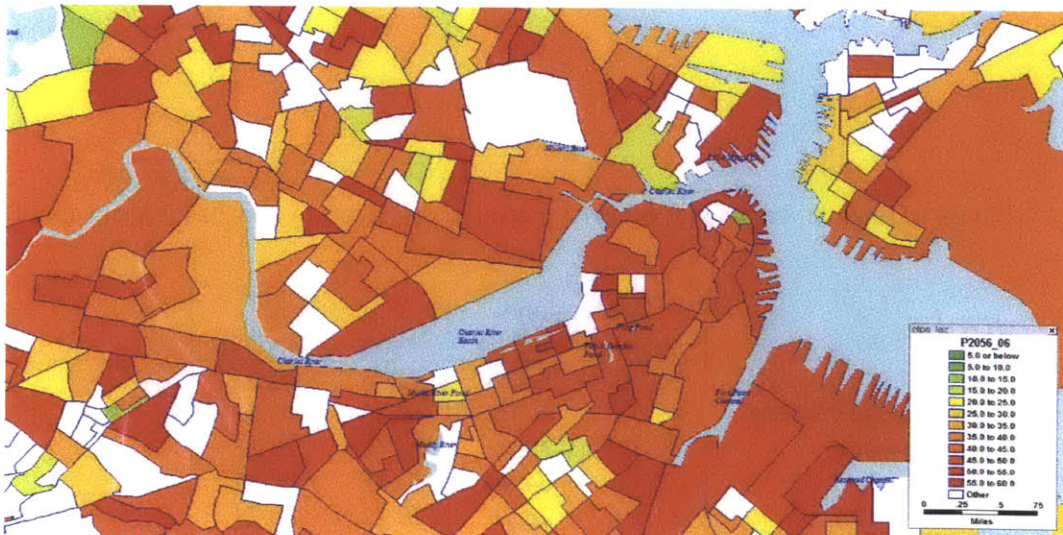


Figure 4.15. Mean Travel times for made trips by transit, displayed by trip destination. CTPP 2000

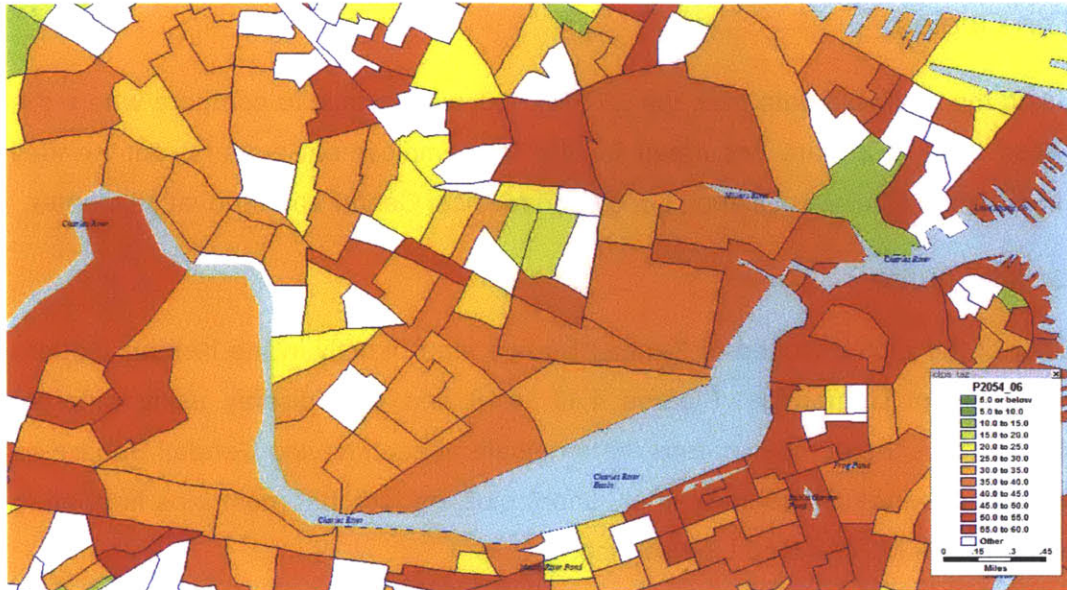


Figure 4.16. Median Travel times for made trips by transit, displayed by trip destination. CTPP 2000

	Subway		Bus		Bike	
	Mean	Median	Mean	Median	Mean	Median
Kendall	37.43	33.01	50.46	37.93	15.08	13.81
Financial District	39.58	39.00	43.77	37.97	17.98	15.60
Longwood	39.34	38.30	49.45	38.33	10.80	8.25
Seaport	44.17	42.92	49.19	46.35	18.67	18.10
Bpark 93	53.78	40.44	39.12	37.02	10.85	11.96

Table 4. 3 Mean and Median Travel Times for HBW trips made by Subway, Bus or Biking. CTPP2000

Exploring the difference in travel times, it is clear that Kendall Square has the best overall actual travel times for people who were, at the time, making the commute to Kendall Square. Unique to this area furthermore was that the travel times by rail are similar to travel times by car, therefore, this would seem to suggest that the origins of the trips for rail commuters were also closer to Kendall Square and in close proximity to transit lines.

Although the CBD is the historic business center, the congestion and trip lengths makes it such that the mean auto travel times are longer. In terms of accessibility though, given the spatial distribution of socio-economic patterns, it cannot be implied that accessibility will be equally low, as presented later on. Trips to the CBD generally have the largest travel times, which might be indicative of the congestion experienced daily in this region.

4.5 Trip Origins

Using the available data from the CTPP 2000, we are able to compare where the Home Based Work Trips are originated for the four employment centers: our Kendall Square, the Central Business District, Longwood Medical Center and Innovation Center.

4.5.1 Kendall Square

Most of the trips destined to Kendall Square start directly in the Kendall Square or in the vicinity of Cambridge. Figures 4.17, 4.18 and 4.19 display using different geographical scales the number of trips that originate at each having Kendall Square as a destination. These results seem to imply short, plus the fact that most trips happen in areas served by the MBTA's Red Line service.

Given that Kendall Square houses MIT and its students, it seems reasonable that a large part of the people that are employed there might also live near the campus. Furthermore, new housing developments in Kendall Square, as well as housing in Main Street and Central Square might provide residences for many of the workers in Kendall Square.

The trip origins nevertheless are largely concentrated in the Cambridge or Boston Area. More specifically, one may notice a trend that most trips originate in areas served by the MBTA rail service.

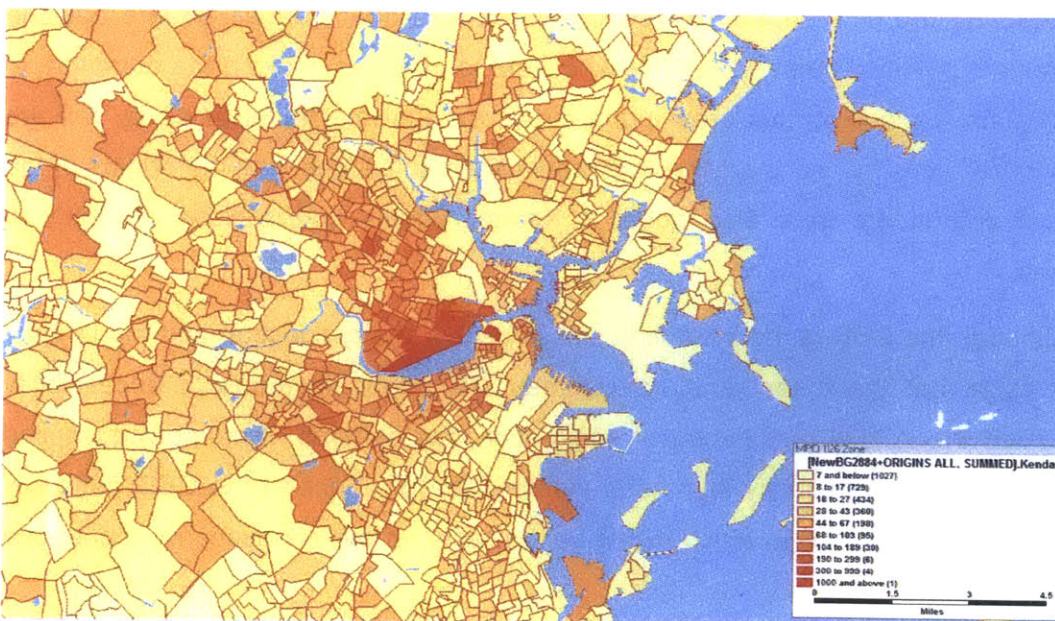


Figure 4.17. Origin of trips made to the Kendall Square Area. CTPP3 2000

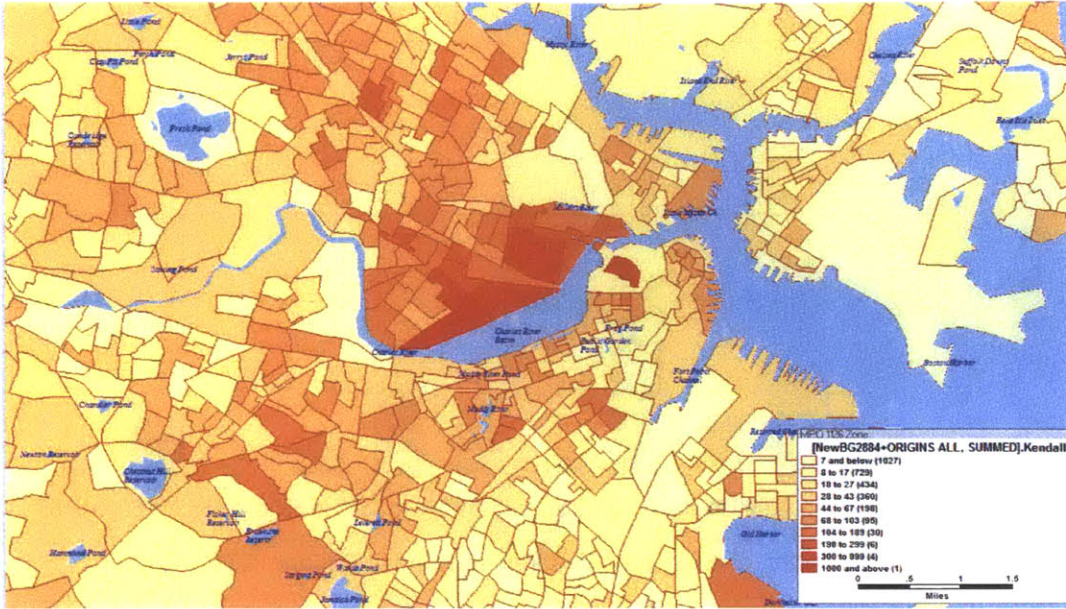


Figure 4.18. Origin of trips made to the Kendall Square Area. CTPP3 2000

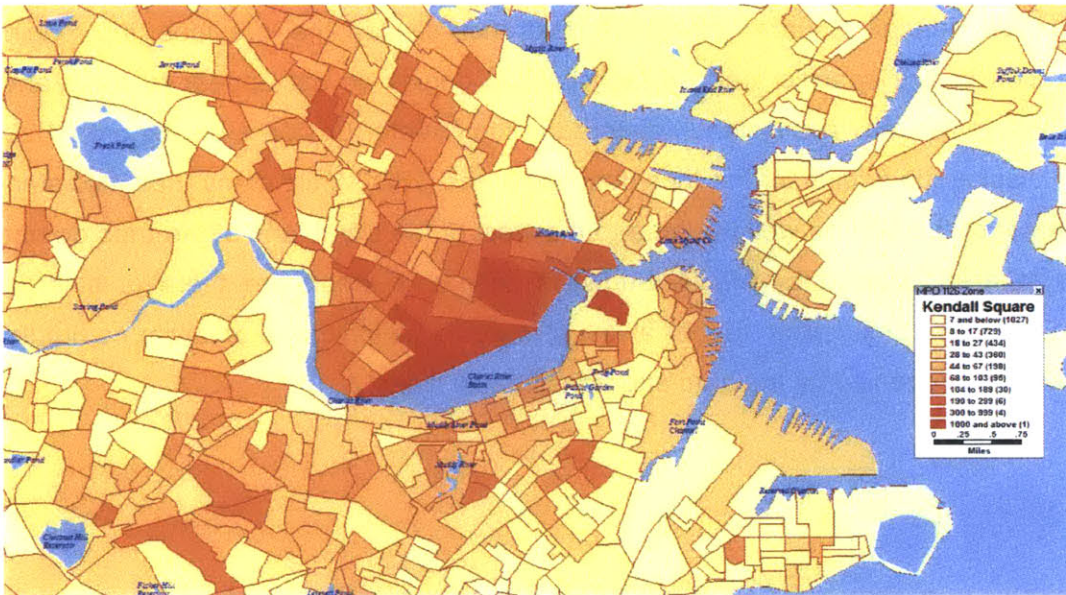


Figure 4.19. Origin of trips made to the Kendall Square Area. CTPP3 2000

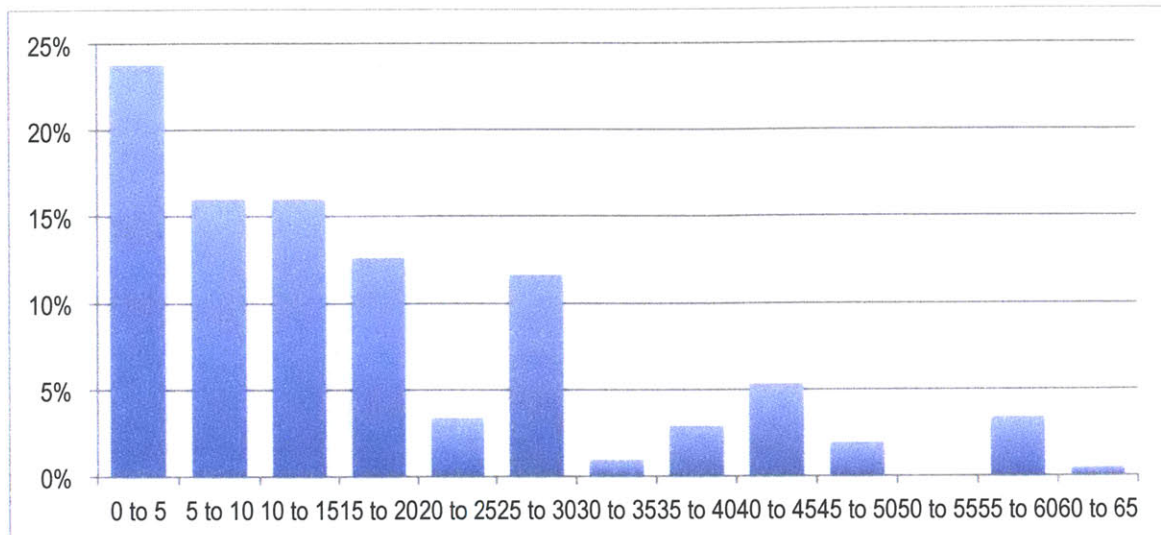


Table 4. 4 Trip Length Distribution of HBW trips destined to Kendall Square. CTPP 2000

4.5.2 Central Business District

Unlike Kendall Square, the CBD does not display the previous trip origin concentration in any specific area. In fact, the trip origins do not appear to have any specific pattern, as they are instead scattered in the Greater Boston area. Figures 4.20 and 4.21 display trip origins for the trips destined to the CBD. While many trips also start in the Center of the city, as well the area to the west of the city. Many of the trips do not originate in areas served by MBTA Subways service. Furthermore there is a large proportion of trips coming from farther away, that would be indicative of larger commute times previously revealed by the auto and transit travel times.

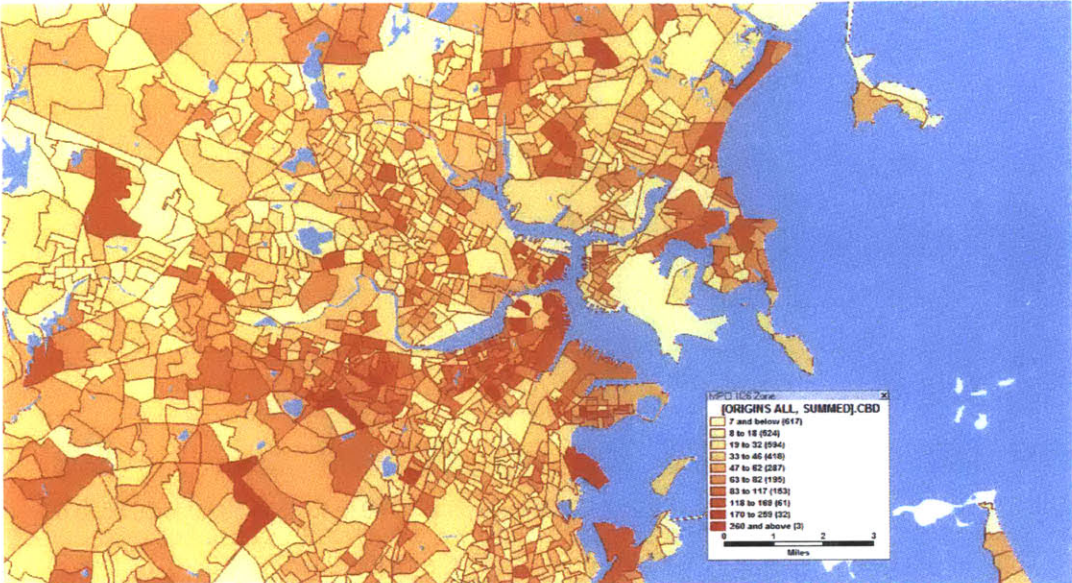


Figure 4.20. Origin of trips made to the Central Business District. CTPP3 2000

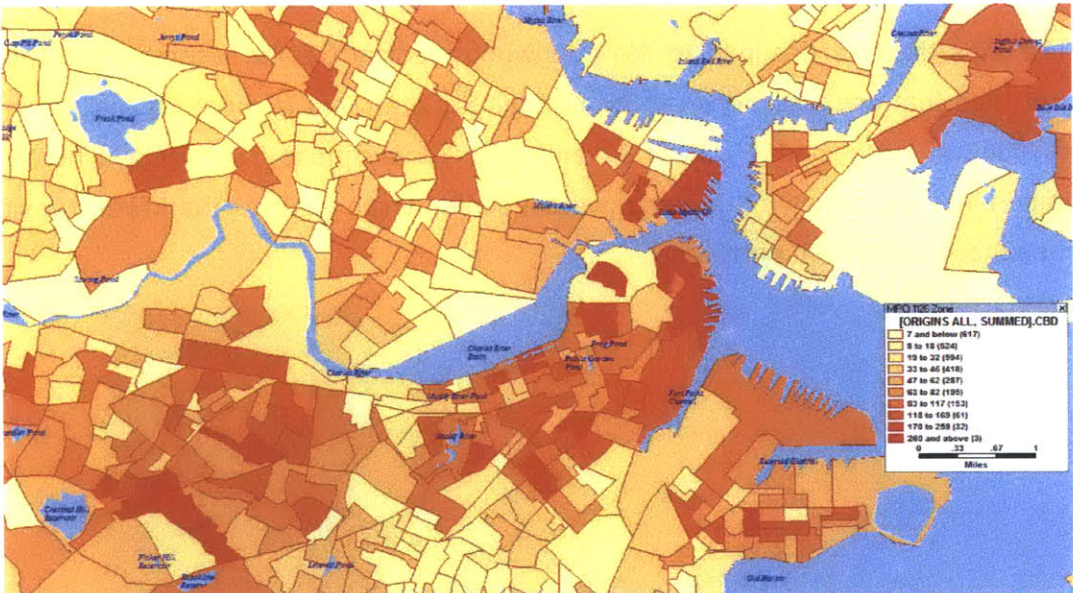


Figure 4.21. Origin of trips made to the Central Business District. CTPP3 2000

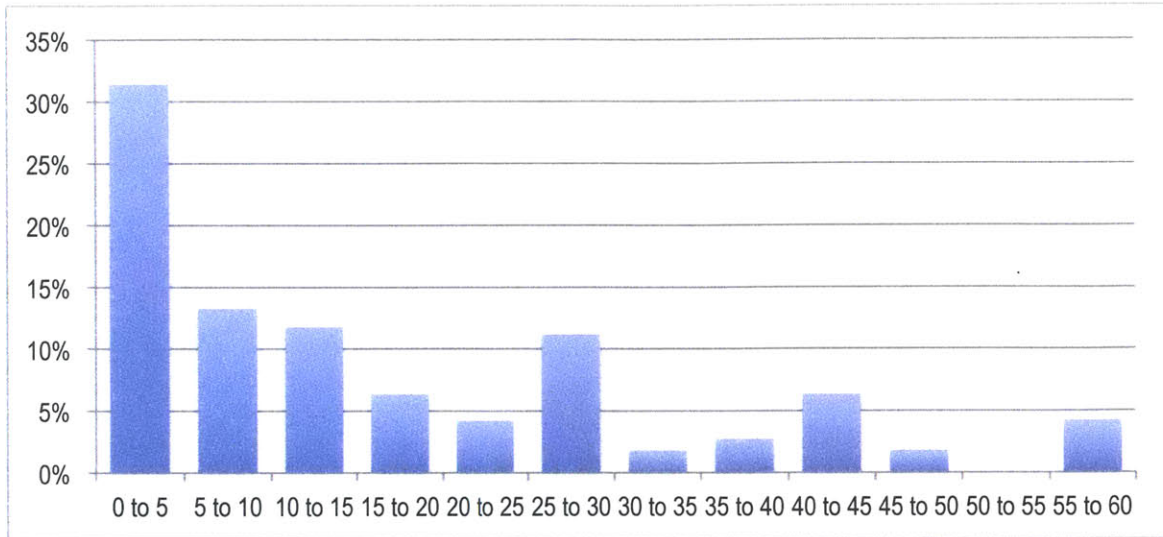


Table 4. 5 Trip Length Distribution of HBW trips destined to the CBD. CTPP 2000

4.5.3 Longwood Medical Center & Innovation District

The trips that are destined to the Longwood Medical Center resemble the trip patterns of trips that are also destined for Kendall Square. That is most origins are in close proximity to Longwood. Figure 4.22 and 4.23 display these trips. With a heavy concentration in the proximity of the employment center which explains the lower transit travel times that were shown previously.

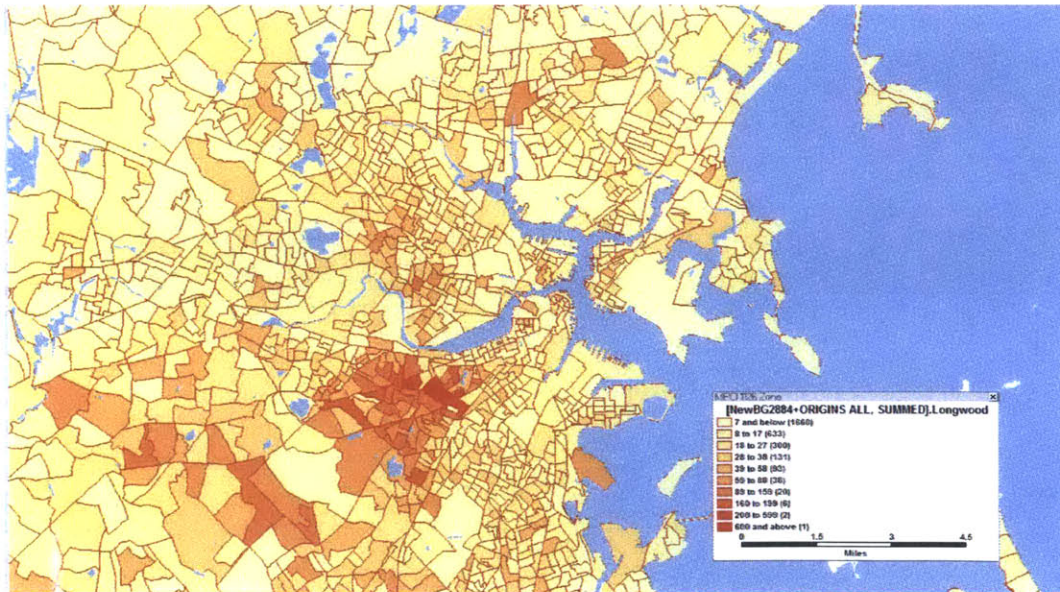


Figure 4.22. Origin of trips made to the Longwood Medical Center. CTPP3 2000

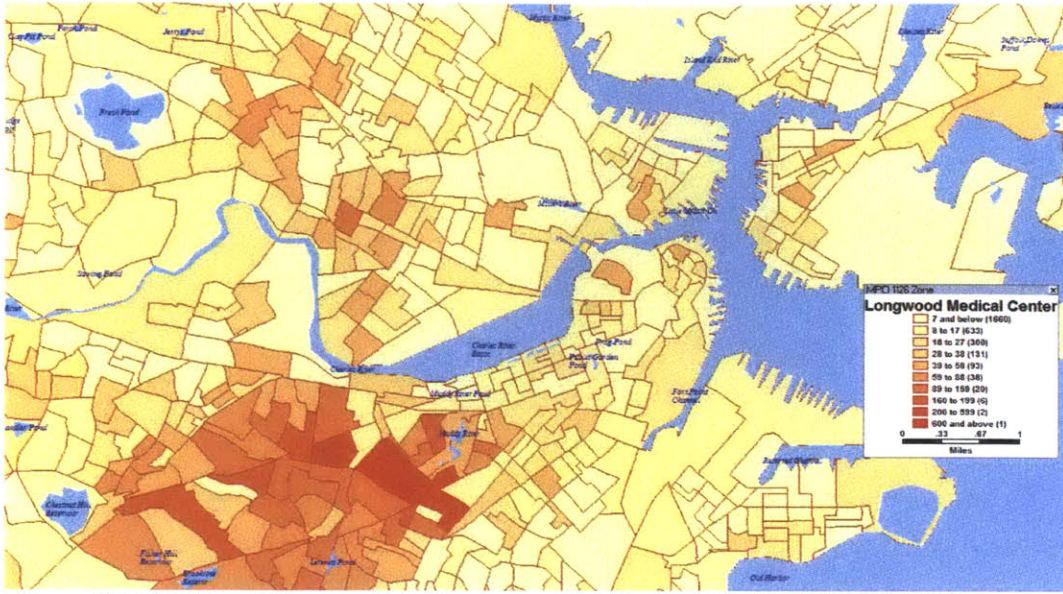


Figure 4.23. Origin of trips made to the Longwood Medical Center. CTPP3 2000

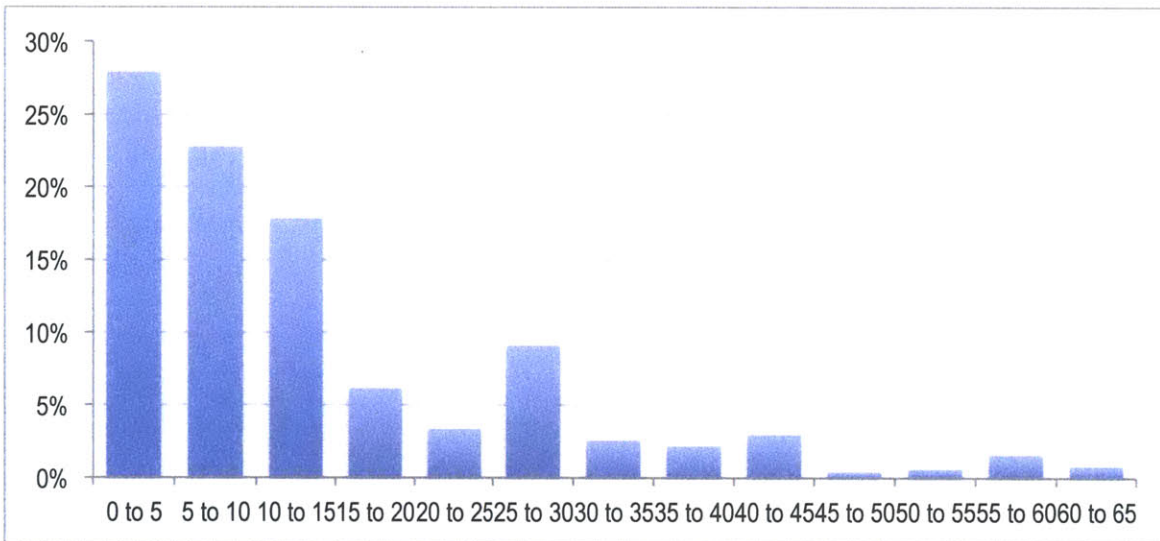


Table 4.6 Trip Length Distribution of HBW trips destined to the Longwood Medical Center. CTPP 2000

Unlike Kendall Square and the Longwood Medical center, the trip origin patterns for the trips destined to the Innovation District more closely resemble those of the Central Business District. There seems to be no apparent pattern in trip origins, as they are rather scattered throughout the Greater Boston Area. Figures 4.24 and 4.25 display the trip origins. The commuting patterns do not seem to have a pattern, and are rather spread out around the city and areas that are served by different modes.

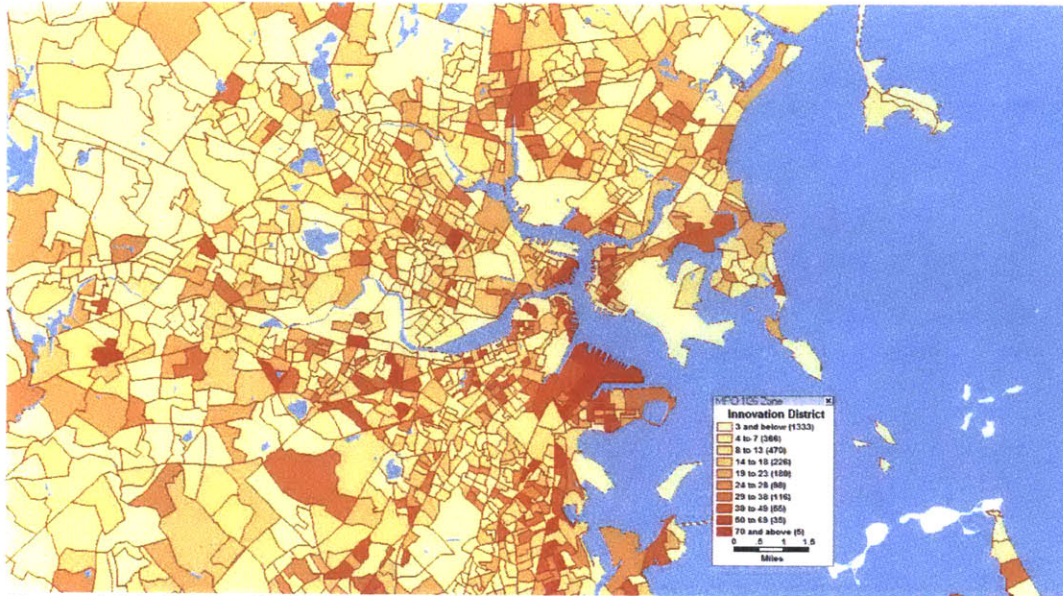


Figure 4.24. Origin of trips made to the Innovation District & The Harbor. CTPP3 2000

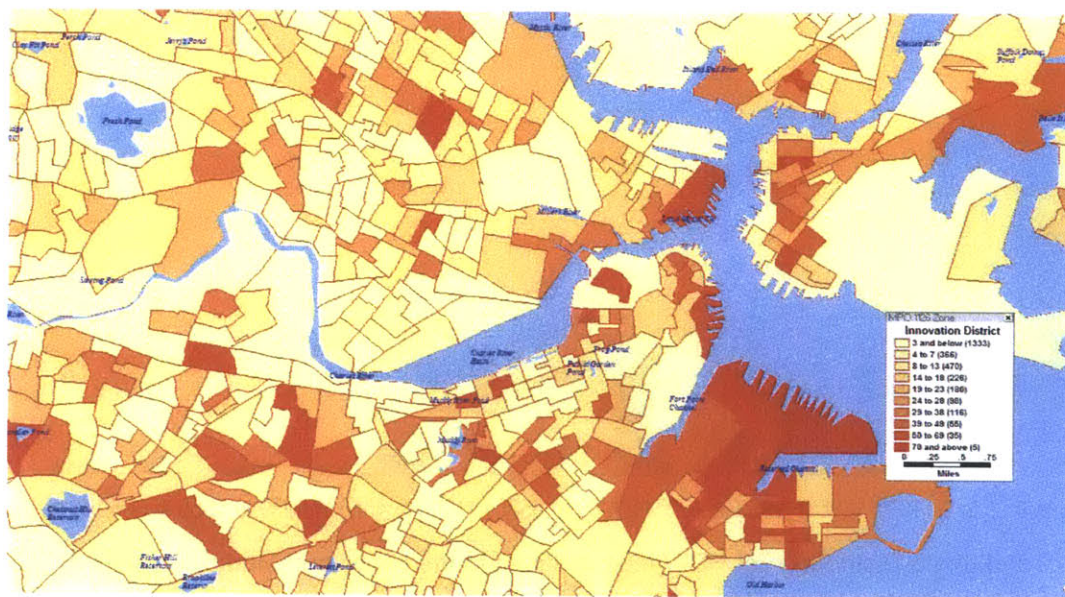


Figure 4.25. Origin of trips made to the Innovation District & The Harbor. CTPP3 2000

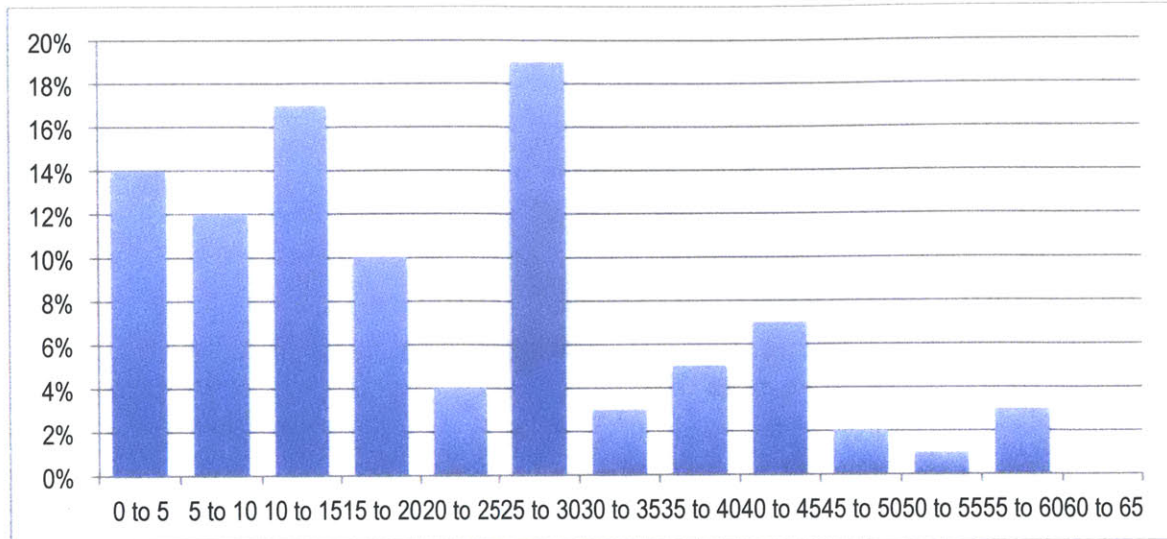


Table 4.7 Trip Length Distribution of HBW trips destined to Innovation District & The Harbor. CTPP 2000

Upon a closer observation of trip origins, Kendall is unlike other employment centers given that trip origins are concentrated in the vicinity of Kendall Square, as well as in Cambridge. Trips to the CBD and the Innovation Center have origins scattered around the greater Boston Area. Longwood Medical Center resembles more closely the patterns seen in Kendall Square, where there is a larger concentration of origins within walking distance, possibly because of the large number of students going to school in the area though trips to Kendall Square rely more heavily on transit.

4.6 Modal Split

Exploring the modal split provides another perspective to analyze the uniqueness of trips made to the Kendall Area. To better understand commuting patterns in the Greater Boston area, we have focused on the modal splits for both the 1990 and 2000 CTPP to verify whether there is a shifting commuting culture from one decade to another.

Figure 4.26 and 4.27 display a close up of modal split (displayed by trip destination) for home based work trips for the year 1990. As we are able to see from these graphics, the mode mostly used is the private automobile. While there is a stronger reliance on public transportation modes in the Central Business district and in the Kendall Square area nearest to MIT, other regions still depended on the auto as their main commute mode.

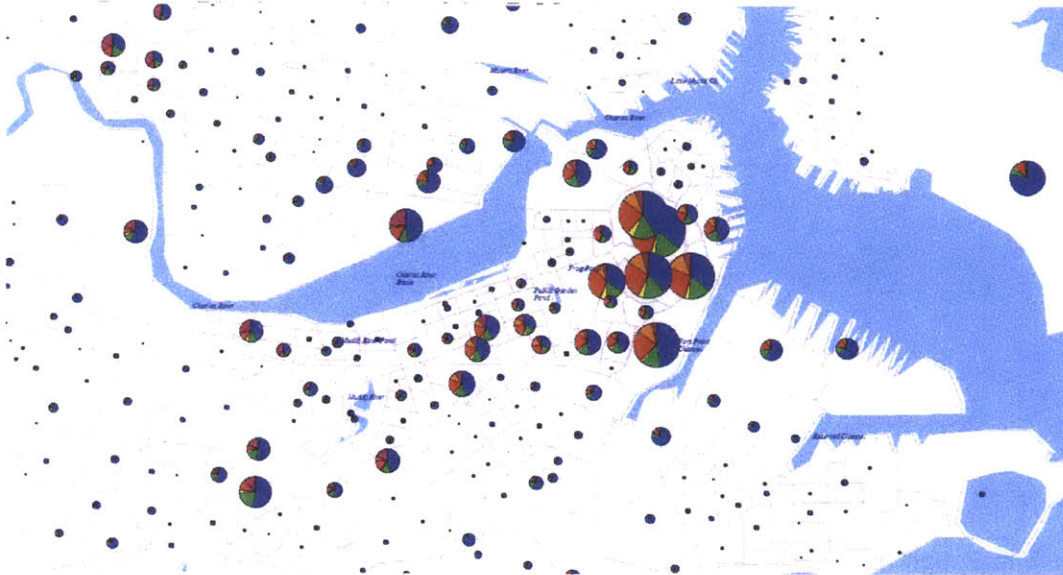


Figure 4.26. 1990 Modal Split displayed by trip destination

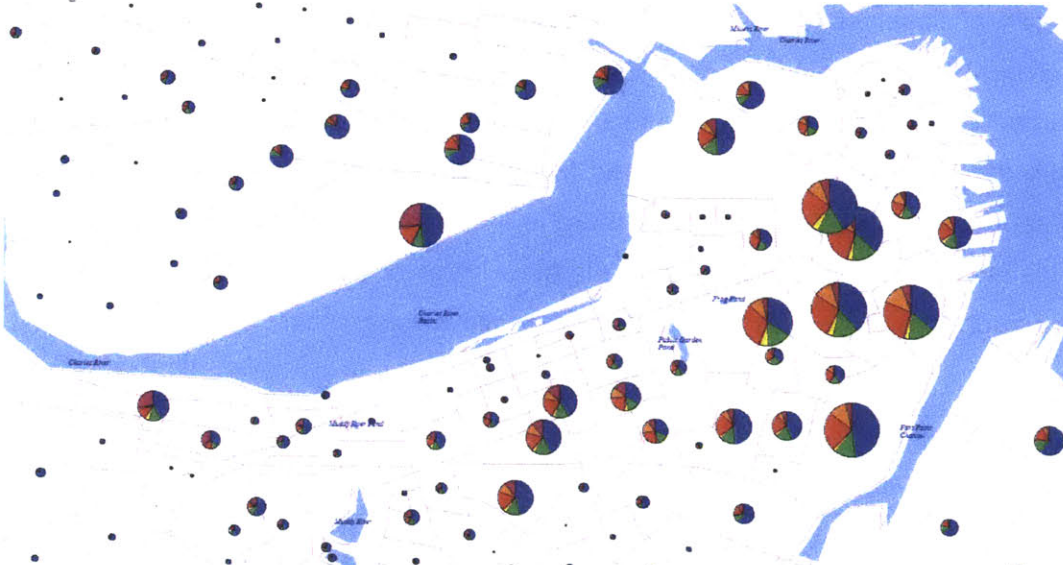


Figure 4.27. 1990 Modal Split displayed by trip destination

Looking at the most recent available CTPP (2000), we can appreciate a shift towards a larger reliance on transit. Figures 4.28, 4.29 and 4.30 display these most recent results of the CTPP survey. Once again, it displays the modal split based on the trip destination.

Whereas, back in 1990, only the CBD was the only region where the auto did not serve the majority of the trips, the 2000 CTPP shows that there are a number of regions that have shifted towards transit, including Kendall Square and Harvard Square. In fact, there is a general shift away from private transportation means, and a heavier reliance

on bus and rail where they are available. These areas appear to have already surpassed the trip limit suggested by Pushkarev and Zupan.

Particularly in Kendall Square, the attached graph shows that the modal split resembles the more dense part of the city and the CBD. The area closest to MIT again shows the least dependency on the auto, which is common for educational institutions. Nevertheless in 2000, Kendall Square does seem to rely less on the automobile and more on transit.

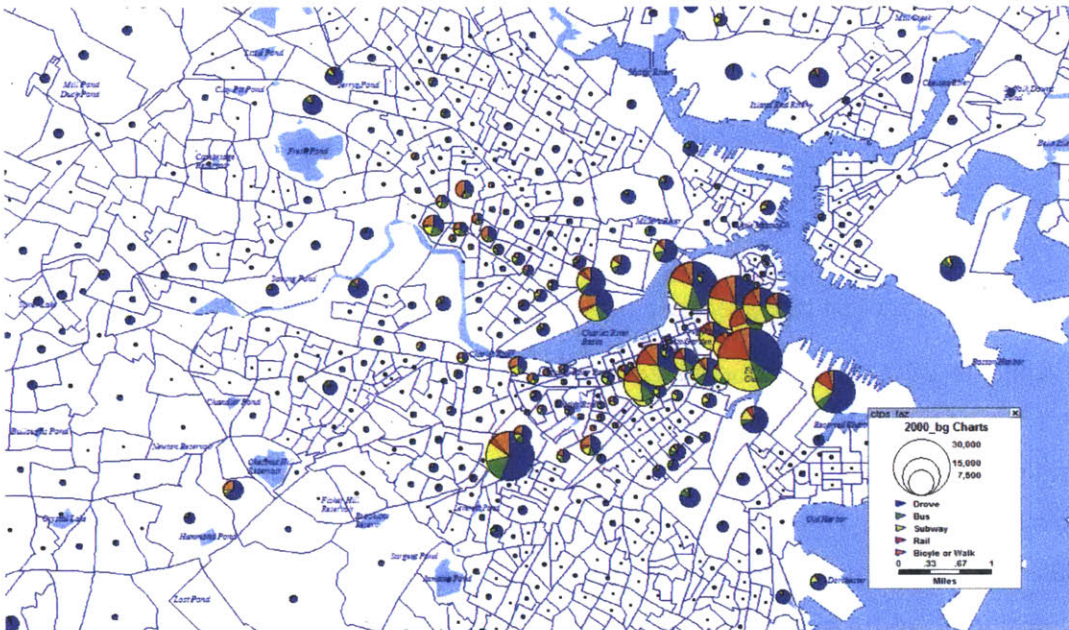


Figure 4.28. 2000 Modal Split displayed by trip destination

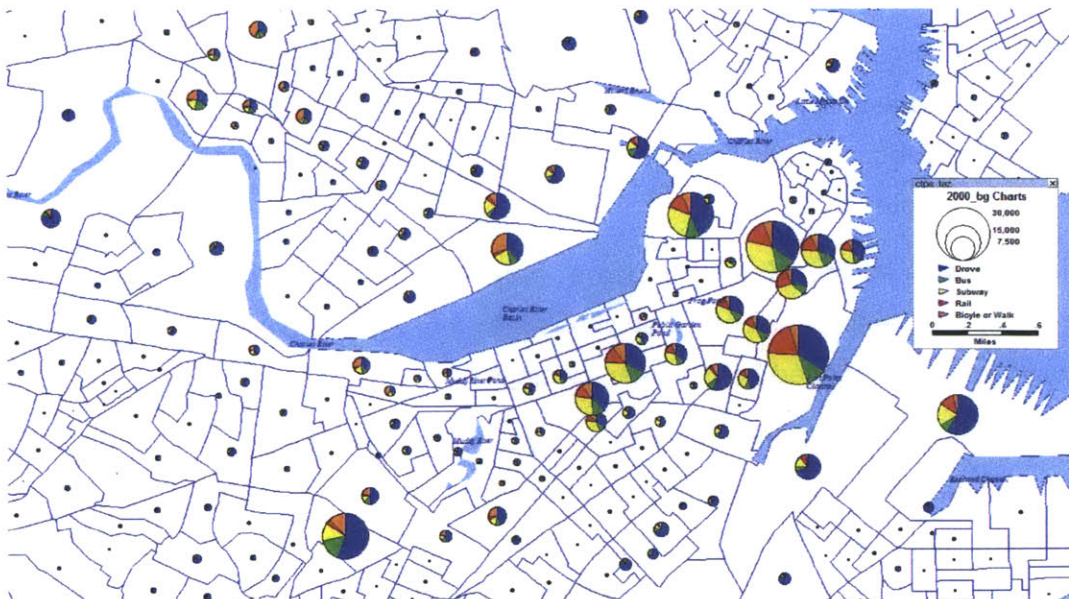


Figure 4.29. 2000 Modal Split displayed by trip destination

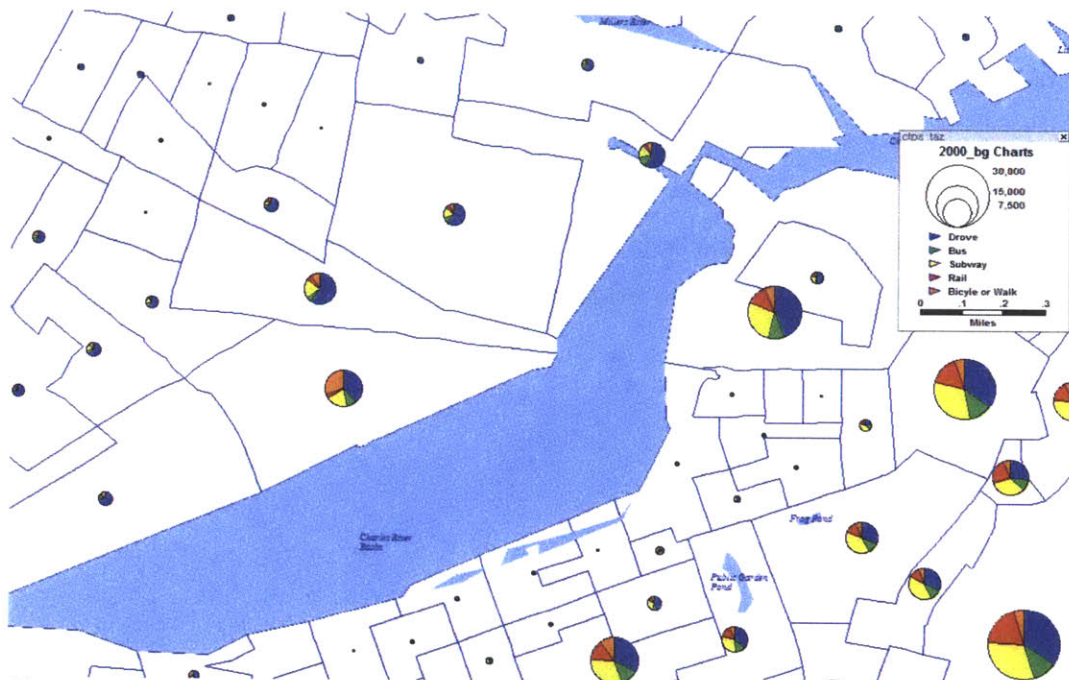


Figure 4.30. 2000 Modal Split displayed by trip destination

From the 2000 CTPP Survey we can infer that driving remains to be the most common form of transportation in the Greater Boston area. However, transit appears to be the main transportation mode in business centers and high-density residential areas and employment areas. There is a significant reliance on walking and bicycles in the MIT & Kendall Area, while the subway remains to be the most common form of transit. Overall the period from 1990 to 2000 witnessed an increase in transit modes and a shift to commute by subway rather than private automobile

Currently Boston holds a small number of dense employment centers, the historic central business district serves as the main employment center, and while recent employment increases in Kendall Square reinforce its uniqueness from the perspectives revealed in this chapter.

Job growth in the Kendall Square area is only comparable to the one experienced in the Central Business District. On the other hand, the jobs also appear to be highly skilled jobs, as deduced from worker earnings.

While areas such as the Innovation District try to compete with the CBD by providing employment in industry types that are similar; Kendall Square has managed to take advantage of the research, academic and scientific culture in the area, given by its proximity to MIT, developing its own unique culture, identity and startups. Kendall Square employment, worker and earning patterns seem to indicate the emergence of a

cluster, as defined by Michael Porter, as an area that fosters an amicable competition and cooperation for the benefit of all the companies nearby. Kendall Square does not compete to provide the best financial services, but rather has defined its own niche, by combining research and academic ventures, with scientific and technology companies.

This uniqueness is evidenced also by the commuting patterns to this area. Transit trips to Kendall offer similar, or better travel times than their automobile counterpart. As this would indicate, most of the trips originate in the proximity of the area, or other areas served by transit.

Given the most recent transit data, we can confirm that this uniqueness that has shifted modal split by relying more heavily on transit rather than the private automobile. The resulting modal split begins to mimic the patterns seen in the more heavily dense the CBD.

This analysis portrays Kendall Square as a unique place of employment due to its closeness to MIT and its easy accessibility, whose distinctiveness has allowed Kendall Square to attract many companies and foster a high employment density areas. Much in accordance with Porter's cluster theory, Kendall Square appears to provide a high employment density area of research, qualified people and corporations resulting in a sustainable and successful business location.

The data from CTPP appears to reflect this similar idea. Kendall Square has been an area of much employment growth over the last decades. Unlike the Seaport Innovation District, which has yet to define its own industry niche and is currently competing for the same industry type as the CBD; Kendall Square houses mostly scientific, educational and venture capital offices. It is not an agglomeration of corporations focusing on one industry, but rather a cluster of inter-related industries offering a unique concept. The employee types and worker earnings in Kendall Square most closely resemble those of the CBD, the other high-density cluster in Boston.

Kendall is also unique in its commuting patterns. Travel times to Kendall Square are lower when compared to the other major employment areas in the region. Furthermore, trips to Kendall Square though transit trips appear to be shorter or equal to trips made by car, a tendency only seen in this area. This suggests that there is a good transit accessibility and close geographical proximity.

In fact trips destined to Kendall Square usually originate in the vicinity, mostly in Cambridge and adjacent communities, possibly because of the large numbers of recent graduates in the workforce. This is in stark contrast to the long distances covered by those who work in the CBD or the Innovation District. These characteristics have led to a growing use of transit as seen in the modal split.

Chapter 5 – Current Growing Trends in Kendall Square

Since the Census Transportation Planning Products (CTTP) has, as of May 2013 not released complete data set for the 2010 census CTPP, current transportation trends have to be examined from other data sources such as the American Community Survey (ACS) 2008. This chapter examines other available data sources that provide further insight to the most recent commuting trends in Kendall Square

5.1 Case Study: Cambridge Innovation Center

Cambridge Innovation Center (CIC) is the “area’s largest and most popular flexible office space facility for small and fast-growing companies”. (CIC, 2013) CIC is situated in One Broadway Street, right in the middle of Kendall Square across from the MIT campus and the Red Line Kendall Square Station. Created in 1999, the start-ups in this office space have raised more than \$1.7 billion in venture capital since 2001, which the administrators of CIC started keeping these records.

Our clients frequently tell us that shoulder rubbing among the investors and other emerging companies located in the center makes CIC an enjoyable place to work. While there is no expectation to do so, we find clients frequently choose to interact and leverage each other’s expertise and networks to uncover new opportunities and build new relationships. (CIC Website, 2012)

CIC provides 160,000 square feet of office space to start ups, mostly in technology and life sciences companies, professional service firms, and venture capitalists.

CIC was a joint venture of Tim Rowe and Geoff Mamlet, based on the idea that Kendall Square had the hidden and historical potential to be an economic pillar in the Boston Area.

The region from Harvard to MIT had long been a center of ideas and technological advancement. As Mr. Rowe, a MIT Sloan Alumni, understood the situation the three keys of start-up development were idea sources, skilled talent and capital. These three components were always present in the MIT environment. “That is why entrepreneurs came to MIT to find these three factors: Money, Ideas, & Talent (M.I.T)”. (Rowe, 2012)



Figure 5.2. Trip Origins of CIC Commuters. CIC Commuter Survey 2012

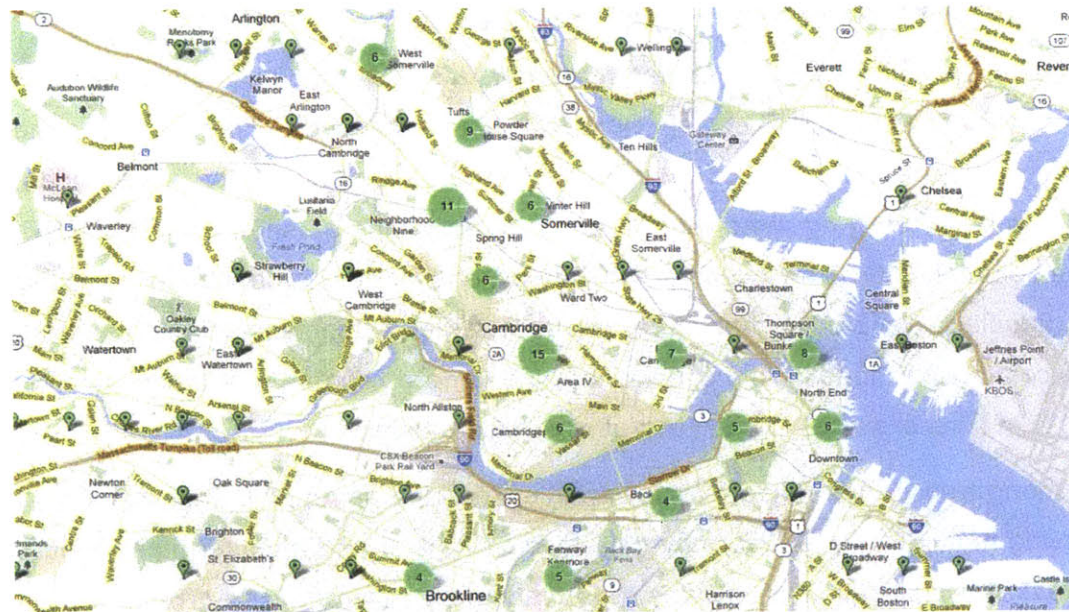


Figure 5.3. Trip Origins of CIC Commuters, not company heads. CIC Commuter Survey 2012

The workers of CIC in 2012 appear to have the same travel time patterns as other home based work trips in the Kendall area as revealed by the CTPP 2000 Data. Most of the trips made to CIC appear to be 15-30 minutes. However, there is a greater tendency to make shorter trips. More than 56% of commuting trips to CIC are 30 minutes or less. Figure 5.4 displays the travel time survey results for the commuters to CIC. Apparent in this figure is the tendency to make shorter trips. This again is indicative of the proximity trip origins for home to work trips. According to the CIC commuter survey transit and auto trips have on average the same travel times, nearly 31 minutes on

average. Trips made on the Red Line however are shorter than both average transit and auto times, on average they are only 29 minutes long (CIC, 2012).

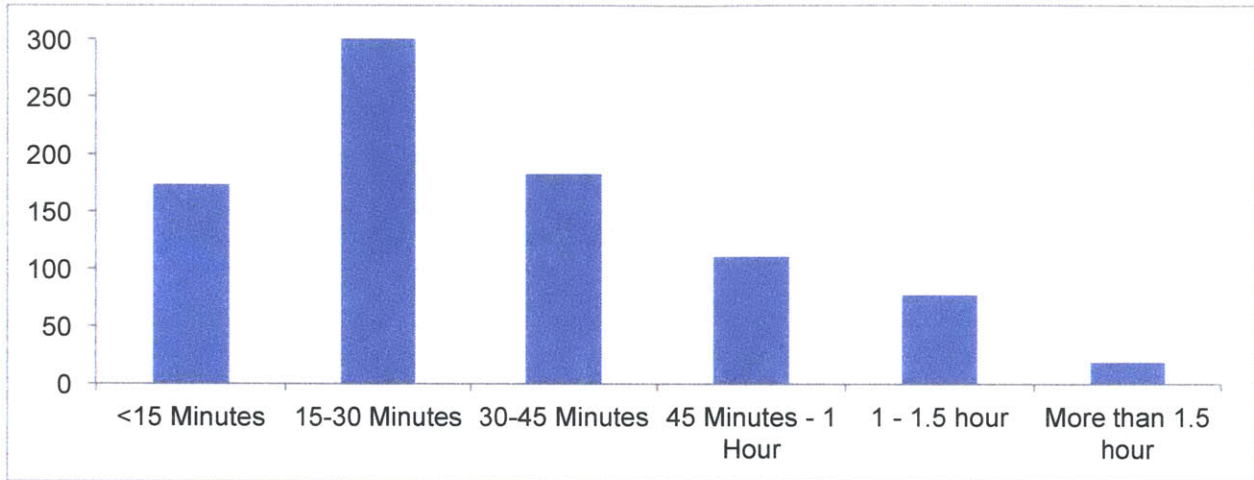


Figure 5.4. Travel time distribution for commuters to CIC

The modal split for CIC commuter trips shows a shift from the commuter patterns last recorded in the 2000 CTPP survey. Only 25% of trips are made with cars, unlike the 60% of such trips recorded in 2000, while the subway seems to be the predominant mode of commute, carrying more than 41% of the daily trips as shown in Figure 5.5. Given the nature of CIC as an incubator for startups, employing a large number of young recent graduates, we predict that there will be a larger percentage of people using alternate commuting modes. This is evident in the large portion of trips made by bike, nearly 11% of trips; likewise, 11.18% of trips are made walking.

Among transit trips made by subway, the Red Line carries the vast majority of trips, serving nearly 80% of all subway trips (and 31.83% of all commuter trips). Figure 5.6 displays the distribution of subway trips among the different lines. These results represent the primary commute mode; therefore some of these trips may connect to the Red Line, evidenced in the fact that eighteen percent of commuters listed the red line as their secondary travel mode. Therefore, on an average peak day, the Red Line may in fact serve, up to 51.20% of all trips.

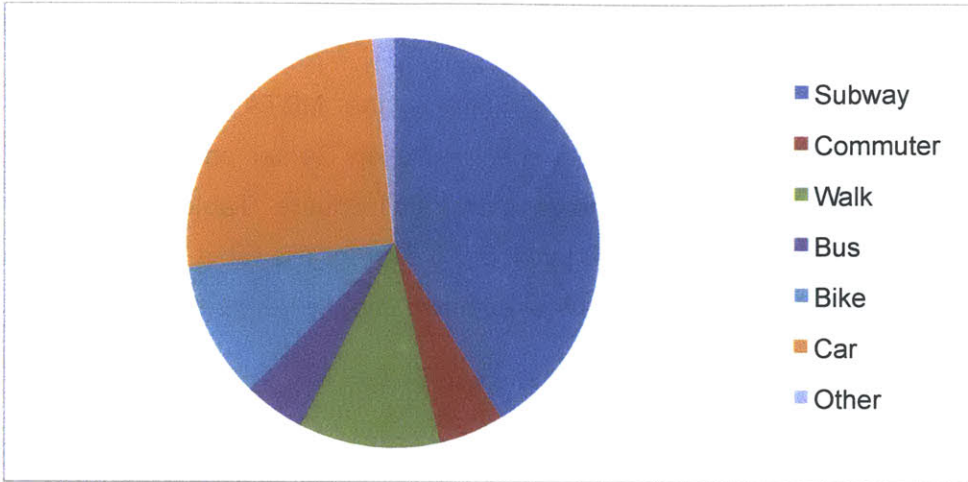


Figure 5.5. CIC Commuter Modal Split

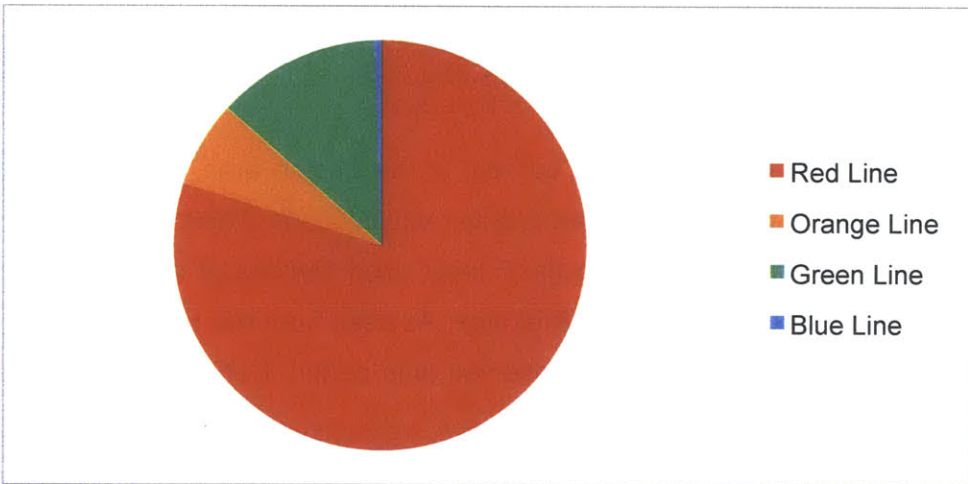


Figure 5.6. Distribution of CIC commuting trips by subway line

Cambridge Innovation Center has proven since 1998 to be a pioneer in innovation and job attraction for Kendall Square. Their working culture is indicative of the changing business culture in Kendall Square, including as their latest commuter survey shows the changing commuting trends in this area.

CIC workers live much closer to where they work and have on average shorter commuting times. Commuting trips depend heavily on transit access to the area. While most of the trips are served by rail, there is still a large dependency on alternative modes such as walking or biking. By and large, the Red Line serves most of the transit trips, which provides easy access to the area.

5.2 MBTA Red Line Service

The main transit access to Kendall Square is the MBTA's Red Line. As evidenced in the commuter survey for Cambridge Innovation Center employees, most commuters utilize this transit line in order to reach Kendall Square. Table 5.1 displays the 2009 ridership for rail lines of the MBTA service. As seen in this table, the Red Line is the most utilized rail line as the ridership is broken down into the service lines.

Red Line	74,445,042
Orange Line	54,596,634
Blue Line	17,876,009
Light Rail	75,916,005
Bus	108,088,300
Trackless Trolley	3,438,160
TOTAL	334,360,150

Table 5.1. Ridership of MBTA Rail Service, 2009 MBTA Blue Book

The Red Line serves the north-south corridor of the Boston area, and thus, we may expect that ridership will be spread out among its many stations. Table 5.2 presents the weekly boardings over the last years for the 6 most used stations of the Red Line: Alewife, Harvard, Kendall, South Station and Braintree. As seen from this table, usage in these station has overall increased over the observed time period. Kendall Square has increased dramatically, as shown in the table.

Year	Alewife	Harvard	Kendall	South Station	Ashmont	Braintree
1989	8,927	19,458	5,830	12,064	7,850	7,371
1993	9,990	14,724	8,163	16,278	9,161	5,024
1997	9,409	20,212	11,214	20,778	8,536	3,424
2001-2006*	9,567	19,146	11,408	18,826	9,799	3,159
2007	10,047	19,640	12,518	21,432	5,675	3,769
2008	10,315	20,373	12,954	22,157	4,841	4,078
2009	10,657	21,868	13,975	20,647	6,019	4,387

Table 5.2. Weekly entries to Red Line Stations

Furthermore, Kendall Square boardings have increased as a percentage of the total weekly entries in the system. Table 5.3 displays the weekly entries in Kendall Square over the last twenty years, and the percentage it represents from the total weekly entries; as well as the total weekly entries in the Red Line. As seen from this table, during this period Kendall Square Station and the Red Line has increased in usage.

Furthermore, Kendall Square has grown in importance, representing a higher percentage of yearly total entries.

Year	Weekly Entries at Kendall Station	Percentage of total	Total Weekly Entries
1989	5,830	4.51%	129,386
1993	8,163	5.86%	139,239
1997	11,214	6.39%	175,417
2001-2006*	11,408	6.28%	181,522
2007	12,518	7.01%	178,657
2008	12,954	7.10%	182,517
2009	13,975	7.26%	192,513

Table 5.3. Weekly entries to Kendall Stations & Total Weekly Entries

The increased overall usage of the Red Line service and the increase in demand in Kendall square demonstrates the increased usage of transit services in Kendall Square. The records from the MBTA's Blue Book, confirm this growing tendency for Kendall Square employees to utilize transit services. (MBTA, 2010)

5.3 American Community Survey (2006-2010)

Using the data from the American Community Survey (ACS) provides a more recent aggregated understanding of commuting patterns for the entire Cambridge Area. Although these figures do not provide block group or Traffic Analysis Zone data, they do allow to better understanding the changing commuting patterns of Kendall Square. Table 5.4 compares the modal split of the 2000 CTPP for the entire city of Cambridge, to the modal split from the 2006-2010 ACS results. From this data we may see a general shift away from driving (alone or in a ride share), and transit is largely absorbing this shift while walking and biking has also increased in this time period.

These results from the ACS show that 45% of people who commute to the city of Cambridge rely on cars, while the results from the CIC showed that only 25% used auto transportation in the Kendall enclave, considering the nature of the startups housed there. However start up employees surveyed may differ from the rest of the workers in Kendall Square. Kendall Square being one of the most dense employment areas in Cambridge, should have to have a smaller auto dependency than the city average.

Furthermore, the survey results reiterate this shifting tendency away from private transportation methods, towards a heavier reliance on transit.

	People who work in Cambridge		People who live in Cambridge	
	2000	2006-2010	2000	2006-2010
Drove Alone	50.30%	45.00%	35.00%	30.70%
Ride Share	8.60%	8.10%	5.40%	4.60%
Transit	22.60%	26.10%	24.80%	28.10%
Bike	2.40%	4.10%	3.90%	6.80%
Walk	12.80%	13.00%	24.40%	22.70%
Other	0.80%	0.80%	1.30%	1.10%
Work at Home	2.50%	3.00%	5.30%	6.10%

Table 5.4. Modal Split of people working & living in Cambridge. Source: CTPP 2000 and ACS 2006-2010

Table 5.5 displays the modal split recorded for trips made by people who commuted to Cambridge as their destination. It disaggregates the results by trip origins; trips that originated in Cambridge, trips that originated in adjacent communities and trips that originated elsewhere.

This new data can be compared to the modal split from CTPP 2000 described in Chapter 4.6. Given the fact most of the trips that come into Kendall Square originate in Cambridge or the adjacent communities, and assuming that these trip origin patterns are still similar for the 2006-2008 time period. This ACS survey demonstrates that for trips originating in Cambridge, only 16.3% use the automobile, while the large majority relies on transit and walking. Similarly, for trips that originate in communities adjacent to Kendall Square, 36.5% are utilizing automobile, while transit absorbs 41.9% of all trips.

	All origins	Origins in Cambridge	Adjacent Communities	Origins Elsewhere
Drive Alone	46.4%	16.3%	36.5%	66.4%
Transit	25.4%	15.3%	41.9%	18.5%
Rideshare	8.6%	3.5%	7.8%	11.5%
Bike	3.4%	7.6%	4.5%	0.7%
Walk	12.4%	42.5%	8.7%	1.6%
Other	1.0%	0.8%	0.5%	1.3%
Work at Home	2.9%	6.2%	0.0%	0.0%

Table 5.5. Modal Split of people working in Cambridge. Source: CTPP 2000, ACS 2006 - 2008

Unfortunately since the newest records for commuter patterns have not been released, we are unaware of the current modal splits for Kendall Square for 2010 on a TAZ level, but utilizing other data sources yields a greater insight on the commuting patterns for this area. As it was previously mentioned, Kendall Square has been home to

a changing culture dominated by start-ups and bio-tech companies that enjoy the benefits of a high density employment areas, proximity to the research conducted at the Massachusetts Institute of Technology and to venture capital. The results from the internal survey of Cambridge Innovation Center display the preference to live closer to work and commute utilizing mass transit methods. From personnel interviews at CIC, the Red Line appeared to be the main transit commuting method to Kendall Square.

The critical role played by the Red Line is confirmed by the most recent results from the 2006-2008 American Community Survey (ACS) and 2006-2010 ACS. According to the MBTA's Blue Book, ridership in the Red Line has been increasing continuously for the past 20 years, and boardings at Kendall Square have grown to represent a bigger proportion of the Red Line trips. Although these data sources provide information only for the entire City of Cambridge, they convey clearly a shifting tendency towards relying more heavily on transit, thus increasing usage of Kendall Square Station.

Chapter 6 - Framework for Modeling the Relationship between Transit Accessibility, Clusters & Economic Growth

In order to test the relationship between transit accessibility, cluster creation and economic growth we utilized an approach similar to the one presented by Lindall et al (2005) who uses a regression technique to calculate patterns of urban growth or economic development.

In order to calculate transit accessibility, we used existing models to estimate the connectivity from an origin to opportunities that are reachable in a designated time period. Utilizing this model and the socioeconomic data of the urban region we conceptualized an accessibility index that displayed a location's accessibility for different types of opportunities. Later we estimated the economic growth in each location in order to develop a regression model that explored the relationship between accessibility and employment density.

6.1 Existing Accessibility Models

In order to develop an appropriate measure of accessibility, we will first examine traditional accessibility models. Although there are a number of models that have been developed, most of them can be categorized as one of four types: isochrone, gravity-based model, utility-based and person-based. All of these focus on the accessibility from an origin. A description of each is provided below. (Geurs & van Wee, 2004; Busby 2004; Warade, 2007;Ducas 2010).

6.1.1 Isochrone Model

The Isochrone model takes into account the total number of opportunities that can be reached within a given time, distance or cost threshold. This model requires the least data calculation since it uses a standard binary (0 or 1) threshold to reach all opportunities.

Equation 6. 1 Isochrone Accessibility (Ducas, 2010)

$$A_i = \sum_j O_j W_j$$

Where

i=origin location

j=destination location

A_j = accessibility at location i

O_j=number of opportunities at location j

W_j = equals 1 is C_{ij} < C_{ij} and 0 otherwise*

C_{ij} = travel time (or distance or cost) from i to j

C_{ij} = given travel time (or distance or cost) threshold*

This model is the easiest to compute but it does not include the temporal and user components of accessibility. The use of a binary threshold considers any opportunity within that threshold equally accessible, although there might be a larger impedance to travel a longer distance. Furthermore, this model disregards any opportunities that are above the threshold, even at a negligible distance from the cutoff threshold. Therefore, although the isochrones accessibility provides a useful and easy calculation tool, it should be utilized with caution.

6.1.2 Gravity-based Accessibility Measures

The gravity-based measure tries to address some of the shortcomings of the isochrone model by utilizing an deterrence function (instead of a binary threshold) to calculate the accessibility of each opportunity. The deterrence function estimates the individual's willingness to travel and is estimated based on observed travel behavior. This model requires more data input and processing since it requires the estimation of a deterrence function, as well as the number of opportunities at each location and the travel time (or distance or cost) for every origin destination pair.

Equation 6. 2 Gravity-based Accessibility (Ducas 2010)

$$A_i = \sum_j O_j f(C_{ij})$$

Where

i=origin location

j=destination location

A_j = accessibility at location i

O_j=number of opportunities at location j

C_{ij} = travel time (or distance or cost) from i to j

F(C_{ij}) = travel time (or distance or cost) impedance function

This model provides a better understanding of accessibility than the isochrone model, while still maintaining a relatively easy calculation approach. The model's

concept is also easily understandable, which makes it comprehensible to many. Nevertheless, the model still does not capture fully the temporal and individual considerations of accessibility.

6.1.3 Utility-based Accessibility & Person-Based accessibility measures

Both of these models are increasingly more complex. The utility based measure uses random utility choice theory and discrete choice analysis to provide a better understanding of the benefit of having an opportunity accessible. Similar equations are commonly used in the traditional four-step model when trying to determine mode choice. The theoretical underpinnings of this model are that each person derives a certain amount of utility for each opportunity and will try to maximize his utility in his choices. The logsum is the expected value, or the expected maximum utility of all the mode choices alternatives available. (Ben-Akiva & Lerman, 1985).

Equation 6. 3 Utility-based Accessibility (Busby, 2010)

$$A_n = E(\max_{i \in C_n} U_{in}) = \frac{\ln \sum_{i \in C_n} \exp(\mu V_{in})}{\mu}$$

Where

i = alternative

n = individual

A_n = accessibility of individual n

E(max U_{in})_{i ∈ C_n} = Expected maximum utility

U_{in} = utility for individual n considering alternative i

V_{in} = systematic component of utility U_{in} for individual n considering alternative i

C_n = choice set

μ = scale parameter of the error associated with each alternative

This model not only takes into consideration attributes of cost and time, but also integrates the specific utility associated to the different transit stages such as transfers, waiting time, walking access time and other factors that might influence an individual's overall derived utility. All the considerations make the utility-based model much more data and calculation intensive than the previous models.

Similar to utility-based models, the person-based models focus on the individual and temporal components of accessibility. The person-based model takes into consideration the individual's temporal and spatial constraints (Hagerstrand, 1970). The calculations are displayed in space-time prisms that estimate the access a person has given the person's budget time constraints.

This is the most complex model, since it includes the individual utility considerations, as well as the temporal and spatial constraints of access. Due to its complexity, calculating the person-based model requires a detailed data set on individual's travel activity including individual time availability and cost formation, which is not easily available.

6.2 Destination Gravity Based Accessibility Model

Using the gravity based model we can develop an equivalent model for the accessibility index for each destination. Using readily available information we should be able to easily calculate the isochrone accessibility. However, the gravity model provides a better understanding of the accessibility, since it captures the tendency to prefer shorter trips and the gradual deterrence to make longer trips. Furthermore, instead of focusing the accessibility of every trip origin, this model intends to capture the accessibility of every single destination.

Furthermore, we can divide all the possible destinations by type of opportunity that we want to examine. Therefore, we can disaggregate all accessible opportunities into types of opportunities, such as: potential employers or employees, students, shopping locations, etc. The gravity-based destination equation used for the purposes of this research is displayed in Equation 6.4

Equation 6. 4 Gravity-based Destination Type Specific Accessibility (Adapted from Ducas, 2010)

$$A_{t,j} = \sum_j O_{ti} f(C_{ij})$$

Where

i=origin location

j=destination location

t = type of opportunity observed (eg. Labor Market, Students, Suppliers)

A_{tj} = accessibility of opportunity type t at destination j

O_{ti}=number of opportunities type t at location i

C_{ij} = travel time (or distance or cost) from I to j

F(C_{ij}) = travel time (or distance or cost) impedance function

6.3 Economic Density and Growth

Economic growth in a region can be measured using a number of indicators including income, employment or total earnings in the area. For the purpose of this thesis, we measured economic growth using the employment and changes in employment density between 1990 and 2010. Since the study area is a niche cluster for start-up businesses, we decided that this would be the best indicator for economic growth rather than utilizing earnings growth since it is likely that such industries will not have high earnings during their initial years of existence. The techniques used to measure employment density and growth are displayed in Equation 6.5 and Equation 6.6.

Equation 6. 5 Calculation for Employment Density

$$ED_j^t = \frac{\text{Employment}_j^t}{\text{Area}_j}$$

ED_j = Economic Density at location *j*, time *t*

Equation 6. 6 Indicator for Economic Growth

$$EG_j = \frac{ED_j^{t2} - ED_j^{t1}}{ED_j^{t1}}$$

EG_j = Economic growth at location *j*

ED_j^t = Employment Density at location

t1 = Initial time period under consideration

t2 = Final time period under consideration

6.4 Regression Model to measure the relationship between accessibility on employment

Using the Destination Gravity Based accessibility model, we will be able to measure an index for the accessibility of a destination to each of the opportunities that are essential to cluster formation as outlined in the previous chapter.

Then we will utilize a technique similar to that used by Cervero (2001) as he created a model to represent the impact of different actors on cluster performance in contrast to regional and industry productivity standards.

Using the employment growth for the last 20 years for each location, we created two regression models utilizing the destination gravity based accessibility model indices for each type of opportunity. The first model, Equation 6.7, utilized the absolute values for accessibility and employment density for a given time; while the second model, Equation 6.8, utilized changes in accessibility and how these related to changes in employment density. Both models may integrate a variety of modal and trip type accessibility according to the issues to be addressed.

Equation 6.7 Regression Model to calculate relationship between accessibility and employment density at a specific point in time.

$$ED_j = \sum_{t,j} c_{tj} * A_{tj} + \alpha$$

Where

i=origin location

j=destination location

t = type of opportunity observed (eg. Labor Market, Students, Suppliers)

ED_j = Economic density at location j

A_{tj} = accessibility of opportunity type t at destination j

c_t = coefficient of accessibility of type t

α = error coefficient

Equation 6.8 Regression Model to calculate relationship between changes in accessibility and employment growth.

$$EG_j = \sum_{t,j} c_{tj} * A_{tj} + \alpha$$

Where

i=origin location

j=destination location

t = type of opportunity observed (eg. Labor Market, Students, Suppliers)

t1 = Initial time period under consideration

t2 = Final time period under consideration

EG_j = Economic growth at location j

A_{tj} = accessibility of opportunity type t at destination j

c_t = coefficient of accessibility of type t

α = error coefficient

The approaches outlined above aim to define for every destination j, the index of accessibility for every type of opportunity. These equation may be calculated used a linear regression model in order to calculate the values of coefficients “c_t” looking at the difference between 2010 and 1990. These coefficients can shed light on the relative

importance of different modal accessibility types in absolute values and changes of employment density.

Chapter 7 – Transportation Network Model

In order to calculate the travel times needed for the accessibility calculations, we utilized an academic four-step travel demand model for the Greater Boston area originally developed by Mikel Murga using Cube Voyager and Trans CAD commercial packages. The model was developed and improved for academic purposes (1.254 Transportation Modeling, MIT, Spring 2013). The model covers 40 miles to the north and south from South Station, and 30 miles towards the west, a total of approximately 2,800 square miles. The model studies the region using 986 Traffic Analysis Zones (TAZ). Although there is a second version of the model, that divides the region in 2727 traffic analysis areas, the granularity of Kendall Square is basically the same in both models. Therefore, given the similarity of the study area in both models, utilizing the 986 TAZ model proved to be more efficient. This model was calibrated based on CTPP 2000, 1991 Boston Travel Survey as well as the MASS DOT Road count and MBTA boarding data.

7.1 TAZ, Nodes & Links

The area represented in the model was subdivided into 986 Traffic Analysis Zones (TAZ) designated by the Central Transportation Planning Staff (CTPS). CTPP data is originally presented in Block Groups that may be aggregated to the 986 TAZs.

The model utilizes nodes in order to represent the conditions in the area. The center of each TAZ is also a node, which is specifically called a centroid. In order to calculate the trip types for the entire region, the model utilizes these centroid nodes. The base model developed for 2010 consisted of 103,757 nodes, 264,747 links and 2727 centroids.

In order to represent the transportation network, the model has links between the nodes. Each link types is associated with a type of function and they all have geometric and functional parameters, such as length, number of lanes, link capacities, posted speeds and more, that characterize the functionality of each link. The link types and coded speeds included are:

- Expressways (65mph; 55mph; 50 mph) & Interchanges (40mph)
- Main & Minor Arterials (50mph; 45mph)
- Distributors & Minor Distributors (25mph)

- Local Streets (25mph or 15mph)
- Subway, Green Line Light Rail & Commuter Rail
- Bus Lanes
- Navigational Channels
- Walk Access to Rail Stations
- Walk Connections Across Rail Platforms
- P&R Drive Access to Commuter Rail Stations
- Centroid Connectors

The network also includes the traffic signals for some parts of Boston, Cambridge and Somerville.

7.2 Socioeconomic Data & Infrastructure

The model attempts to calculate trip generation, attraction and distribution according to the road and transit network and the socioeconomic data. Therefore, obtaining precise and reliable data is essential for the model calibration. In order to calibrate the model, the data used was primarily:

- 2000 Census Transportation Package (CTPP) (US, DOT, 2000)
- 1991 Boston Household Survey (conducted by the Central Transportation Planning Staff (CTPS))

The data provided by the CTPP included socioeconomic data in the block group level, as well as the results of the journey to work survey. Using this data, we are able to categorize each transit trip as either associated to a captive (someone with no automobile) or to a choice rider. In each centroid we lumped twenty-two types of households (based on different number of people, workers and automobiles); job types broken down into industrial, commercial, service and educational jobs; and information on special generators such as hospitals, shopping malls, and Logan airport.

The model was calibrated utilizing the infrastructure for 2010, with the full completion of the Big-Dig project.

The transit layer for this model includes most of the MBTA services. Included in the model are:

- MBTA buses (Those lines serving 80% of the total demand are incorporated) including trolley service and the Silver lines

- Red Line, Orange Line and Blue Line
- Silver Line BRT to South Boston
- Green Line
- Commuter Rail, although some outer stations fall outside the model boundaries
- Ferry Lines, although their terminal times are still under development

Once the model had been calibrated, we created three different conditions to replicate the conditions in 1990, 2000 and 2010. Initially, the model was run utilizing the socio-economic data for every time point year and the current Boston transportation infrastructure, with the completed Big Dig project. A summary of the variables utilized for each of the model runs is shown in Table 7.1.

	Population	Households	Workers	Cars	Jobs
1990	4,043,437	1,501,662	2,001,672	2,312,803	2,193,133
2000	4,290,378	1,636,939	2,104,649	2,508,585	2,311,832
2010	4,456,405	1,825,421	2,184,568	2,795,937	2,360,539

Table 7. 1 Summary of socio-economic data utilized in the model for 1990, 2000 and 2010

A later iteration of the transportation model for the Greater Boston Area included the transportation infrastructure for every study year. This included a model without any of the Big-Dig development for 1990 and with partial completion of the Big-Dig for 2000.

The travel times utilized for accessibility replicated the morning commute (AM Peak travel times) and thus we would expect that the infrastructure completed during this time period, would have a negligible effect on regional accessibility measures. As seen in Table 7.2, the infrastructure improvements seem to have attracted a large number of trips, increasing congestion levels in both the AM and PM peaks and thus decreasing average speeds. The increases in congestion levels will increase commuter travel times and will probably decrease auto accessibility. Table 7.3 shows the total daily trips for the three models. As expected auto trips have increased (which causes the increased congestion levels), but this has also increased transit trips in the area. A full study of congestion, road flows and daily trips per trip type with the changing infrastructure of the Big Dig is presented in Appendix C.

		1990	2000	2010
AM	Road Trips	449,723	444,821	483,667
	Average Speed	34.95	34.90	29.90
	Average Distance	12.66	13.30	14.60
PM	Road Trips	727,699	676,621	752,959
	Average Speed	32.99	33.50	29.40
	Average Distance	10.50	11.10	12.50

Table 7. 2 Road Trips, speeds and distances for AM and PM peak in 1990, 2000 and 2010 model

	1990	2000	2010
Total Walk Trips	5,179,362	4,042,003	4,125,747
Total Linked Transit Trips	797,824	766,028	966,738
Total Auto Trips	988,3108	9,105,544	10,130,125
Total Auto Pax Trips	1,945,071	1,217,238	1,333,228
Total	17,805,365	15,130,813	16,555,838

Table 7. 3 Total daily trips for 1990, 2000 and 2010 model

7.3 The Four Step Model

The model utilizes the traditional four steps to replicate the transportation conditions of the greater Boston area. These steps are:

- Step 1: Trip Generation and Attraction
- Step 2: Trip Distribution
- Step 3: Modal Split
- Step 4: Traffic, Public Transportation & Pedestrian assignment

The model uses a gravity approach for the Distribution Stage, a Multi-Nominal Logit (MNL) model for modal split, and static assignment for road traffic, public transport and pedestrians. The model is run once to replicate free flow condition. Outputs of this run are used as inputs for a congested model that loops to recalculate the trip distribution, modal split and road assignment to replicate the effects of road congestion.

7.3.1 Travel time Calculations

An essential part of calculating the accessibility was to calculate the travel times, or generalized cost for each origin destination pair in each mode. Thusly, we used model-generated, skim matrices of 986 by 986 that described the cost for traveling

between each centroid. There is one matrix calculated for each mode and time period. These matrices are referred to as skims

The model utilized three types of transportation modes: walking, auto and transit. Auto and Transit skims are calculated for the “AM peak”, “mid-day”, “PM peak” and “rest of day” periods. Walking and initial free flow auto are calculated in the same way. The model considers every single centroid pair as an origin destination and uses the network links to minimize the cost function (time plus operating cost) to reach each destination. This is a one-cycle process for the walking skim. For automobile times, skims are recalculated to reflect congestion levels.

Transit skims require a little bit more processing since there are a series of travel stages calculated as part of a transit trip. In order to calculate the skims we consider: access and egress time (walking or driving), initial wait time, transfer wait time, in vehicle time and transit fares. We use a value of time of \$12 per hour to convert the fares to their time equivalents in the case of choice riders, while a \$4 per hour cost if used for captive riders. Similarly, auto trips incorporate parking costs and add them to the auto travel times and costs in the same way.

The skims calculated after the congested looping of the four step model where the main inputs for the accessibility calculations. These reflected the total cost of traveling from one TAZ to another (C_{ij} in the equations presented in Chapter 6).

7.3.2 Trip Generation

The socioeconomic data was processed prior to being included in the model, and used to calculate the trip rates for each type of household. There are 26 socio-economic varieties of households per TAZ (although we disregard the least common 4 types) that are subdivided by resident, worker and auto owners. The model utilizes the socioeconomic data to calculate the trips generated and attracted by from each kind of household and job. We can compare our initial trip generations to the recommendations from the NCHRP Report 365. As can be seen from the results in table 7.1, the calculations are close to the recommendations. The calibration of trip generation and attraction was shown by its comparison to the results established in the 1991 Boston Travel Survey with very match. Table 7.4 compares the ranges of generated trips for the different types of households with 1, 2 or 3 or more people to the numbers of the NCHRP Report 365.

Likewise, using the information from the socioeconomic characteristic, we calculate the attracted trips

Persons per Household	Range of values	NCHRP Report 365 recommendations
1	3.67-5.4	3.7-5.4
2	6.03-8.33	6.3-7.9
3 or more	11.47-20.7	8.1-15.3

Table 7.4. Model trip generation rates and NCHRP Report 365 recommendations

Among the trip purposes the model considers:

- Home Based Work (HBW);
- Home Based School(HBS);
- Home Based Other (HBO);
- Non-Home Based Work (NHBW) &
- Non-Home Based Other (NHBO).

The CTPP survey only provides information on HBW trips. Therefore we rely on the 1991 Boston Travel Household Survey to calibrate other trip types.

7.3.3 Trip Distribution

After we have calculated trip productions and attractions, we strive to geographically distribute the trips among TAZs. The challenge then becomes to simultaneously distribute flows according to the geographical location of centroids and the overall Trip Length Distribution (TLD; the time length of each trip).

Calibrating the model to match these two characteristics becomes an iterative process. We use a gamma function to determine friction factors that generate the distribution of trips in the time and geographical scales. The results from the model are compared to the results from the survey distribution in an aggregated representation of TAZ. The trips estimated by the model are compared to the TLD and the Production-Attraction matrices are compared to survey matrices. In order to compare the geographical fit, the 986x986 matrix is aggregated into a 164x164 towns matrix in order to be able to plot them.

This process is repeated in order to calibrate the model to the observed TLD and geographical distribution.

To use the gravity model, we had to create a model for the impedance of traveling from one point to another, C_{ij} . A formula estimated the traveler's impedance towards longer trips. Initially, the impedance formulas were calculated by changing the constants in the standard gamma function displayed in Equation 7.1.

Equation 7.1. Gamma Function for Friction Factors

$$\text{Friction Factor}(C_{ij}) = a * C_{ij}^b * e^{c * C_{ij}}$$

Where

C_{ij} = Cost of going from i to j

a, b, c are constants

The first step involved the processing of survey results in order to determine the revealed TLDs and Production Attraction matrices. The results from the 2000 CTPP survey were utilized to compare results for Home Based Work trips, while the 1991 Boston Household Travel Survey were used for other trip types. Using these survey results, we were able to observe the revealed results for trip durations depending on trip type. As seen in Figure 7.1 though, since TLDs are derived from survey results, the answers require rounding from people's perception of their own trip's duration. For example, people are more likely to report that a trip is 30 minutes, when maybe 25 minutes is more accurate.

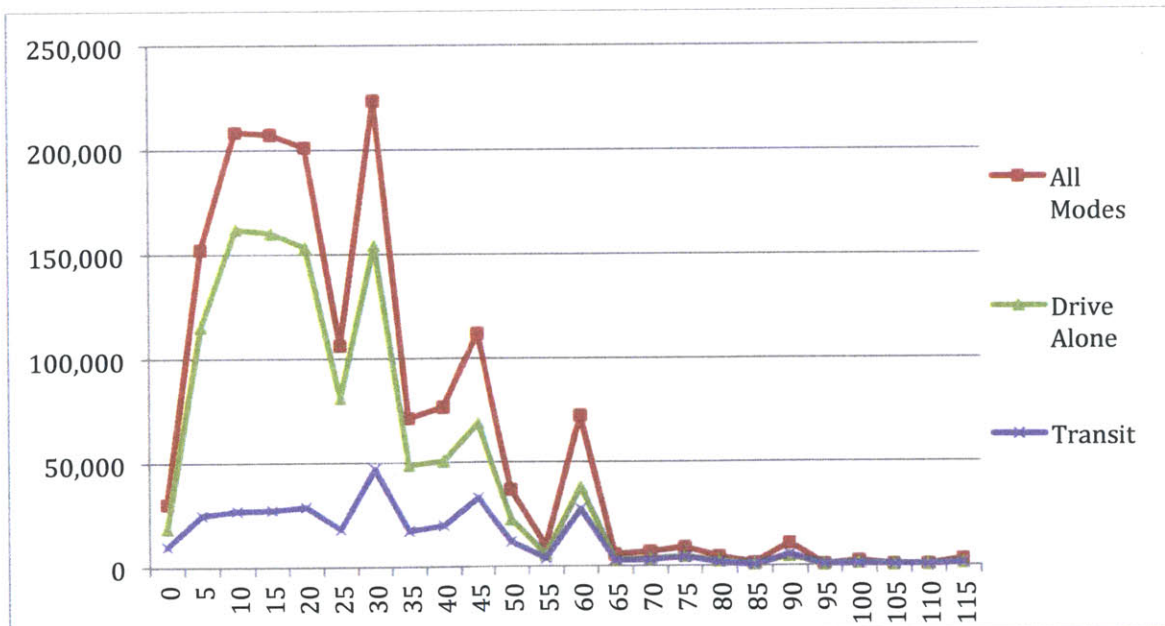


Figure 7.1 Trip Length Distribution for Home Based Work Trips based on 2000 CTPP Survey

Therefore, although the model results attempt to replicate the form of the TLDs, we compare it to a smoothed out version of the TLD, rather than to the actual survey results as reported, including people's own rounded values. Figure 7.2 displays the results of the model's choice and captive trip lengths, compared to the results from the survey.

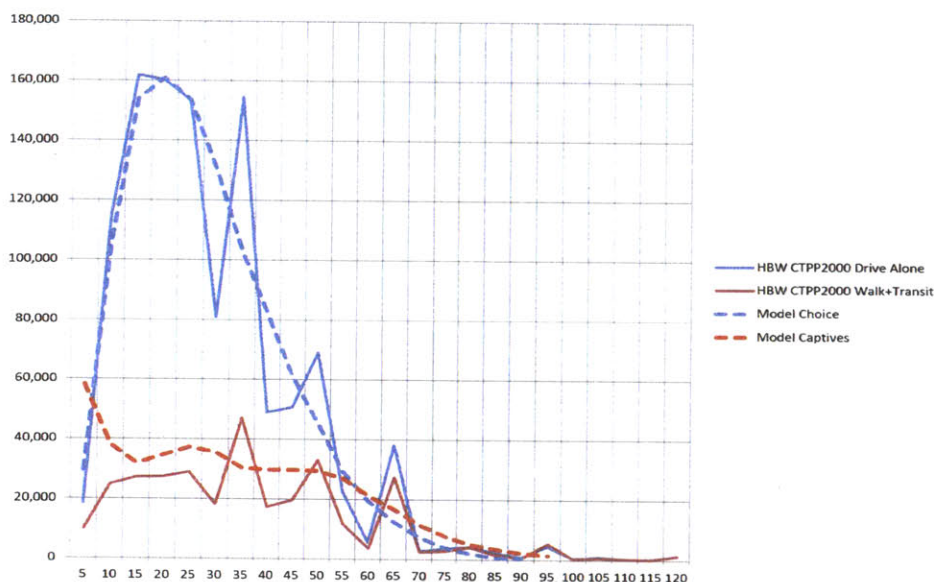


Figure 7. 2 Trip Length Distribution for HBW trips and Model Results

Besides comparing that the distribution of the length of the trips calculated by the model were accurately representing the trip distribution from the survey results, the geographical distribution of the model's trips were compared to the survey production attraction matrix. In order to make this comparison the 986 TAZs were aggregated to a 164x164 matrix representing the 164 towns of the model. Using the model and survey results, we plotted each location into Excel and created a trend line utilizing all the points. Ideally, the slope of this trend line would be 1, meaning the model results were exactly correlated to survey results. We also calculated the value of R^2 for this graphic representing the geographical fit; once again, the ideal value of R^2 would be 1, demonstrating a perfect fit between all point and the trend line. Figure 7.3 displays the geographical comparison between the model and the survey results.

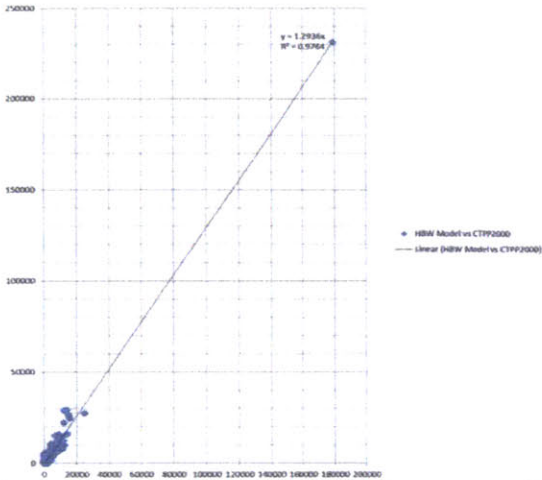


Figure 7. 3 Model and CTPP Survey results comparing geographical fit for Home Based Work Trips.

The point in the top right corner represents the trips for Central Boston. Given that Central Boston, is by large the area which attracts and produces the most trips, we recalculated the geographic fit of the model and the survey results excluding the Boston centroid, in order to make sure that the large quantity of trips in this area was not skewing the model’s calibration. We calculated slope values and R^2 values once again to see the fit of these results. Figure 7.4 displays this calculation processes for Home Based Work Trips excluding Boston.

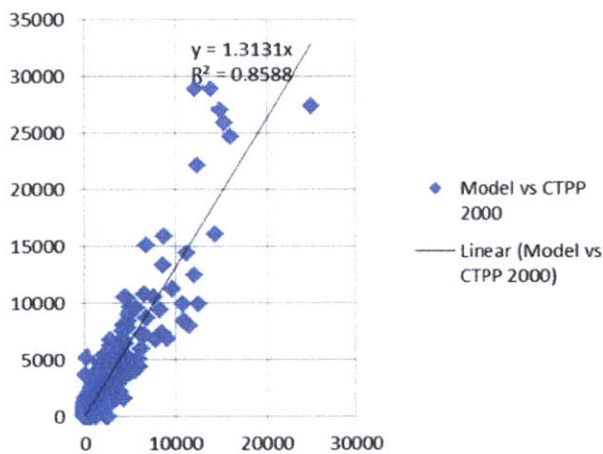


Figure 7. 4 Model and CTPP Survey results comparing geographical fit for Home Based Work Trips, Boston excluded.

The same process is repeated for all the other trip types. The results are displayed in the figures displayed below. Besides recalculating the geographical fit excluding Boston, this process was repeated once again, excluding Central Boston and Cambridge, the second largest production and attraction trip center for the greater

Boston Region. We calculated slope values and R^2 values once again to see the fit of these results.

Following the geographical match of the flows among the 164 towns represented in this model for all trip purposes, the distribution of trip times distributions were recorded and compared to either CTPP or 1991 Boston Travel Time Survey as shown in Figures 7.5 though 7.12

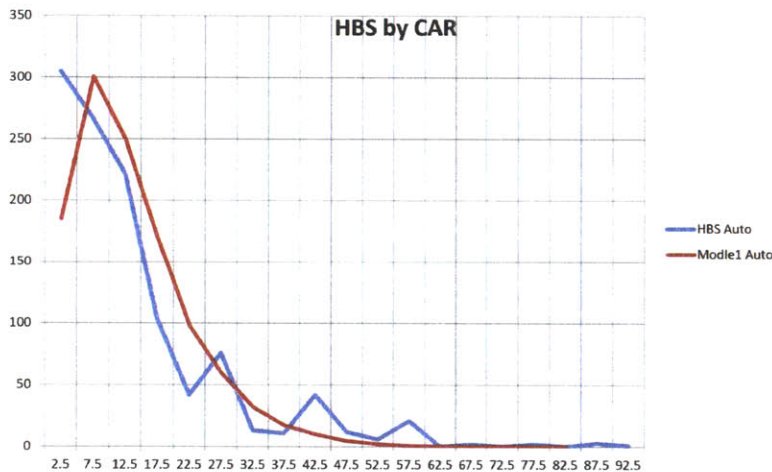


Figure 7. 5 Trip Length Distribution for HBS trips and Model Results, Automobile Riders

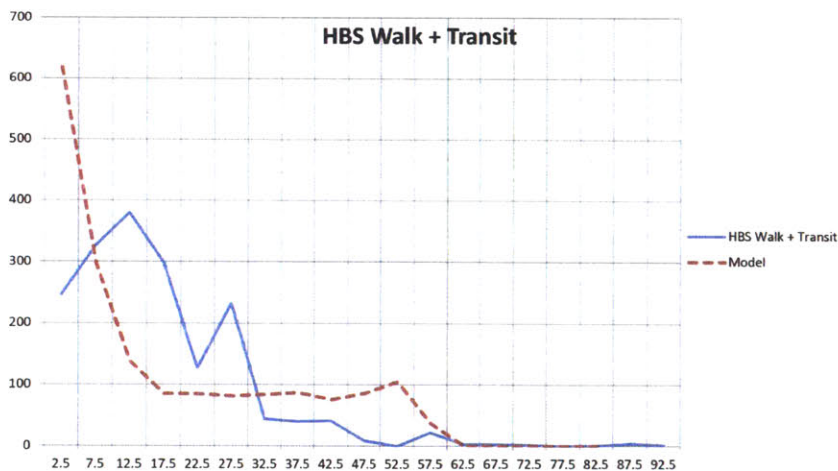


Figure 7. 6 Trip Length Distribution for HBS trips and Model Results, Walk and Transit Trips

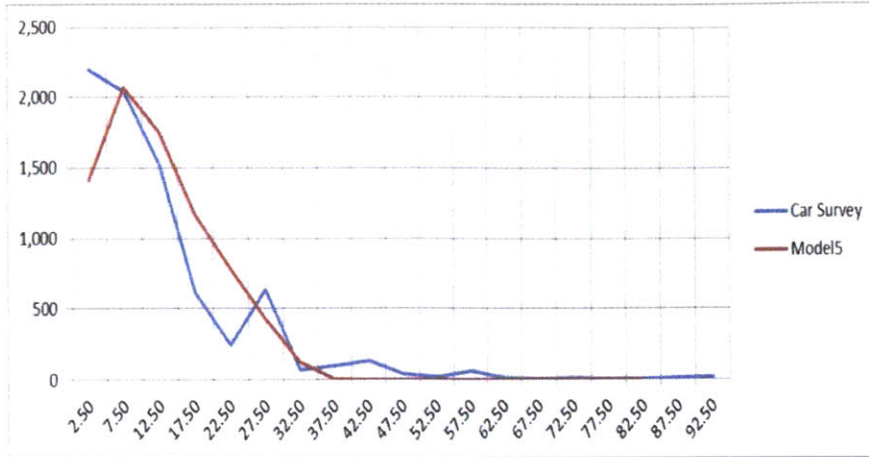


Figure 7. 7 Trip Length Distribution for HBO trips and Model Results, Choice Riders

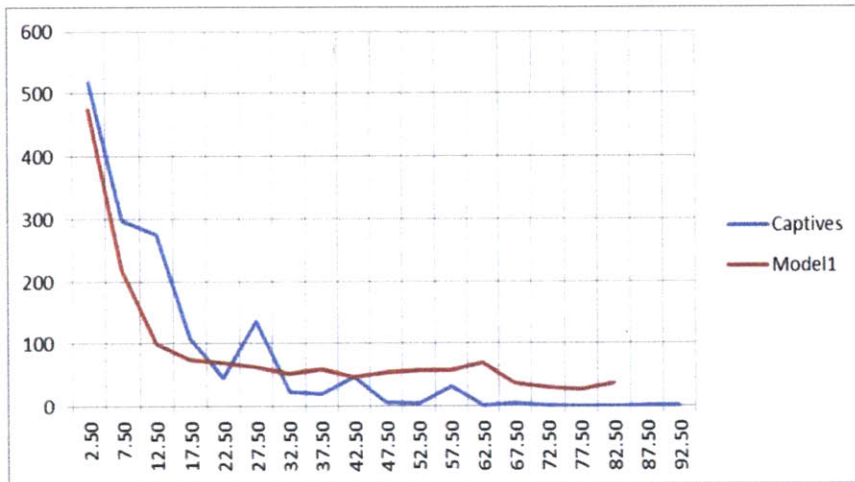


Figure 7. 8 Trip Length Distribution for HBO trips and Model Results, Captive Riders

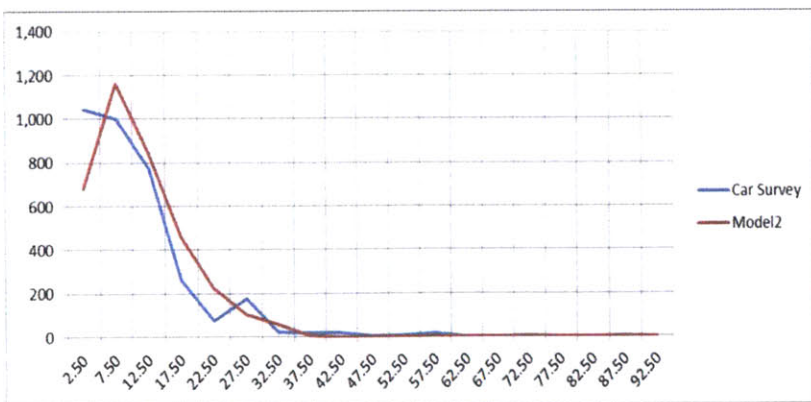


Figure 7. 9 Trip Length Distribution for HBSHops trips and Model Results, Choice Riders

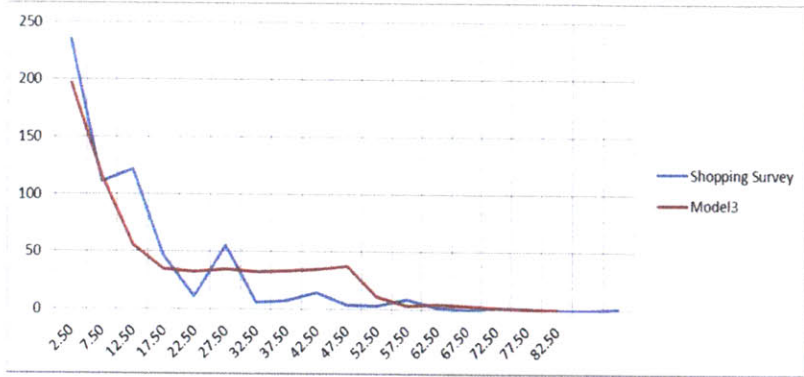


Figure 7. 10 Trip Length Distribution for HBSHOP trips and Model Results, Captive Riders

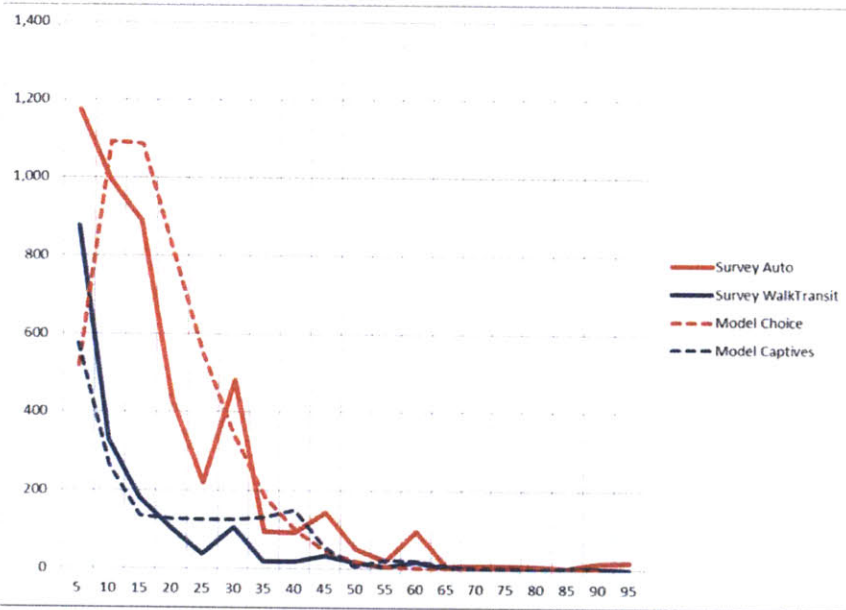


Figure 7. 11 Trip Length Distribution for NHBW trips and Model Results, Choice & Captive Riders

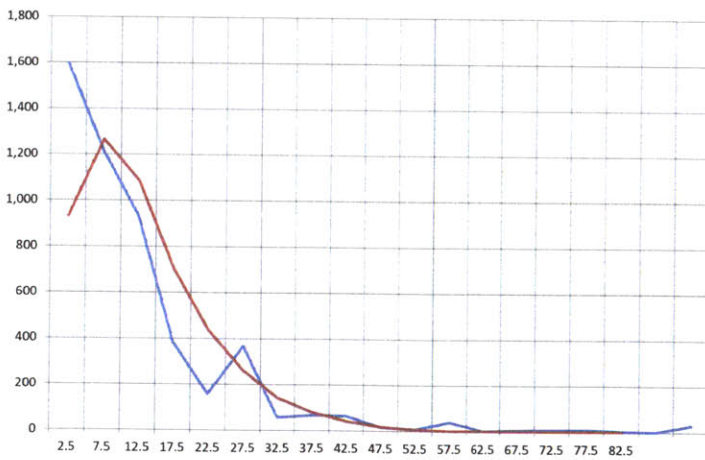


Figure 7. 12 Trip Length Distribution for NHBO trips and Model Results, Choice Riders

The results of the values for the slope and R^2 values are displayed in Table 7.5. As Seen in this table, the model was able to achieve a very good geographic fit.

Trip Purpose	Including Boston		Without Boston		Without Boston & Cambridge	
	R2	Slope	R2	Slope	R2	Slope
HBW	0.977	1.290	0.859	1.310	--	--
HBS	0.923	0.990	0.820	0.820	0.730	0.800
HBO	0.882	1.090	0.681	0.650	0.679	0.610
HBSshop	0.899	1.280	0.761	0.910	0.755	0.880
NHBW	0.949	0.639	0.731	0.690	0.719	0.810
NHBO	0.958	0.976	0.788	0.840	0.752	0.840

Table 7.5. Slope and R^2 values for geographical fit comparisons, utilizing final friction factor results.

The values for the a, b and c constants in the Gamma function, after continuous iterations of the model calculations are displayed in Table 7.6.c

Trip Purpose	Choice			Captive		
	a	b	c	a	b	c
HBW	1.00	-0.020	-0.085	1.000	-0.020	-0.055
HBS	1.00	-1.332	-0.100	1.000	-1.000	-0.200
HBO	1.00	-0.850	-0.255	1.000	-1.285	-0.094
HBSshop	1.00	-0.850	-0.175	1.000	-0.850	-0.200
NHBW	1.00	-0.400	-0.120	1.000	-1.332	-0.200
NHBO	1.00	-1.332	-0.110	1.000	-1.332	-0.300

Table 7.6. Final values for a, b & c constants of Gamma Function Friction Factor calculations per trip type

A well-calibrated model is clearly a pre-requisite for the calculation of the accessibility model. The academic Cube Voyager model distributed trips for the different trip types fitting closely the travel patterns of the greater Boston area. The travel time matrices for all origin destination pairs by trip mode, represented the congested conditions for every travel mode, since these travel time skins are essential for the calculation of the accessible opportunities.

Chapter 8 – Accessibility Deterrence Functions Calculation

As previously described, there are a number of accessibility index calculation approaches that could have been utilized for the purpose of this research. Utilizing available data, we started by determining the radius for the isochrone accessibility and then modified this binomial radius to the more complex deterrence used for the gravity model. The deterrence function describes the user's willingness to travel to reach a certain kind of opportunity. It is estimated by an iterative process that adjusted the impedance function to replicate the patterns observed in trip length distributions. This chapter outlines this process.

8.1 Isochrone Radius Estimation

The first model used to calculate an accessibility index was the isochrone model¹. This calculation method used a set time radius around each destination and counts the number of opportunities accessible in that time-cost threshold radius.

The cost radiuses used in the Isochrone model were unweighted travel times; therefore they represent the actual clock time of traveling from an origin to a destination. This means that transit travel times, are weighed equally as access walk time, wait time, transfer wait time, in-vehicle travel time and, access and egress walk time, without the associating penalties for transfers or for long wait times.

Threshold times are defined using the travel times from the model trip lengths. This is calculated by the 90th percentile travel times of all transportation modes. Utilizing the 90th percentile travel time ensures that the threshold is meaningful and at the same time insensitive to outliers. Thresholds are defined for each type of trip, work, shop, and school, recreational and other. Furthermore, the thresholds are also defined by the time period peak (AM or PM) in which they are more likely to happen.

The thresholds are outlined in table 8.1. As seen from the table, the shortest trips are usually the school trips, whilst the largest thresholds are for the work and recreational trips.

¹ For a full description of the Isochrone Model. Refer back to Chapter 6.1.1

Trip Type	Period	90th Percentile Travel Time
Home Based Work	AM	45min
Home Base Work (Transit only)	AM	55min
Home Based Shop	PM	35min
Home Based School	AM	25min
Home Based Other	AM	35min

Table 8.1. Isochrone Accessibility Travel Time Thresholds. Recalculated from Ducas 2010

Utilizing this model any opportunity that is located inside the time-cost threshold of a given origin are summed as part of the ‘accessible opportunities’.

8.2 Gravity Model Calculations

The gravity model is a more complex estimation, which utilizes an approach similar to the isochrone accessibility model. Whereas the isochrone model considered all the opportunities in the given threshold as being equally accessible, the gravity model weighs opportunities using a deterrence function derived from the user’s willingness to travel to reach a certain kind of opportunity. For the purposes of this research, the deterrence functions were derived from an iterative process that used the impedance function to imitate the observed trip length distributions.²

The cost radius used in the gravity model was unweighted travel times, therefore they represent the actual clock time of traveling from an origin to a destination. In respect to the transit travel times, it weighs equally access walk time, wait time, and transfer wait time, in-vehicle travel time and egress walk time. As for the isochrone travel times, no penalties for any transfers or long wait times.

In order to calculate the trip length distribution for the home to work trips the model relied on information from the CTPP 2000 data and the generation and attraction model. Figure 8.1 displays the trip length distribution driving, transit and walking trips, as well as the total number of trips for Home Based Work Trips.

² The trip length distribution is derived from Travel studies detailed in Chapter 7.

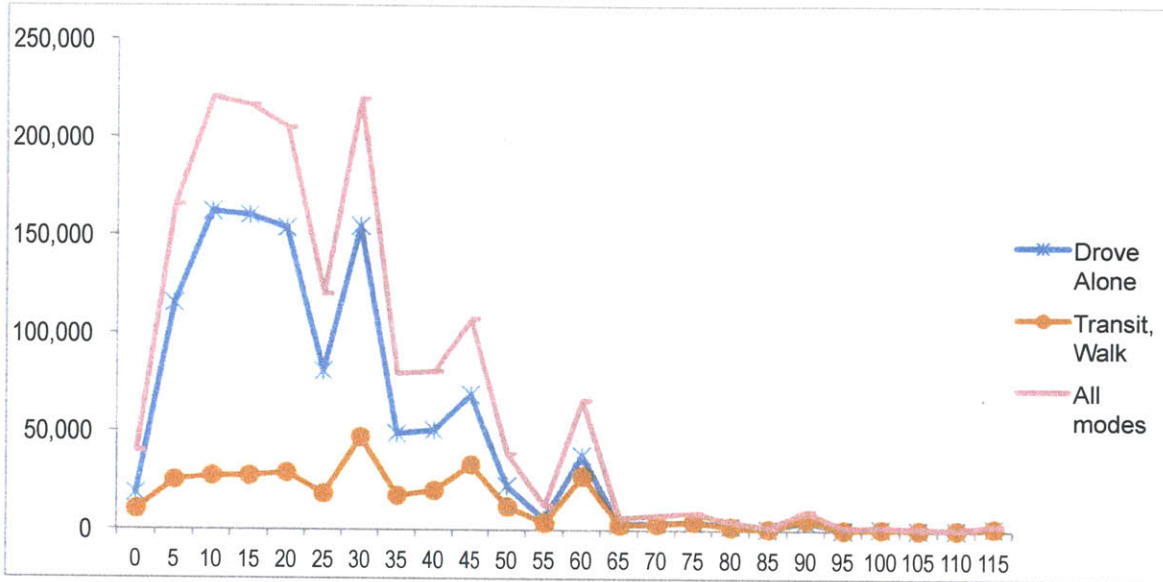


Figure 8.1. Trip Length Distribution for Home Based Work trips

The above trip length distribution is based on the survey results of typical home based trips. This explains the large jumps that are made, for example, from 25min to 30min. The reason being that it is much more likely for people to respond that their trip was 30 minutes rather than 25. Thus, to calculate the impedance function, we considered a smoothed out version of the trip distribution

The observed trips seem to peak around 20-25 minutes. However, the deterrence function that we sought to create did not replicate this 'peaking' since this is not representative of the travel preference of the user, but rather of the normal spread of trips given the spatial distribution of vehicles and economic activity in the model area. Therefore, all trips before this peak were considered to be equally accessible.

The initial deterrence model function was derived utilizing the impedance function used to calculate friction factors from the production generation step in the four-step model. This function was calculated using the Gamma Function and setting distinct values for a, b and c.

Equation 8.1. Gamma Function for Trip Calibration

$$Friction\ Factor(C_{ij}) = a * C_{ij}^{-b} * e^{-c * C_{ij}}$$

Where

C_{ij} = Cost of going from i to j

Using the model previously described the values for a, b and c were calculated for all types of trips, for both choice and captive users. The initial results of these calculations were the following factors:

Trip Purpose	Captives			Choice		
	a	b	C	a	b	c
HBW	1.00	-0.020	-0.085	1.0	-0.020	-0.055
HBS	1.00	-1.332	-0.100	1.00	-1.000	-0.200
HBO	1.00	-0.850	-0.255	1.00	-1.285	-0.094
HBSHop	1.00	-0.850	-0.175	1.00	-0.850	-0.200
NHBW	1.00	-0.400	-0.120	1.00	-1.332	-0.200
NHBO	1.00	-1.332	-0.110	1.00	-1.332	-0.300

Table 8.2. Final parameters for the gamma functions used for the model trip calibration.

In order to utilize the friction factors, these were normalized to values between 0 and 1; where 0 represents that the point is not considered to be accessible, and 1 is completely accessible. In order to compare friction factor patterns to TLD of the survey results, these were also normalized. This normalization provides a reasonable representation of what the user's deterrence to travel might be.

8.2.1 Home Based Work Trips

As previously mentioned, in order to calculate the deterrence function for Home to Base Work (HBW) trips we normalize both the survey and the friction factor calculations to values between 0 and 1. Using the normalized equations, we are able to compare both results. Figure 8.2 displays the results for model choice and captive users, as well as the survey results for driving, transit and combined trips.

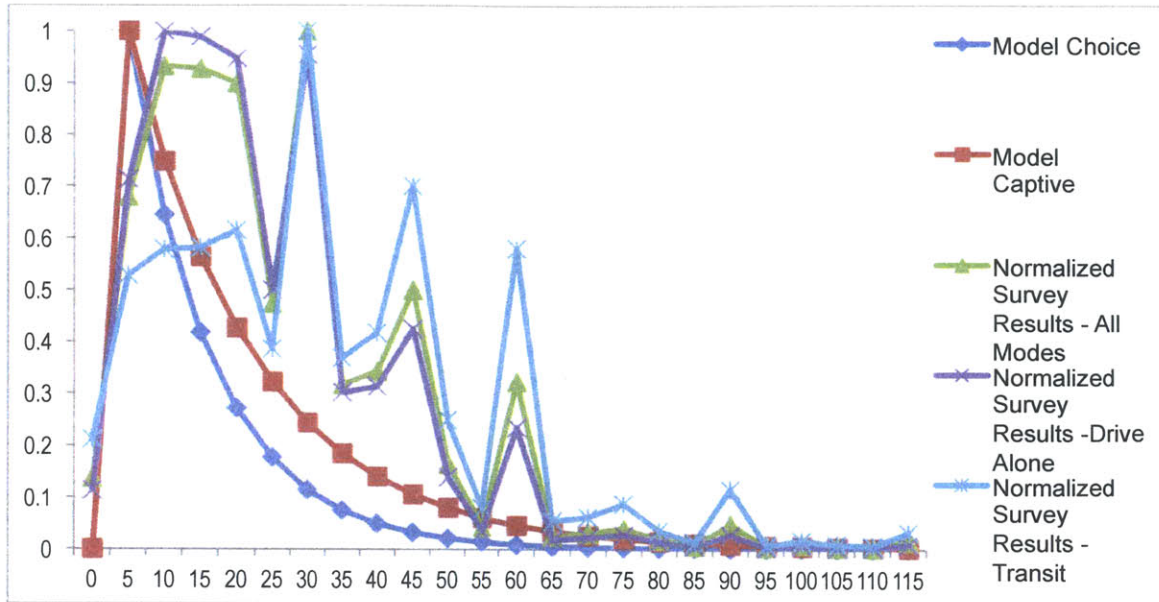


Figure 8.2. Survey and Impedance Function for Home Based Work Trips normalized from values between 0 and 1

As evidenced in the above graphic, the model function rises abruptly and then descends as time increases. This is a function of the model properties and observed distribution of the trips, rather than the actual impedance of people to make short trips. In order to correct this property of the model, we modified the gravity function such that it equals 1 for all short length trips. This attempts to replicate the likelihood of people to make shorter trips; and the indifference of trip length in very short trips.

In order to derive a deterrence function for the trips, we initially utilize the friction factor equation for the choice travelers, (since choice users as a better indication of trip preferences). After a study and modification of the friction factor function to better represent the probability to make a trip according to the TLD pattern a new deterrence function was calculated. The final function is presented in Figure 8.3 and Equation 8.2

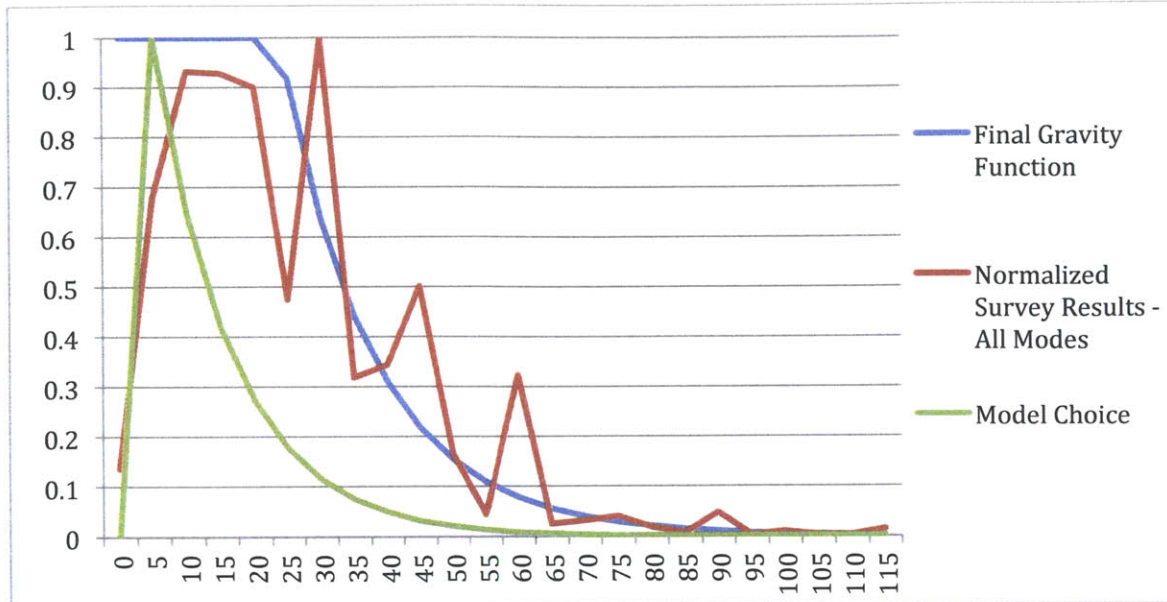


Figure 8.3. Final Deterrence Function and Normalized Survey Results for Home Based Work Trips.

Equation 8.2. Deterrence function calculation for Home Based Work (HBW) Trips utilizing all modes and driving trips

$$f(C_{ij}) = \begin{cases} 1, & C_{ij} < 23 \\ 12.5 * C_{ij}^{-0.35} * e^{-0.062 * C_{ij}}, & C_{ij} \geq 23 \end{cases}$$

Where

$$C_{ij} = \text{Unweighted travel time from an origin } i \text{ to destination } j$$

8.2.2 Home Based School Trips

In order to calculate the deterrence function for Home Based School trips, we replicate the process outlined previously for this specific trip type. The initial normalized Survey results and friction factor equations are displayed in Figure 8.4.

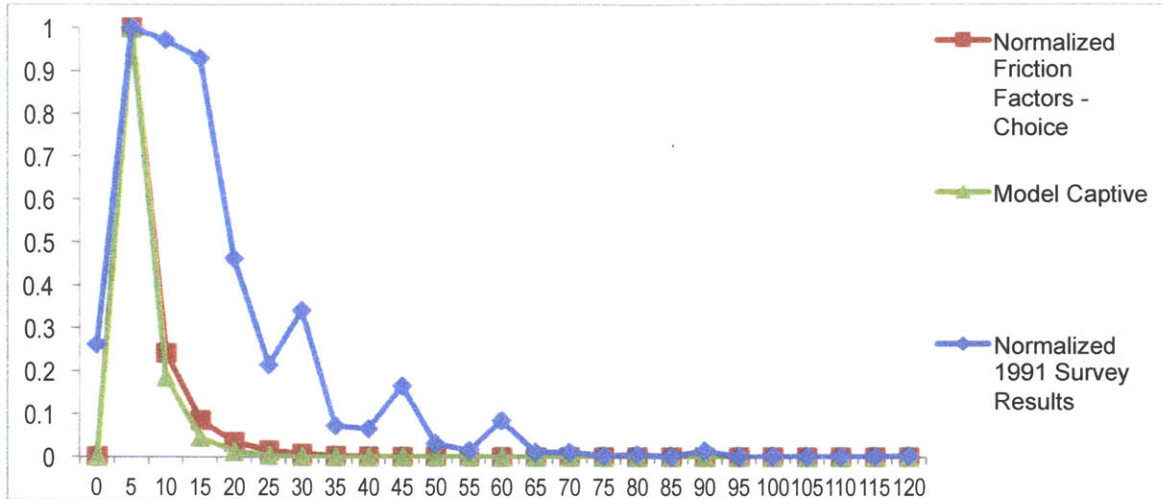


Figure 8.4. Survey and Impedance Function for Home Based School Trips normalized from values between 0 and 1

As was done previously, the friction factor equation for model choice travelers is modified in order to better represent the probability of making a Home Based School Trip, given a trip of a certain length of time. This results in the finalized deterrence function displayed in Figure 8.5 and Equation 8.3.

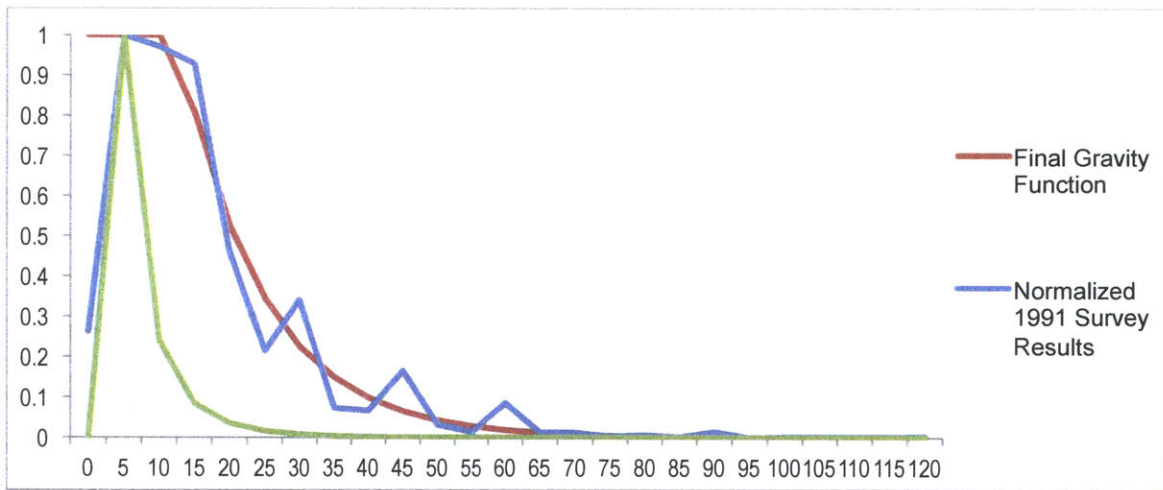


Figure 8.5. Final Deterrence Function and Normalized Survey Results for Home Based School Trips.

Equation 8.3. Deterrence function calculation for Home Based School (HBS) Trips

$$f(C_{ij}) = \begin{cases} 1, & C_{ij} < 12.5 \\ 3.51 * C_{ij}^{-0.1} * e^{-0.08 * C_{ij}}, & C_{ij} \geq 12.5 \end{cases}$$

Where

C_{ij} = Unweighted travel time from an origin i to destination j

8.2.3 Home Based Shopping Trips

Once again, this process was repeated for Home Based Shopping (HBSshop) trips. Comparing the model's friction factors with the 1991 Survey results; once they had all been normalized from a scale of 0 to 1 (Figure 8.6) showed that the friction factor does not correspond to the travel patterns of HBSshop trips.

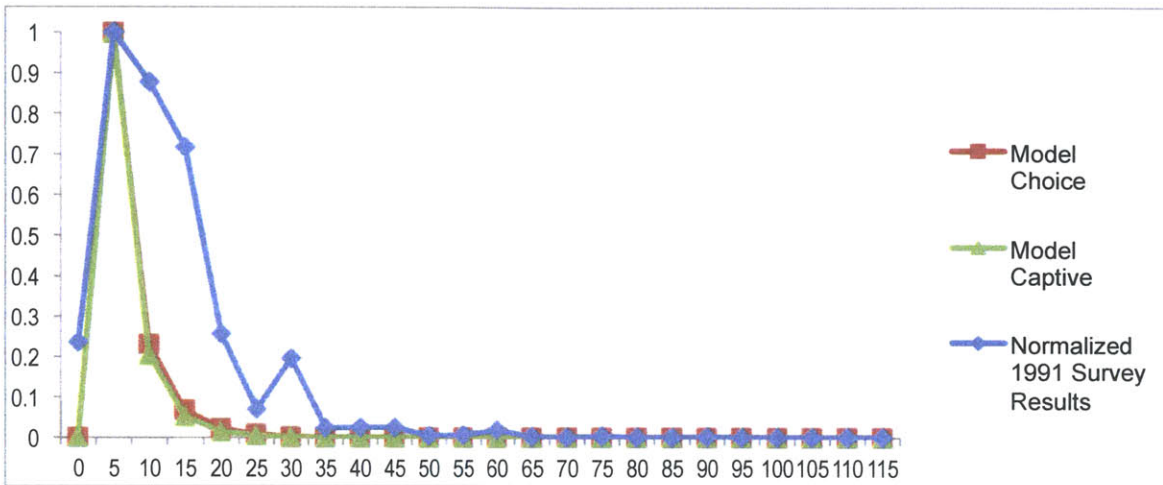


Figure 8.6. Survey and Impedance Function for Home Based Shopping Trips normalized from values between 0 and 1

Utilizing the same Gamma Function, we modified the constants in order to yield a function that better represented the observed length of Home Based Shopping trips. Once again, this function ranges from 0 to 1, representing the probability of making the trip given its length. As done previously, the function was parsed such that it would equal 1 for shorter trip lengths, given that people are likely to make shorter trips. Figure 8.7 displays the finalized deterrence function as well as the survey results and the initial friction factor equation. The final values for the constants of the new gamma function may be observed in Equation 8.4.

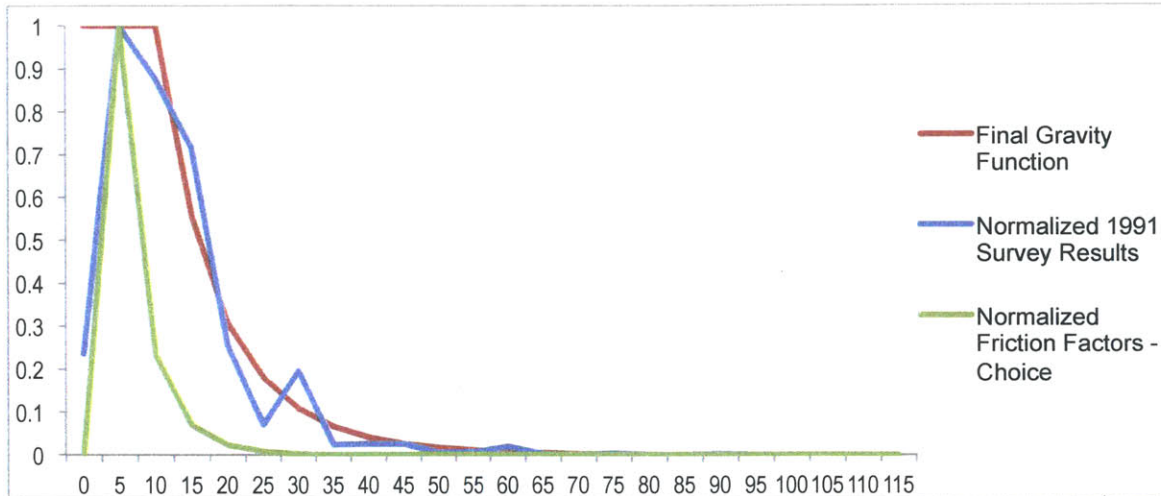


Figure 8.7. Final Deterrence Function and Normalized Survey Results for Home Based Shopping Trips

Equation 8.4. Deterrence function calculation for Home Based Shopping (HBSHop) Trips

$$f(C_{ij}) = \begin{cases} 1, & C_{ij} < 10.6 \\ 13.0 * C_{ij}^{-0.75} * e^{-0.075 * C_{ij}}, & C_{ij} \geq 10.6 \end{cases}$$

Where

C_{ij} = Unweighted travel time from an origin i to destination j

8.2.4 Home Based Other Trips

This process continued with the observation of Home Based Other (HBO) trips. This initial friction factor equation suggested by the model, along with the 1991 Survey results are displayed in Figure 8.8. As seen from this graph, the initial equation does not match the trip length distribution pattern.

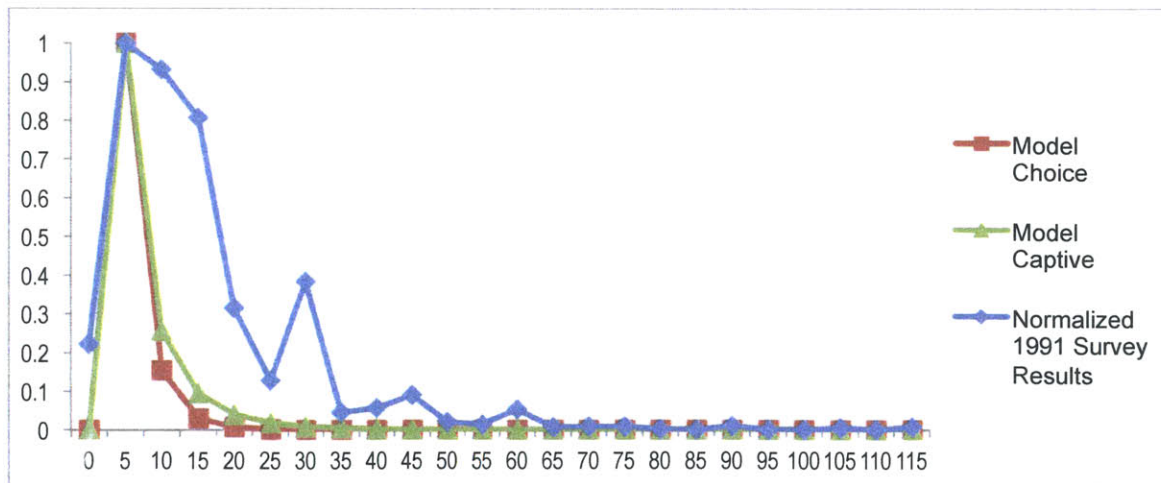


Figure 8.8. Survey and Impedance Function for Home Based Other Trips normalized from values between 0 and 1

To this end therefore, the model was modified in order to mimic the trip length distribution of observed HBO trips. The final deterrence function as well as the survey results and the initial friction factor equation is displayed in Figure 8.9. The final values for the constants of the gamma function may be observed in Equation 8.5

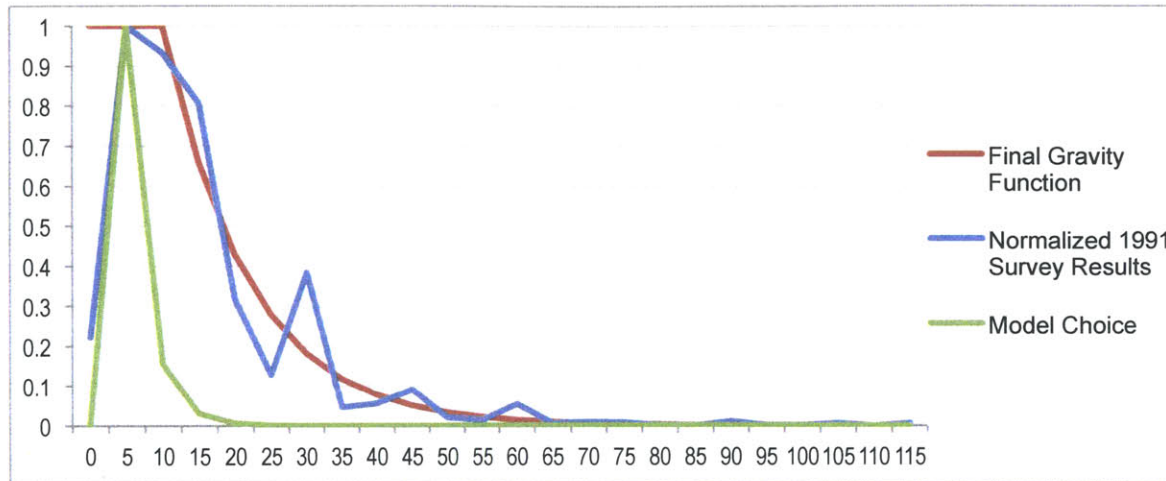


Figure 8.9. Final Deterrence Function and Normalized Survey Results for Home Other Trips

Equation 8.5. Deterrence function calculation for Home Based Other (HBO) Trips

$$f(C_{ij}) = \begin{cases} 1, & C_{ij} < 10.2 \\ 2.5 * C_{ij}^{-0.02} * e^{-0.085 * C_{ij}}, & C_{ij} \geq 10.2 \end{cases}$$

Where

C_{ij} = Unweighted travel time from an origin i to destination

8.2.5 Non Home Based Trips

The model considered two kinds of trips that do not originate at home: Non-Home Based Work related (NHBW) and Non-Home Based Other trips (NHBO) trips. These are trips that do not originate at home and tend to be shorter. For the purpose of creating a deterrence function, we initially analyzed both kinds of trips separately, as seen in Figures 8.9 and 8.10. In both of these trips types we see that the friction factors utilized in the model to replicate observed trip distribution and geographical matching of O-D matrices do not result in a slope function similar to the pattern of observed trips.

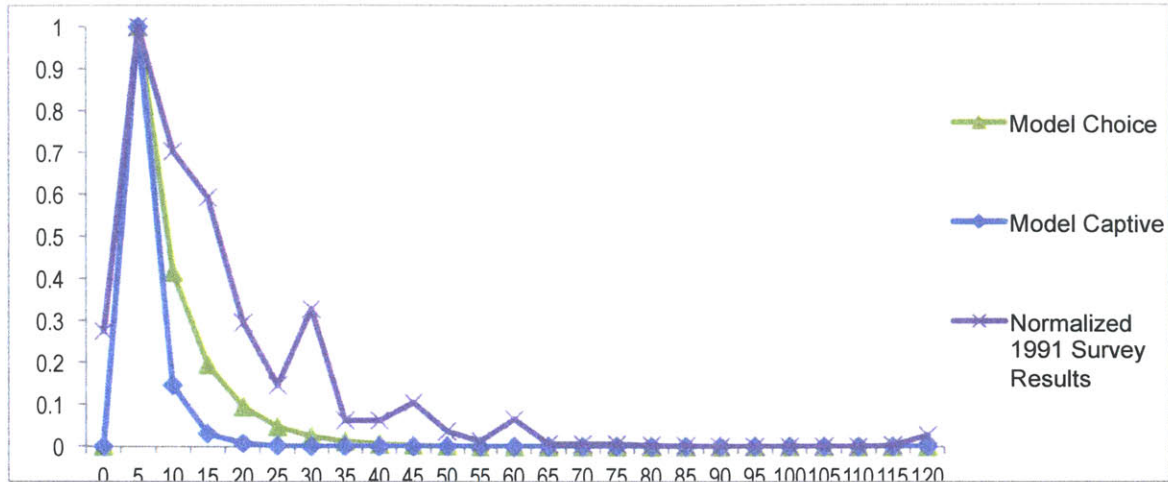


Figure 8.10. Survey and Impedance Function for Non Home Based Work Trips normalized from values between 0 and 1

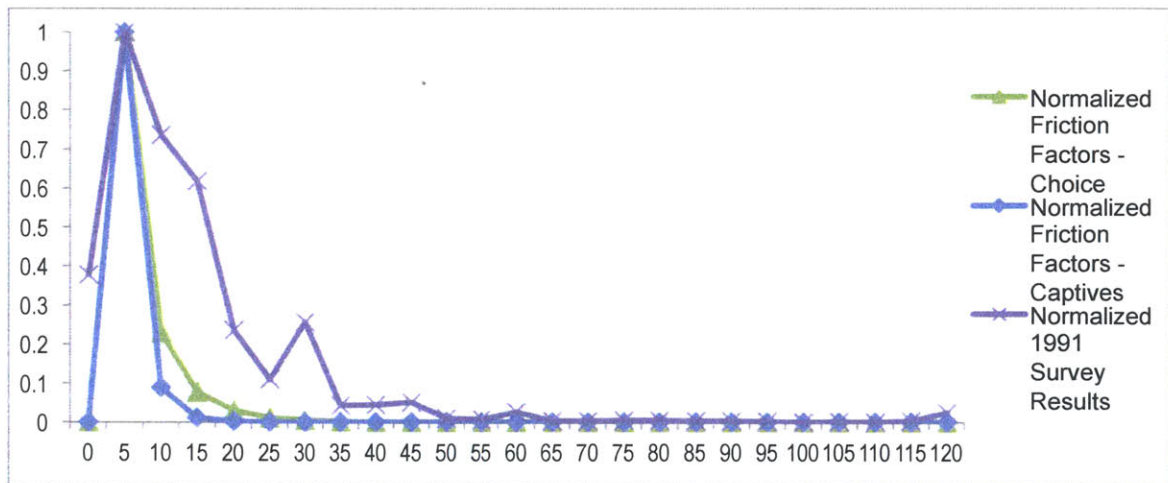


Figure 8.11. Survey and Impedance Function for Non Home Based Other Trips normalized from values between 0 and 1

This is why, for both NHBW and NHBO trips, the initial friction factor function were modified for the sole purpose of obtaining a deterrence function similar to the observed trip distribution. The final results of this processes are displayed in Figures 8.11 and 8.12. Analyzing these trip types separately yielded the same deterrence function for both trip types. Therefore, the same equation was used to represent the probability of making a non-home based trip. This equation is presented in Equation 8.6

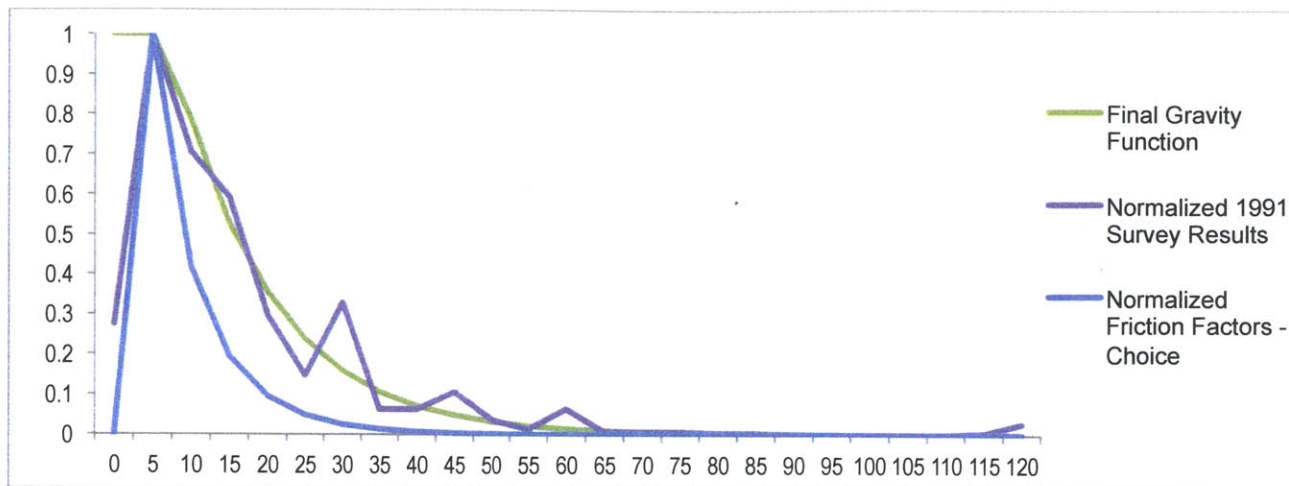


Figure 8.12. Final Deterrence Function and Normalized Survey Results for Non Home Based Work Trips.

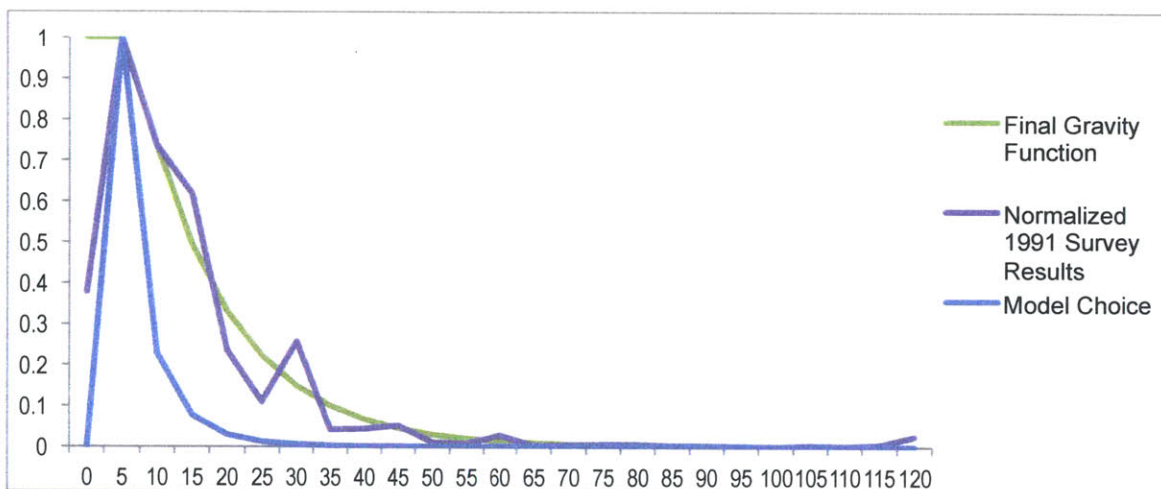


Figure 8.13. Final Deterrence Function and Normalized Survey Results for Home Based Other Trips.

Equation 8.6. Deterrence function calculation for Non Home Based (NHBW & NHBO) Trips

$$f(C_{ij}) = \begin{cases} 1, & C_{ij} < 7.0 \\ 1.75 * e^{-0.08 * C_{ij}}, & C_{ij} \geq 7.0 \end{cases}$$

Where

C_{ij} = Unweighted travel time from an origin i to destination j

8.3 Deterrence Function Summary

Utilizing observed trips and utilizing the initial constants for the gamma function of the friction factors used for the academic model, we were able to produce a set of functions that represented the probability of making a trip, as a function of the length away.

For all trips, we modified the initial part of the function to set it as equal 1, given that most people are likely to be indifferent to make trips of a threshold time duration. Although the observed trips display an increase in the initial part of the graph, this is due to the fact that actual trips made are commonly not recorded as short trips since the opportunity is farther away, rather than due to an actual preference to make longer trips.

The final values for the constants in the deterrence functions are displayed in Table 8.3.

Trip Purpose	Value of 1 until	a	b	c
HBW	23	12.50	-0.33	-0.062
HBS	12.5	3.51	-0.1	-0.08
HBO	10.6	13	-0.75	-0.075
HBSshop	10.2	2.5	-0.02	-0.085
NHB Trips	7.0	1.75	0	-0.08

Table 8.3. Final Constant Values for Deterrence Function

The equations calculated in this chapter, which represent the probability that an individual will make a specific trip given that trip's length was one of the main components for the gravity based accessibility calculation.

Chapter 9 – Destination Accessibility Estimation for Kendall and the Greater Boston Area

Once the concept and key functions had been established to calculate the accessibility of Kendall (as well as other parts of the Greater Boston area) we processed the data in order to determine and visualize numerical accessibility values. In order to have a better understanding of the region we calculated its accessibility as a destination for all trip types (HBW, HBS, HBSshop, HBO, NHBW & NHBO) in order to provide an in depth analysis of travel accessibility to the area, and also to better understand its recent growth.

In order to determine the accessibility to Kendall, we also had to define what opportunities (trip origins) were to be considered as reachable from the rest of the metropolitan area. Since our objective was to understand locations as accessible 'destinations', the aim was to find which potential trip origins were in the range of accessibility to it. To this aim we initially considered opportunities for home based trips to be: population, households and labor force; and for non-home based trips to be: population and jobs.

Using these as the opportunities for each of the 986 TAZs, we calculated the accessibility, utilizing the skims generated by the model described in Chapter 7 and the deterrence functions calculated in Chapter 8.

9.1 Opportunities

The aim of traditional accessibility models is to describe the attractiveness of a given location based on its to opportunities. Thus it quantifies each location's nearness to opportunities such as jobs, educational, recreational or other opportunities. In essence, the goal is to assess the appeal for each location as a potential trip origin.

For this iteration however, we are aiming to evaluate the attractiveness of a given location as a destination for trips. Therefore, we search to see how many people may reach such location as a destination for their trip.

Working within the framework of prescribed trip types (HBW, HBS, HBO, HBSshop, NHBW & NHBO), we aim to find the places that are within an appropriate radius from a certain destination. Home-based trips, as implied by the trip name,

originate in an individual's home. Therefore, the opportunities that we aim to quantify are the homes and residents that live within the travelling radius of a given destination. Therefore, for most Home-Based Trips, we utilize populations and households as the opportunities in the accessibility calculation. Figures 9.1 – 9.4 present the recorded population and households for each Block Group for the years 1990, 2000 and 2010.

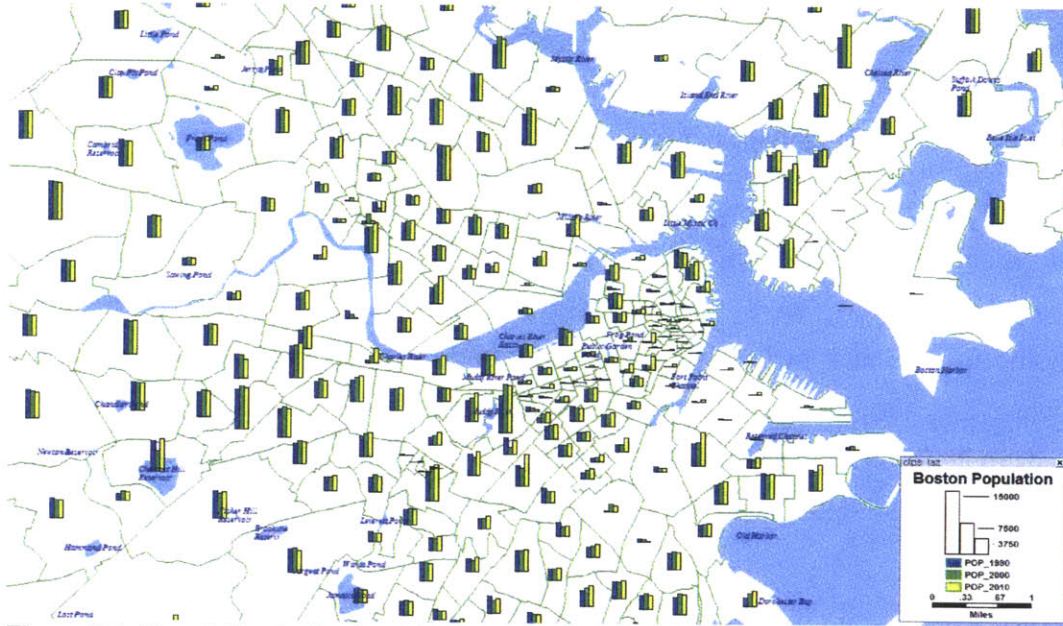


Figure 9.1. Population in Boston, Regional View 1990, 2000 & 2010

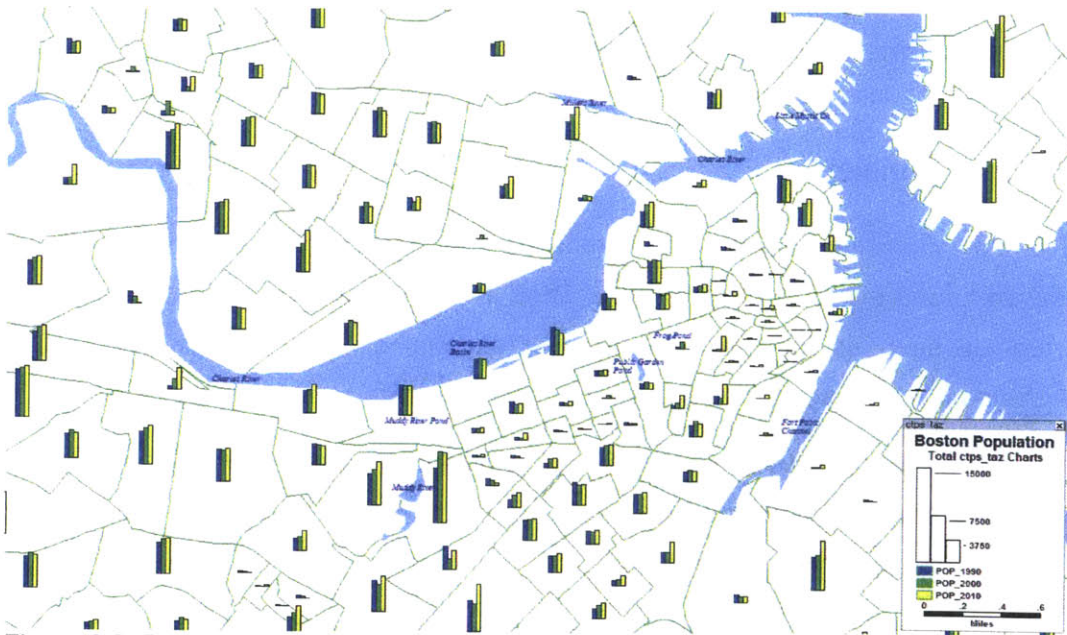


Figure 9.2. Population in Boston, Local View 1990, 2000 & 201

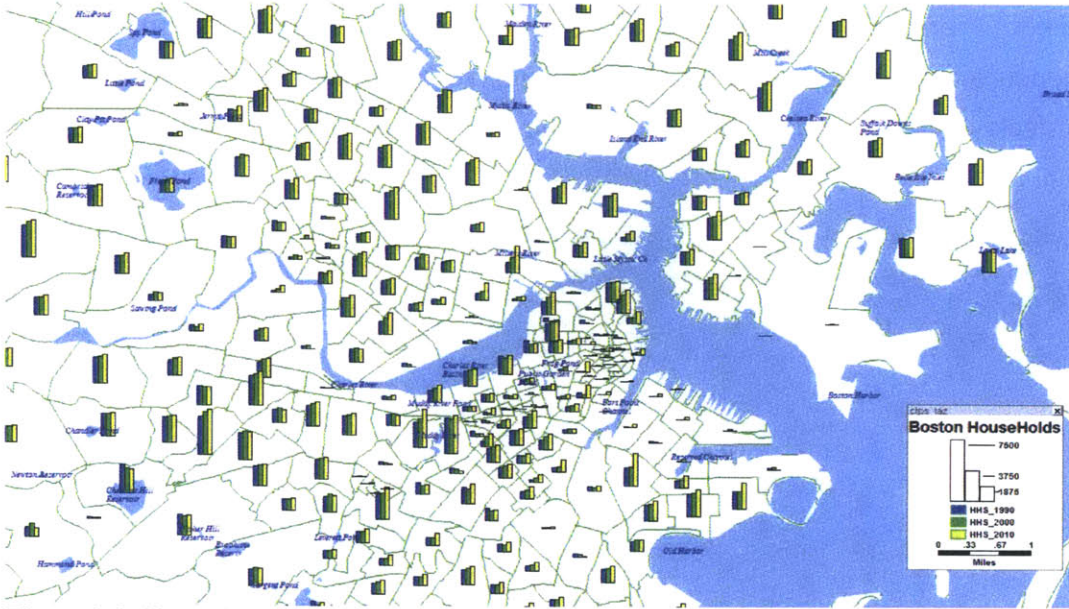


Figure 9.3. Households in Boston, Regional View 1990, 2000 & 2010

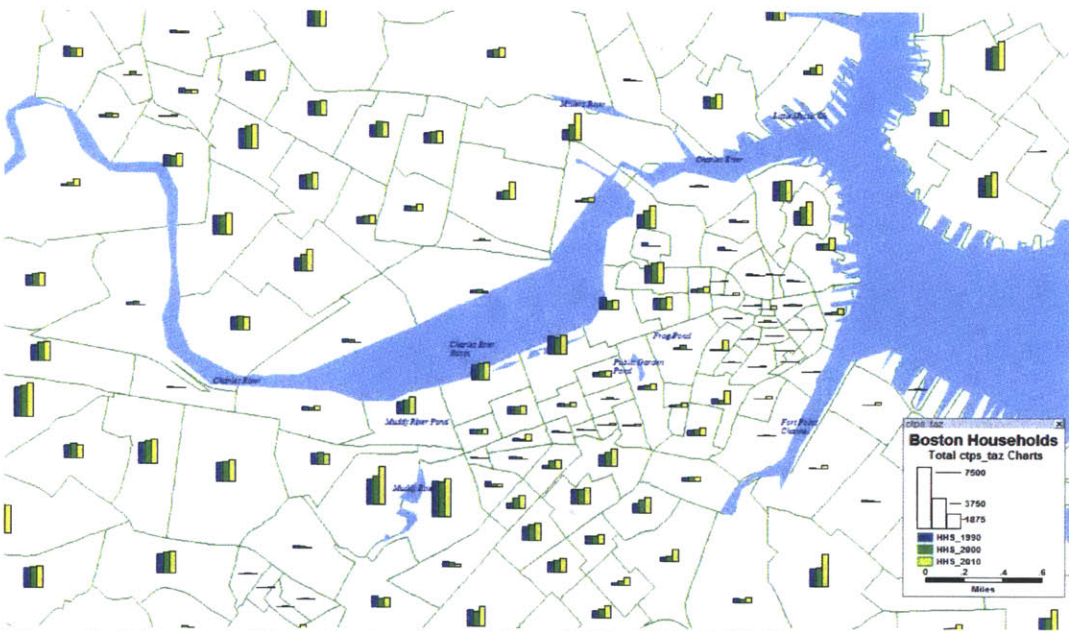


Figure 9.4. Households in Boston, Local View 1990, 2000 & 2010

Home Based Work trips are the most common trip types in the Boston Area. Furthermore, HBW trip accessibility would appear to be essential on a destination's appeal as an employment center. As other home-based trips, HBW trips originate in a residents home. However, besides utilizing population and households as the opportunity, we may utilize the number of people in the labor force as a better index of the destination's appeal. The labor force consist of all people who are within working age, over the age of 16 and below the age of 64, who are employed or actively seeking

employment. Therefore, the accessibility of the labor force to a destination might be a better measure to utilize in the calculation of home based work accessibility. Figures 9.5 and 9.6 display the size of the labor force for the three years in review, 1990, 2000 and 2010.

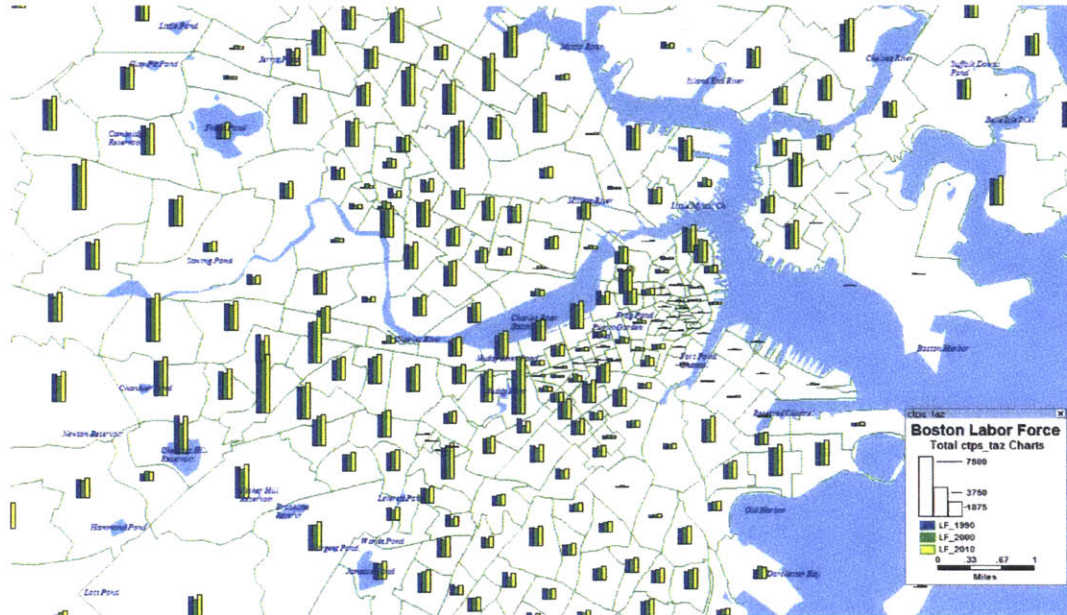


Figure 9.5. Labor Force in Boston, Regional View 1990, 2000 & 2010

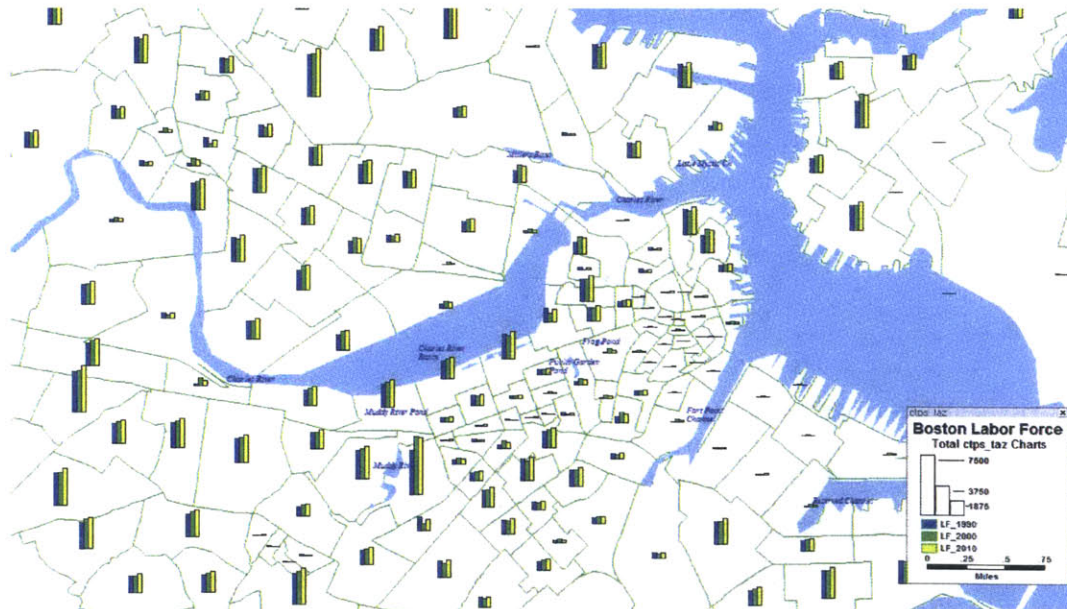


Figure 9.6. Labor Force in Boston, Local View 1990, 2000 & 2010

The accessibility of non-home-based trips is harder to calculate, since these trips do not have a well-established origin. Therefore we have to utilize another measure in order to calculate the destination's accessibility. For this purpose, we utilize jobs as an

indicator of potential trip origins. However, due to the fact that the latest data for employment of the 2010 census is not yet available, we utilized growth rates for the general area to predict 2010 employment. Figure 9.7 and 9.8 display the jobs for each BG for the years 1990 and 2000.

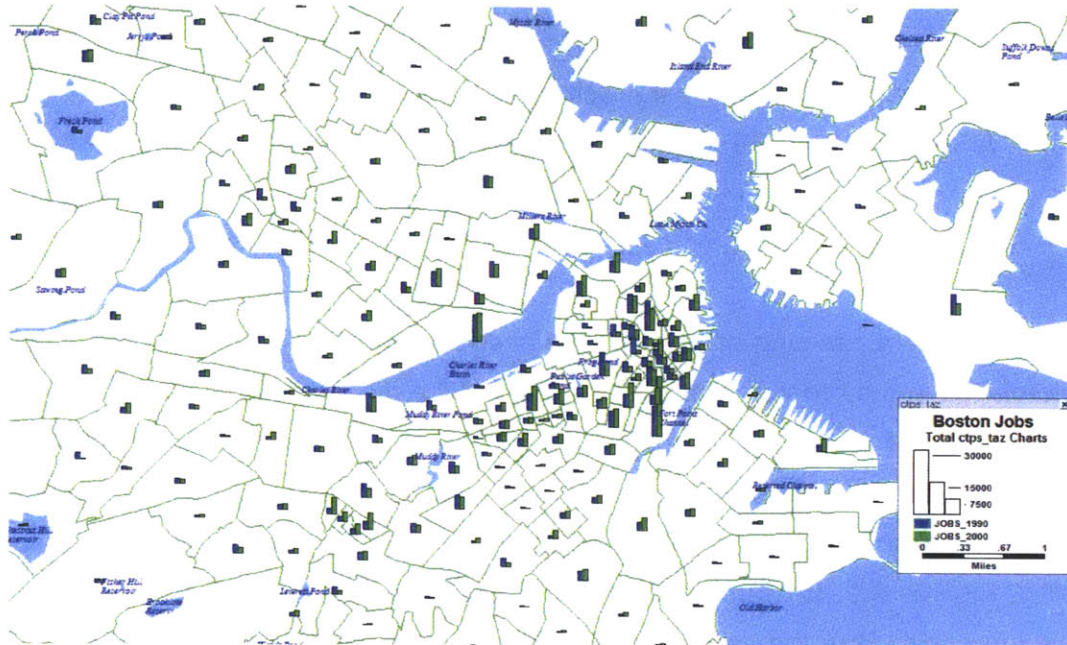


Figure 9.7. Jobs in Boston, Regional View 1990, 2000 & 2010

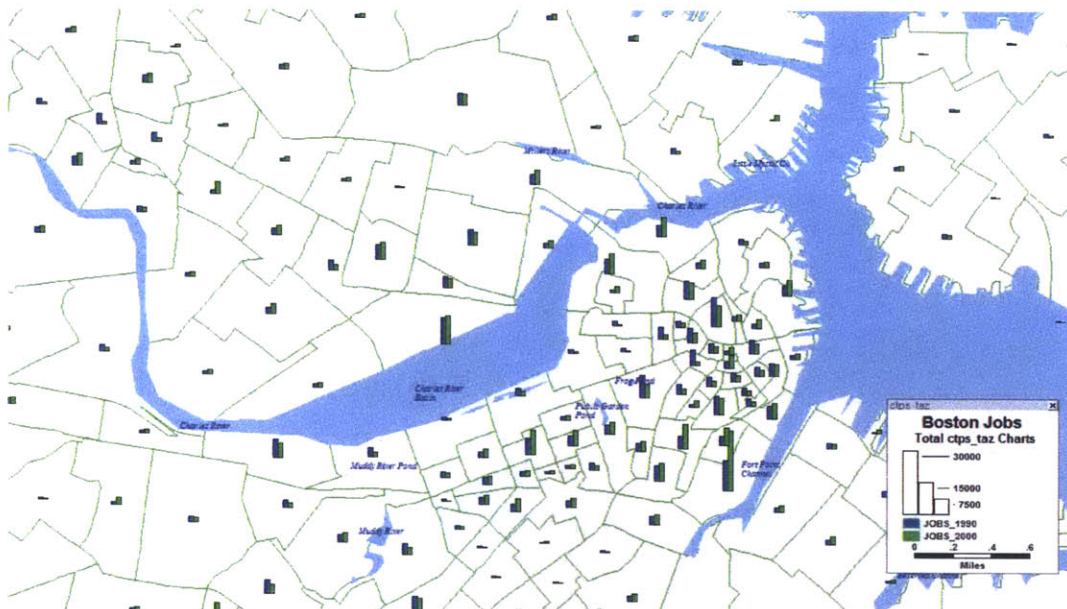


Figure 9.8. Jobs in Boston, Local View 1990, 2000 & 2010

9.2 Home Based Work Accessibility

As Kendall Square keeps growing as an employment center accessibility of Home Based Work trips seems to be one of the most important growth contributors. To this end, we calculated the accessibility of Kendall as a destination depending on all previously mentioned opportunities for the years of 1990, 2000 and 2010. The most weight of this analysis was given to the accessibility of Labor Force numbers to this destination. We also analyzed the changes of accessibility for Home Based Work trips in this area.

9.2.1 Automobile

Kendall Square has long been, since the analysis period in 1990, one of the most accessible places in the greater Boston area. One of the things that we note initially is that due to congestion increases from 2000 to 2010, auto accessibility in the greater Boston area has decreased. Although there is a larger labor force, auto travel times have increased, even with the implementation of the Big Dig, decreasing the auto accessibility. Figures 9.9, 9.10 and 9.11 show the auto accessibility, considering labor force as a trip origin, from the years 1990, 2000 and 2010. As it is displayed in these figures, Auto Accessibility increased with from 1990 and 2000. However, inspection of Figure 9.13, which shows the changes in accessibility from 1990 to 2010 demonstrate that accessibility to this area has actually decreased a little, which might be a product of congestion to the area.

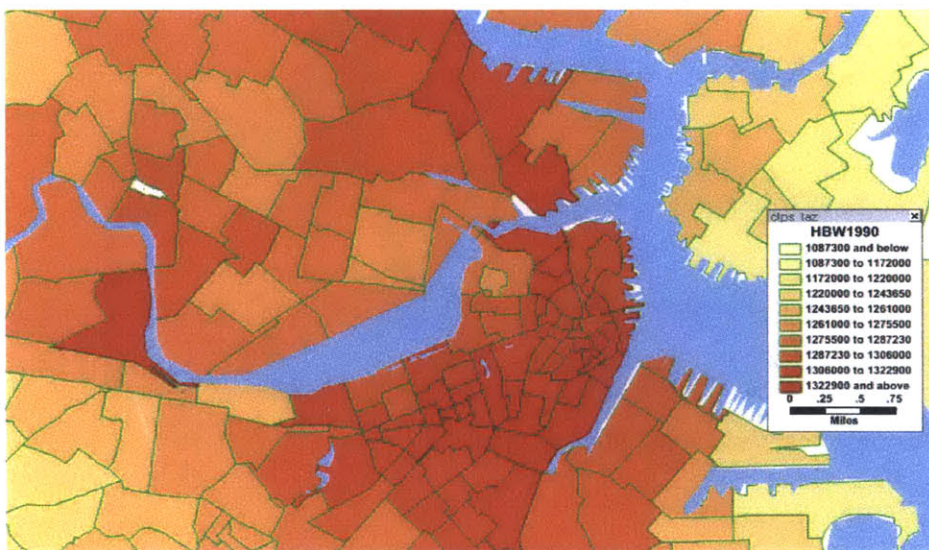


Figure 9.9. Auto Gravity Accessibility for HBW trips. Regional View Labor Force, 1990

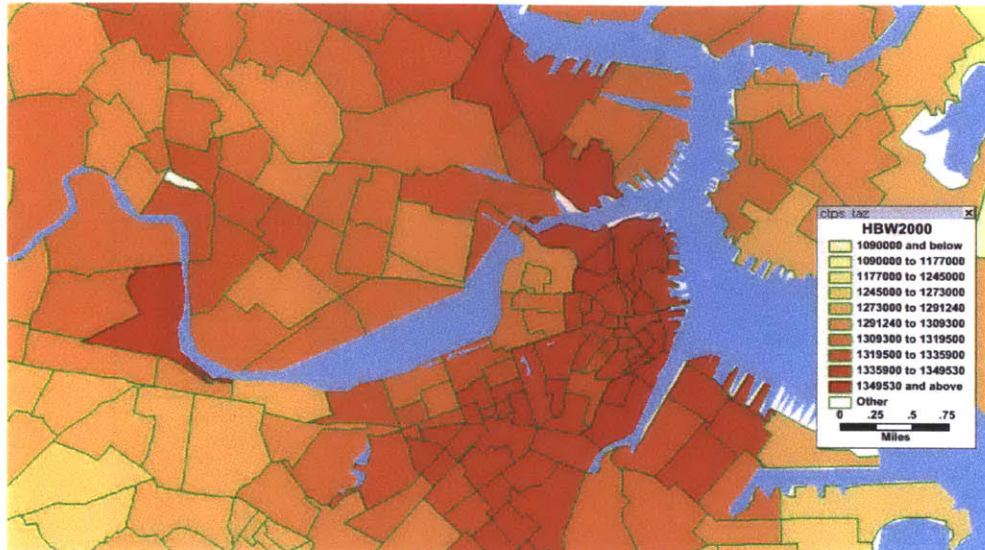


Figure 9.10. Auto Gravity Accessibility for HBW trips. Local View Labor Force, 2000

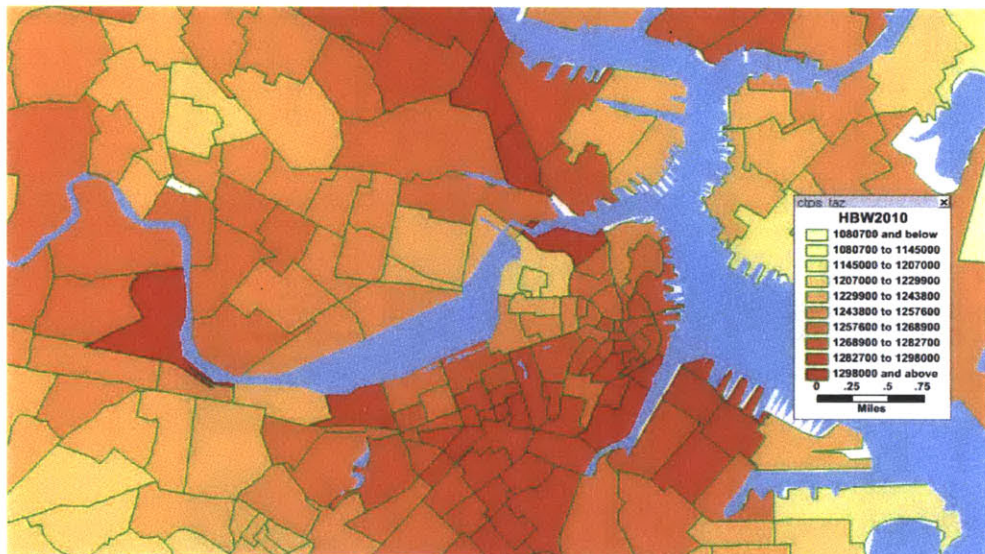


Figure 9.11. Auto Gravity Accessibility for HBW trips. Larger Boston Area Labor Force, 2010

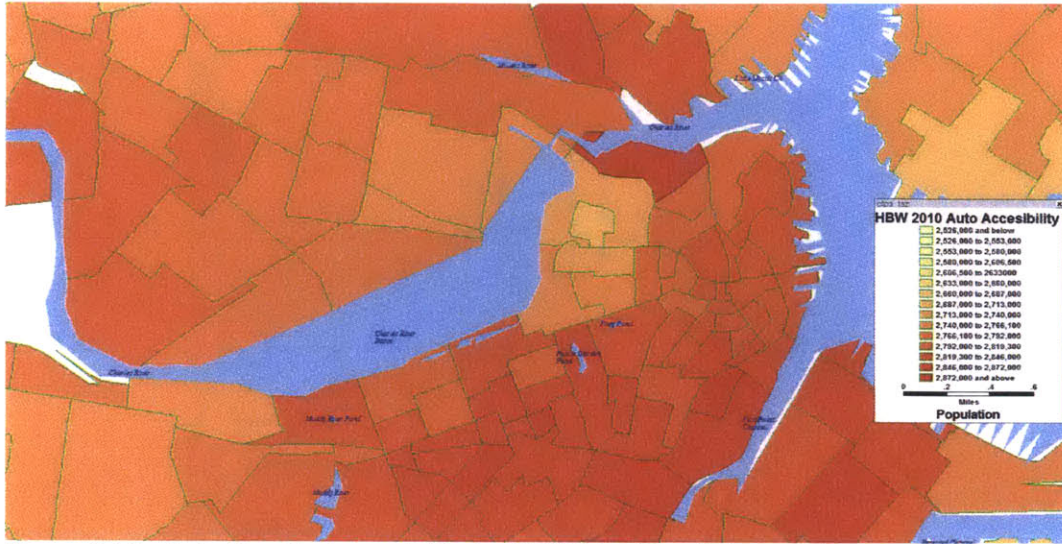


Figure 9.12. Auto Gravity Accessibility for HBW trips Population, 2010

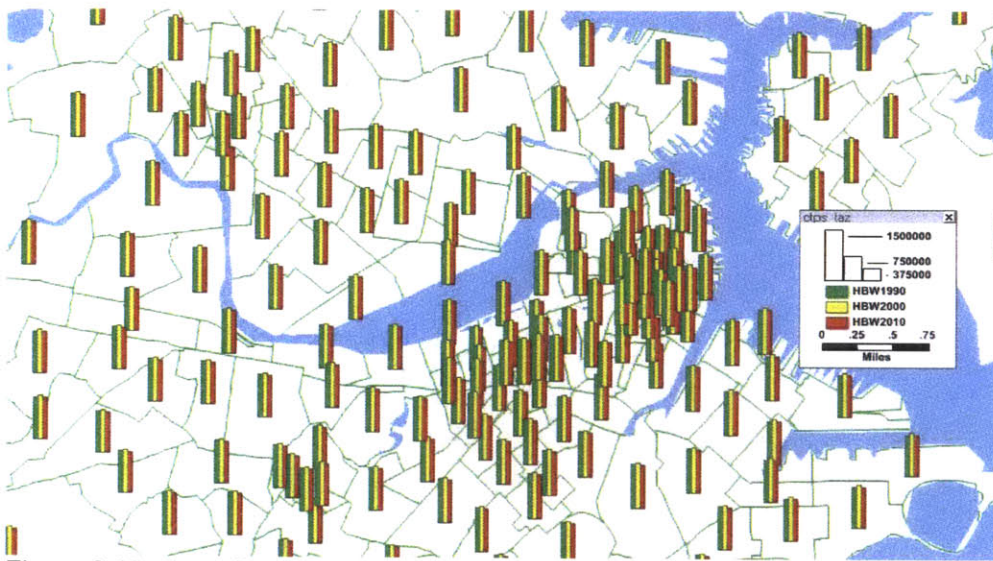


Figure 9.13. Auto Gravity Accessibility for HBW trips. Changes from 1990 to 2010

The values for HBW trips that are auto accessible for every employment area in each of the study time points, 1990, 2000 and 2010, are displayed in Table 9.1. The numerical value estimates the amount of people in the labor force who would be willing (given the revealed trip length preferences from the census) to commute to each destination. The table outlines the employment areas that had been previously compared: Kendall Square, the Central Business District, Longwood Medical Center, the Innovation District, and the Business Park off of Route 93. It also shows the mean values for the employment centers and for the Greater Boston area. The values shown in this graph, as predicted show that auto accessibility for 2010 decreased. Furthermore, it shows that Kendall Square is not the most auto accessible location, showing that the

attraction to this area, and the main commuter mode is not the auto. On average, the auto accessibility of the city has decreased due to the increase congestion in the city. As described in Chapter 7.2, the increase in auto trips for 2010 has caused heavier congestion causing an increase in travel times and a reduction in the city's auto accessibility.

	1990	2000	2010
Kendall	1,310,175	1,311,648	1,238,260
Financial District	1,351,485	1,348,569	1,275,701
LMC	1,319,474	1,317,758	1,265,657
Innovation District	1,306,267	1,326,241	1,271,859
Business Park Route 93	1,337,590	1,342,511	1,277,538
Average	1,322,461	1,325,922	1,260,291
Median	1,314,824	1,321,999	1,268,758
GBA Average	991,303	1,017,520	988,856
GBA Median	1,084,966	2,436,715	1,101,361

Table 9. 1 Summary of Auto HBW Accessibility for main employment centers, statistics & Greater Boston averages

9.2.2 Transit

Kendall Square appears to be one of the most accessible destinations by transit in the greater Boston area. From the years 1990 to 2010, Kendall Square has been solidified as a main destination reachable through public transportation. Figures 9.14, 9.15 and 9.16 demonstrate this increase in accessibility in those years. Accessibility by transit has increased as a destination for Home Based Work trips based on all types of opportunities, population, employment residences, households and labor force. This increase in the HBW accessibility of Kendall Square may well be a product of the physical changes that were previously seen in Chapter 5, such as the changing trends in Kendall Square and the case study of Cambridge Innovation Center. There seems, to be an overwhelming increase in the residences of people that are better served by transit.



Figure 9.14. Transit Gravity Accessibility for HBW trips. Regional View Labor Force, 19



Figure 9. 15 Transit Gravity Accessibility for HBW trips. Local View Labor Force, 2000

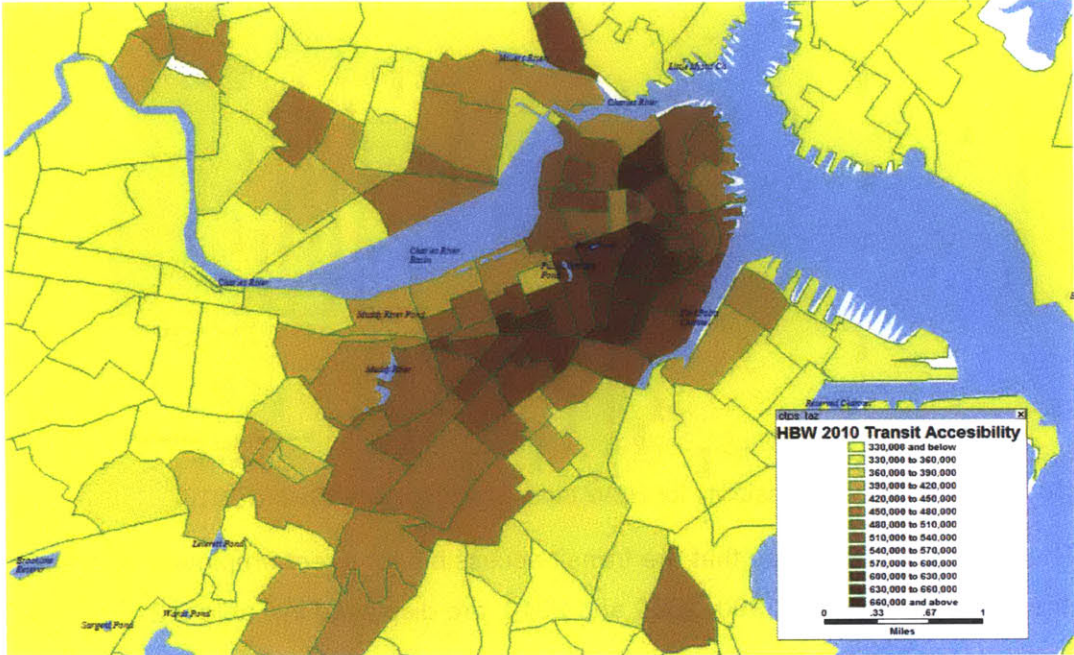


Figure 9.16. Transit Gravity Accessibility for HBW trips. Labor Force, 2010



Figure 9.17. Transit Gravity Accessibility for HBW trips. Population, 2010

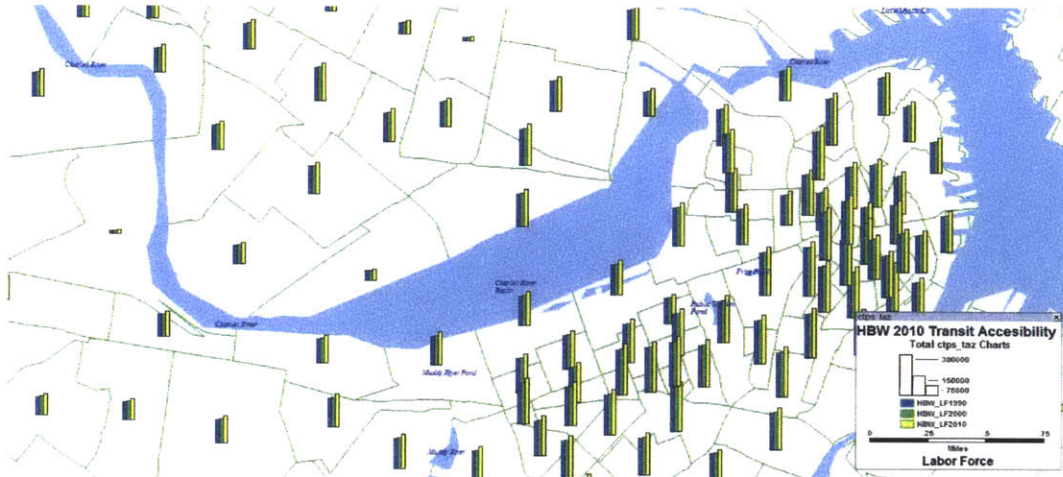


Figure 9.18. Transit Gravity Accessibility for HBW trips. Changes from 1990 to 2010

The values for HBW trips that are transit accessible for every employment area in each of the study time points, 1990, 2000 and 2010, are displayed in Table 9.2.

	1990	2000	2010
Kendall	175,170	182,418	192,738
Financial District	214,058	225,156	241,398
LMC	187,000	193,377	206,055
Innovation District	80,310	83,009	90,337
Business Park Route 93	63,138	65,814	68,528
Average	147,232	153,328	163,051
Median	169,443	176,306	185,996
GBA Average	37,288	37,730	40,411
GBA Median	4,917	165,855	3,729

Table 9. 2 Summary of Transit HBW Accessibility for main employment centers, statistics & Greater Boston averages

9.2.3 Walking

Although walking is amongst the smallest used modes, it is still important to analyze the accessibility of Labor Force to each of the destination. Furthermore ACS data presented in Chapter 5.3 indicated that walking and biking are increasing as commuter modes, and this values can also serve as a rough proxy for bicycling. Figure 9.19 shows the walking accessibility for the labor force in 2010 that demonstrates a fairly well accessible area to people who are living in the downtown area, near where the employment centers are. Figure 9.20 shows the changes in walking accessibility from the year 1990 to 2010. The walking network has not changed in this time period therefore the same travel time values apply for 1990 and 2000. Changes in walking accessibility are lead by changes in the population density of the area. Additionally

Kendall Square shows practically the biggest increase in walking accessibility, demonstrating that density in Kendall Square has increased. This also reflects the increases in residential locations in Kendall Square, as well as the growing tendency in Kendall Square to commute by alternative (bike and walking) modes.



Figure 9.19. Walking Gravity Accessibility for HBW trips. Labor Force, 2010



Figure 9.20. Walking Gravity Accessibility for HBW trips. Population 2010

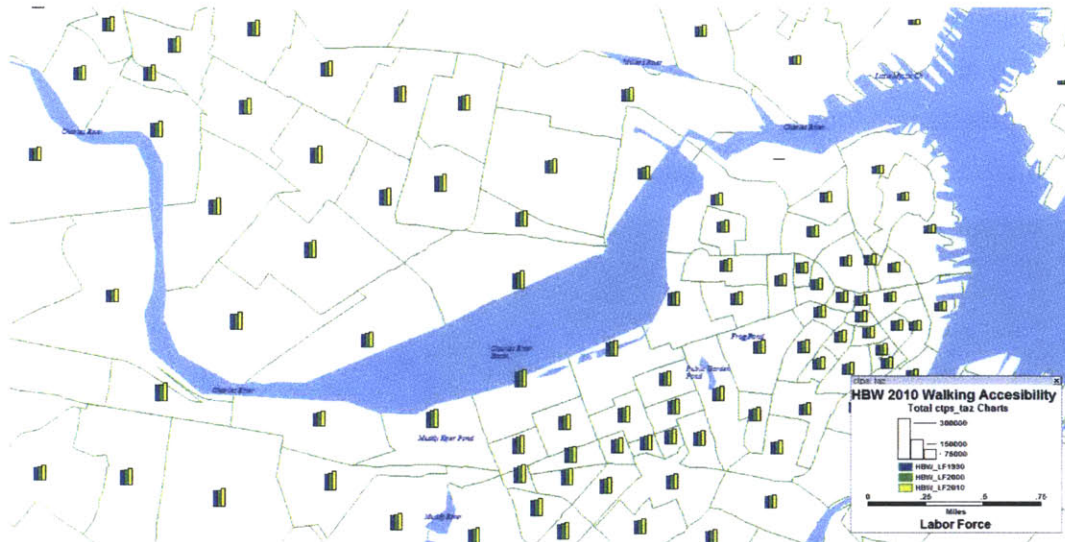


Figure 9.21. Walking Gravity Accessibility for HBW trips. Changes from 1990 to 2010

The values for HBW trips that are walking accessible for every employment area in each of the study time points, 1990, 2000 and 2010, are displayed in Table 9.3.

	1990	2000	2010
Kendall	69,603	73,720	78,632
Financial District	52,890	56,689	63,553
LMC	84,428	87,482	95,340
Innovation District	38,144	40,834	46,421
Business Park Route 93 ³	43,112	46,215	48,727
Average	59,077	62,555	68,073
Median	59,587	63,541	69,660
GBA Average	23,606	24,550	25,838
GBA Median	12,270	12,542	12,823

Table 9. 3 Summary of Walking HBW Accessibility for main employment centers, statistics & Greater Boston averages

9.3 Home Based School Accessibility

Home Based School accessibility was calculated repeating the same process, although utilizing the deterrence function calculated for HBS trips and the block group population. Given that one of the main attractors for businesses in Kendall Square is said to be the closeness to MIT, we expected Kendall Square to be accessible for student trips. Since professors and full time researcher trips to MIT would be considered

³ The size of TAZs in this location is very sparse. Therefore, the actual distance between TAZs results in the figures above, instead of representing actual intended walking trips or how realistic walking trips are in the suburbs.

HBW trips access, it was not necessary to account for their accessibility for HBS trips, and thus focused for people in the age bracket that are most likely to be in their late years of high school, college or graduate school.

The analysis performed examined every transportation mode separately. Figure 9.22 displays the HBS auto accessibility for 2010 population levels. The local view of this accessibility shows that the accessibility is equally distributed between the Boston center and adjacent areas. There appears to be higher accessibility among campuses such as Harvard Square, the Harvard Business School Campus and some areas of the City Center. A regional view of HBS auto accessibility (Appendix B, Figure B.1) shows that the accessibility decreases as we move away from the center of the city. This is consistent with population patterns that demonstrate that younger people tend to live closer to the city center, and closer to school campuses. The values for HBS trips that are auto accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.4. Once again, the increases in congestion causes a decrease in HBS auto accessibility for the city.

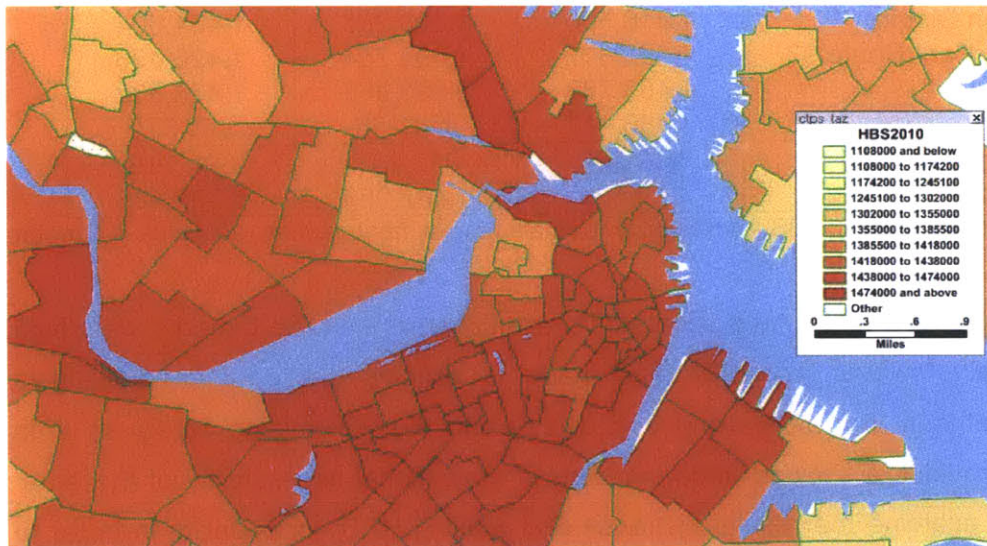


Figure 9.22. Auto Gravity Accessibility for HBS Trips. Local View. Population 2010

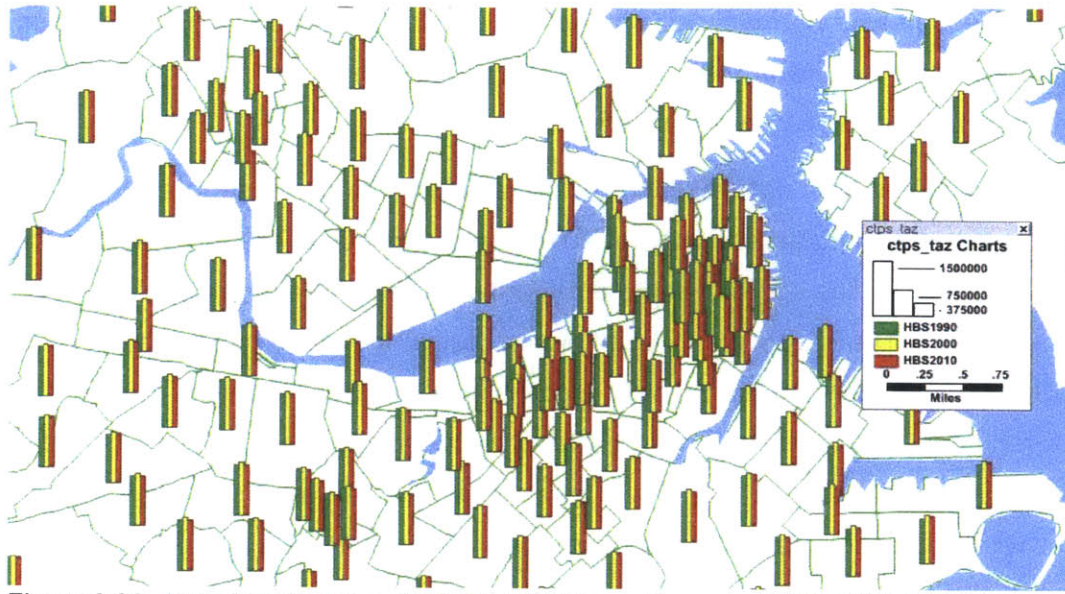


Figure 9.23. Auto Gravity Accessibility for HBS Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	1,480,517	1,482,056	1,392,488
Financial District	1,525,565	1,505,868	1,463,020
LMC	1,510,392	1,473,456	1,433,000
Innovation District	1,418,506	1,508,285	1,434,604
Business Park Route 93	1,492,317	1,495,744	1,426,496
Average	1,483,788	1,493,962	1,433,802
Median	1,486,417	944,266	920,375
GBA Average	919,500	912,291	891,119
GBA Median	878,522	1,482,056	1,392,488

Table 9. 4 Summary of Auto HBS Accessibility for main employment centers, statistics & Greater Boston averages

The patterns of HBS Auto accessibility are coherent with the patterns we would expect to see. However, most of trips made to schools are done in alternative commuting methods: transit, walking and biking, and thus examining solely on auto accessibility provides a skewed understanding of educational accessibility of the area. Thus we may examine the results of transit and walking HBS accessibility in order to better understand the accessibility of each destination.

The results for HBS Transit accessibility better highlight the presence of educational institutions and campuses in the area. Figure 9.24 displays the HBS transit accessibility. This figure demonstrates the high HBS accessibility of Kendall Square, which is expected due to the presence of MIT. The figure also highlights the CBD, which has a number of campuses, as well as the Harvard Campus. We may also notice the increased accessibility of HBS along the MBTA Red Line in Cambridge (connecting

Kendall to Harvard Square). The values for HBS trips that are transit accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.5.

Using the available information we may also calculate the changes in HBS Transit accessibility for the years 1990, 2000 and 2010. Given that the transit system has remained unchanged and most schools since the beginning of this period, HBS transit and auto accessibility has remained fairly constant; growing at the same rate as HBW trips.

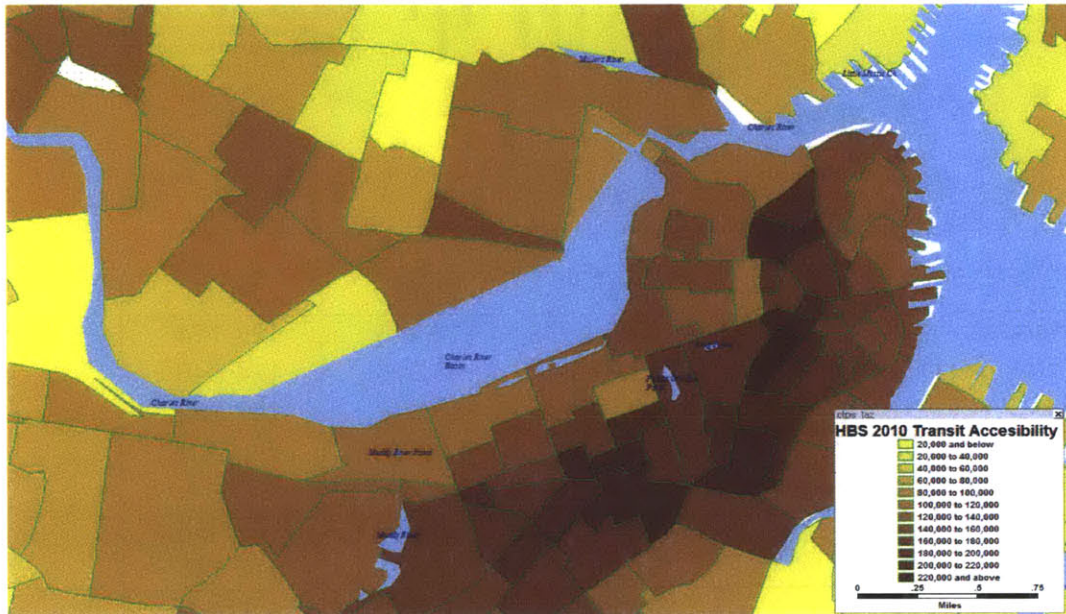


Figure 9.24. Transit Gravity Accessibility for HBS Trips. Local View. Population 2010

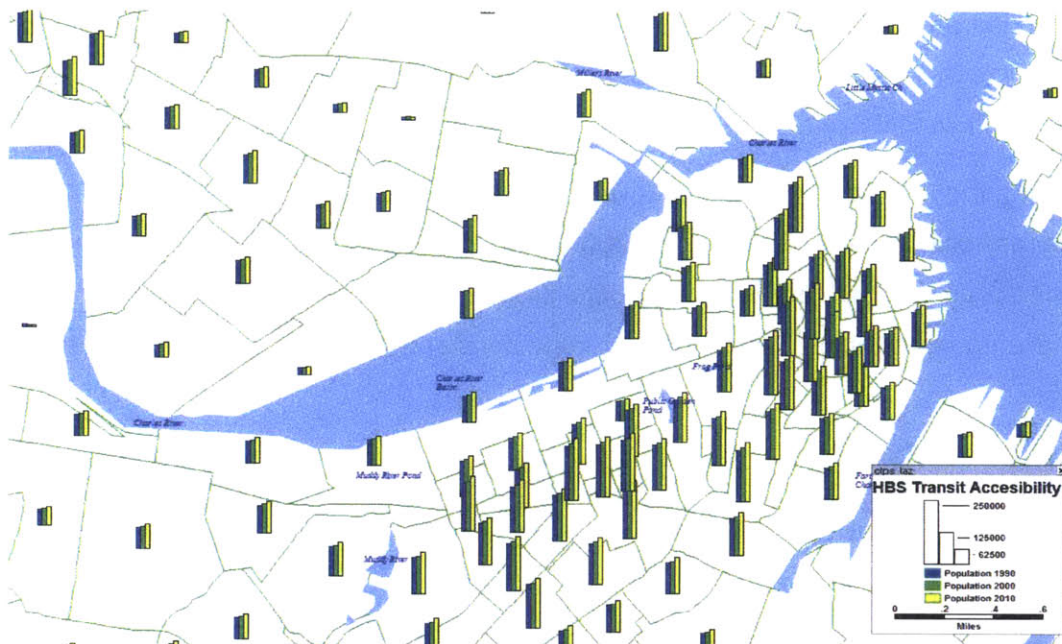


Figure 9.25. Transit Gravity Accessibility for HBS Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	106,758	112,243	121,114
Financial District	148,375	158,016	174,540
LMC	139,047	143,378	157,262
Innovation District	45,327	47,170	52,821
Business Park Route 93	33,828	35,044	37,114
Average	95,357	99,901	109,018
Median	102,783	107,901	116,186
GBA Average	26,569	27,083	29,643
GBA Median	6,628	6,218	6,518

Table 9. 5 Summary of Transit HBS Accessibility for main employment centers, statistics & Greater Boston averages

Given that many students decide to live on Campus for school, we may also examine the HBS Walking accessibility. Figure 9.26 presents the results of these calculations. As expected, the most accessible areas are along the schools. From this figure we may notice the predominance of Harvard, MIT, Boston University, Northeastern, the Longwood medical center, and the Back Bay area (which serves as a residential areas for many students of the area. The values for HBS trips that are walk accessible for every employment area and Greater Boston area statistics, in each of the study time points are displayed in Table 9.6.



Figure 9.26. Walking Gravity Accessibility for HBS Trips Population 2010

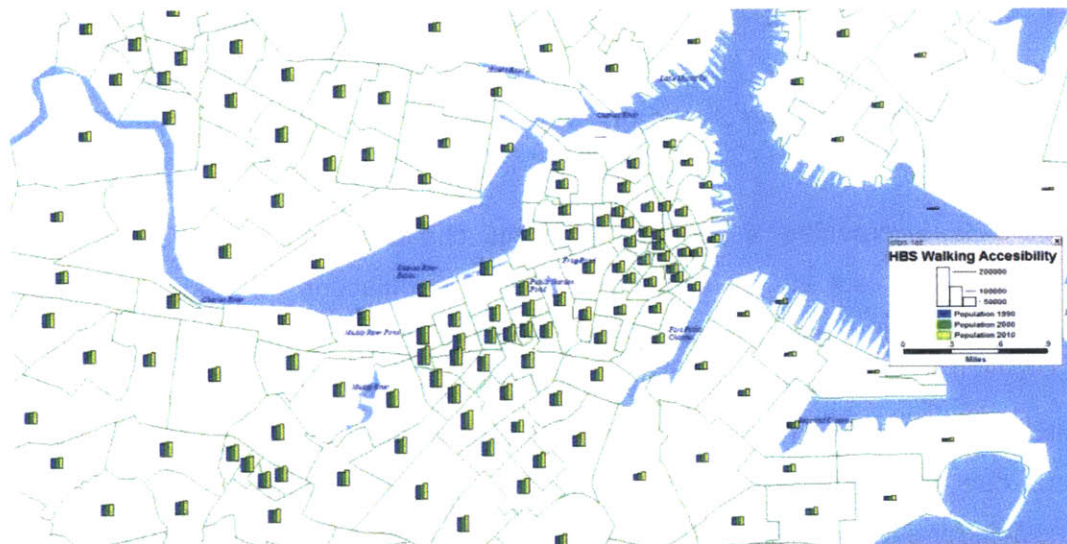


Figure 9.27. Walking Gravity Accessibility for HBS Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	43,839	47,390	51,390
Financial District	36,715	40,205	47,587
LMC	68,905	70,719	79,054
Innovation District	25,658	27,558	32,016
Business Park Route 93	29,442	31,315	33,231
Average	41,250	43,893	48,944
Median	39,827	43,188	48,986
GBA Average	20,031	20,893	22,107
GBA Median	10,746	11,138	11,682

Table 9. 6 Summary of Walking HBS Accessibility for main employment centers, statistics & Greater Boston averages

9.4 Home Based Shopping Accessibility

Home based shopping trips were calculated utilizing the deterrence function for Home Based Shopping trips calculated in Chapter 8 and block group population for trip origins. Once again, the accessibility was calculated for all three modes, automobile, transit and walking. Kendall Square has grown as a major employment center for biotech, start-up and research companies, which do not rely on personal shopping. Thus, we predicted that Kendall Square would not necessarily be of one the most accessible HBSshop places in the Greater Boston Area.

Examining the results for HBSshop accessibility by automobile resonates this previous idea. Figure 9.28 provides a local view of auto accessibility in the Boston. Most areas demonstrate a high level of HBSshop auto accessibility, especially most of the Downtown area, areas to the east of Boston Center and the Kendall MIT area. A regional view of the region (Appendix B, Figure B.3) demonstrates that other employment centers such as the Seaport provide one of the lowest automobile HBSshop accessibility.

Figure 9.29 provides a representation of changes in HBSshop automobile accessibility over the last 20 years utilizing different populations and skims for each years. As seen from this graph, accessibility has changed at a similar rate in all block groups, consistent with the increase in accessibility for 2000 and a decrease in auto accessibility in 2010. Changes in accessibility are most likely a product of changes in travel times due to the increase in congestion. The values for HBSshop trips that are auto accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.7.

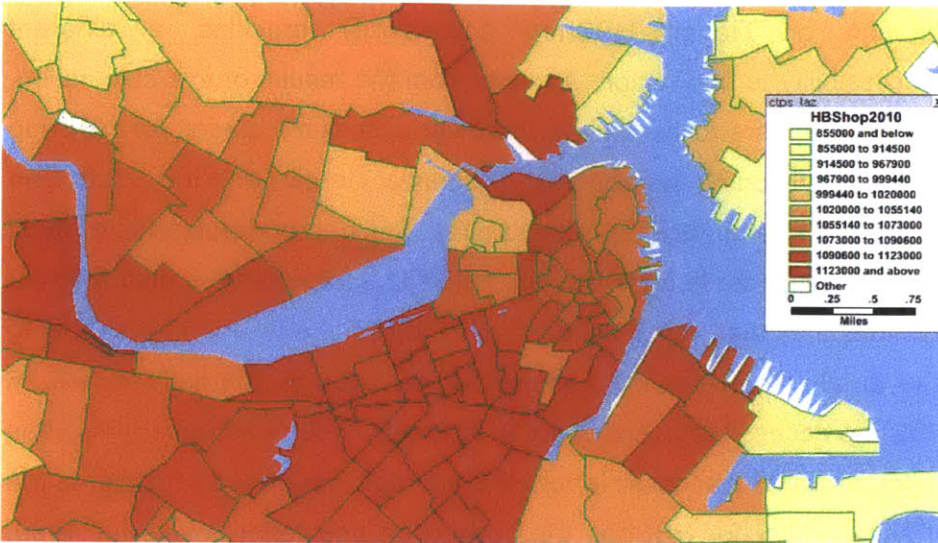


Figure 9.28. Auto Gravity Accessibility for HBSHops Trips. Local View. Population 2010

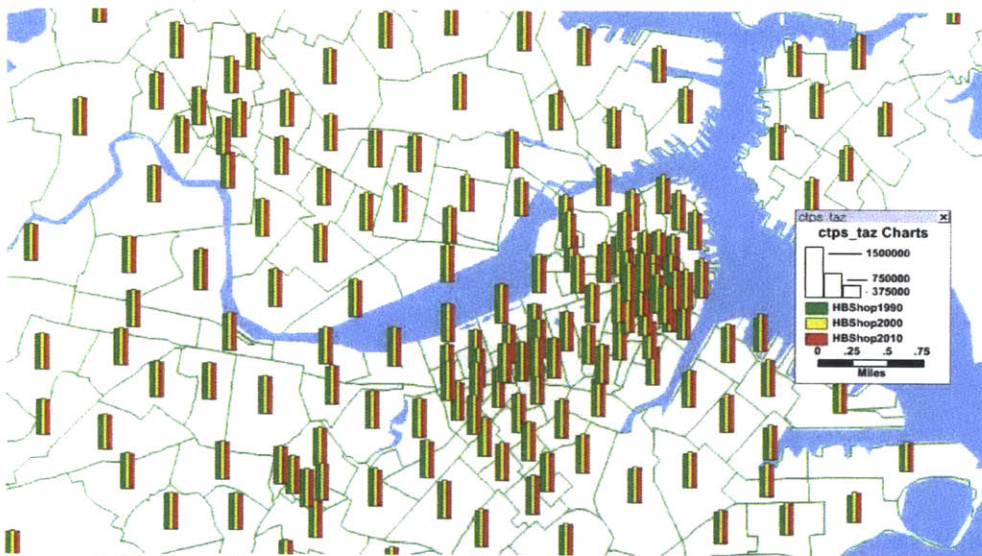


Figure 9.29. Auto Gravity Accessibility for HBSHops Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	1,105,987	1,111,327	1,034,505
Financial District	1,130,398	1,145,200	1,083,807
LMC	1,142,731	1,142,290	1,115,126
Innovation District	1,016,224	1,079,998	1,055,737
Business Park Route 93	1,108,694	1,130,529	1,066,111
Average	1,100,516	1,118,801	1,063,710
Median	1,107,341	1,120,928	1,060,924
GBA Average	607,745	625,155	609,873
GBA Median	517,351	539,353	526,526

Table 9. 7 Summary of Auto HBSHops Accessibility for main employment centers, statistics & Greater Boston averages

An examination of Transit HBSshop accessibility provides a different understanding of accessibility to this region. As seen from the results of this calculation, in Figure 9.30, the CBD appears to be among the most accessible places for HBSshop trips. The Copley Area (Boylston St, Newbury St, Prudential Center) and the South End are also highlighted for its strong HBSshop accessibility, which is understandable given that these are the commercial centers for Boston. HBSshop accessibility is also high for Kendall Square, this indicates that transit access to this region is quite high for shopping trips that foster the smaller but growing commercial ventures in Kendall Square. A regional view of HBSshop accessibility (Appendix B, Figure B.4) demonstrates that areas outside the city center are quite inaccessible for HBSshop trips. Figure 9.31 highlights the changes in transit accessibility for HBSshop trips based on population levels for 1990, 2000 and 2010. From this figure, it is noticeable that most of the increases in accessibility have been quite constant. Kendall Square proper does appear to have a percentage increase that is above normal for the area. The values for HBSshop trips that are transit accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.8.

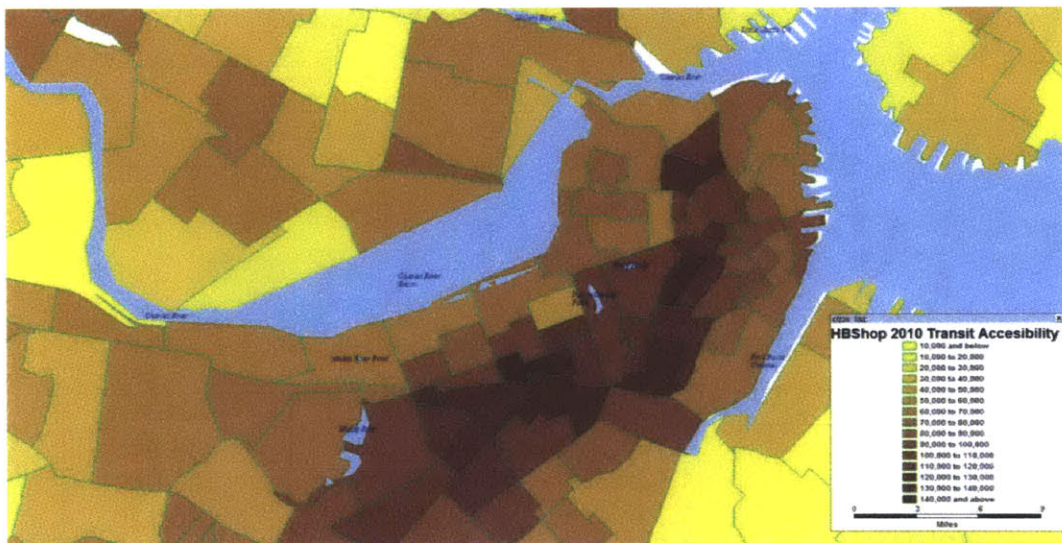


Figure 9.30. Transit Gravity Accessibility for HBSshop Trips. Local View. Population 2010

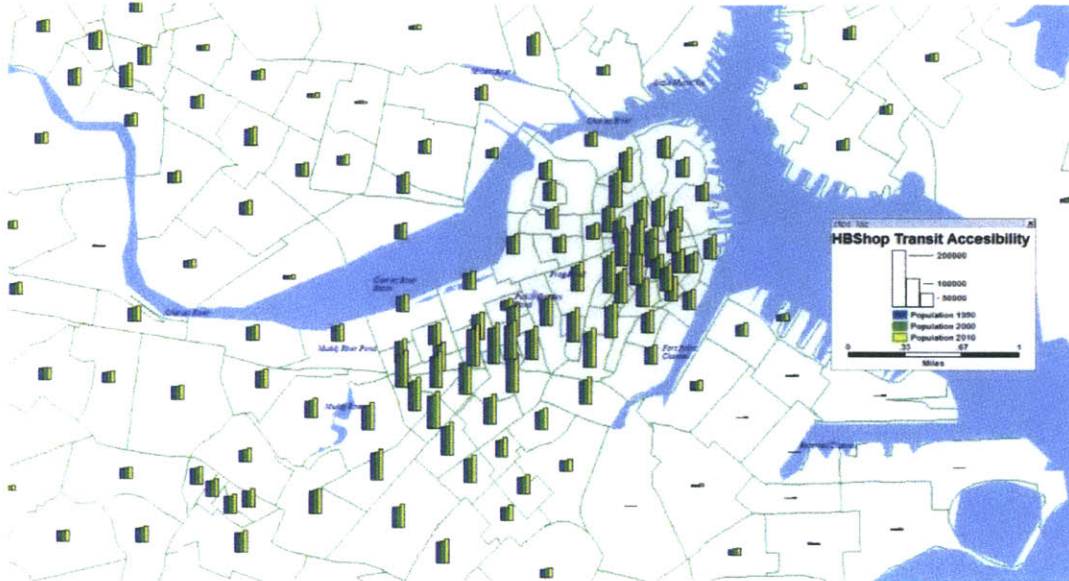


Figure 9.31. Transit Gravity Accessibility for HBSHOP Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	51,300	54,442	59,279
Financial District	77,611	83,440	94,081
LMC	79,792	82,327	91,079
Innovation District	20,455	21,481	24,480
Business Park Route 93	16,047	16,375	17,546
Average	48,748	51,350	56,768
Median	49,292	52,238	56,711
GBA Average	15,383	15,827	17,468
GBA Median	5,984	6,066	6,367

Table 9. 8 Summary of Transit HBSHOP Accessibility for main employment centers, statistics & Greater Boston averages

Inspection of the walking accessibility for HBSHOP trips most closely resembles the patterns of the auto HBSHOP accessibility. Figure 9.32 displays the walking accessibility for HBSHOP trips based on the population values for 2010, while figure 9.33 presents the changes in walking accessibility over the last 20 years. Once again the CBD and the Copley area are highlighted for their high Walking accessibility, which further reiterates its importance as a commercial center for the Greater Boston Area. It appears to be that Kendall Square has quite a high walking HBSHOP accessibility in relation to the rest of the city. Since the walking network has not changed in the last twenty years, this is most likely a product of growing residential spaces in the area around Kendall Square. The values for HBSHOP trips that are walking accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.9.



Figure 9.32. Walking Gravity Accessibility for HBSHOP Trips Population 2010

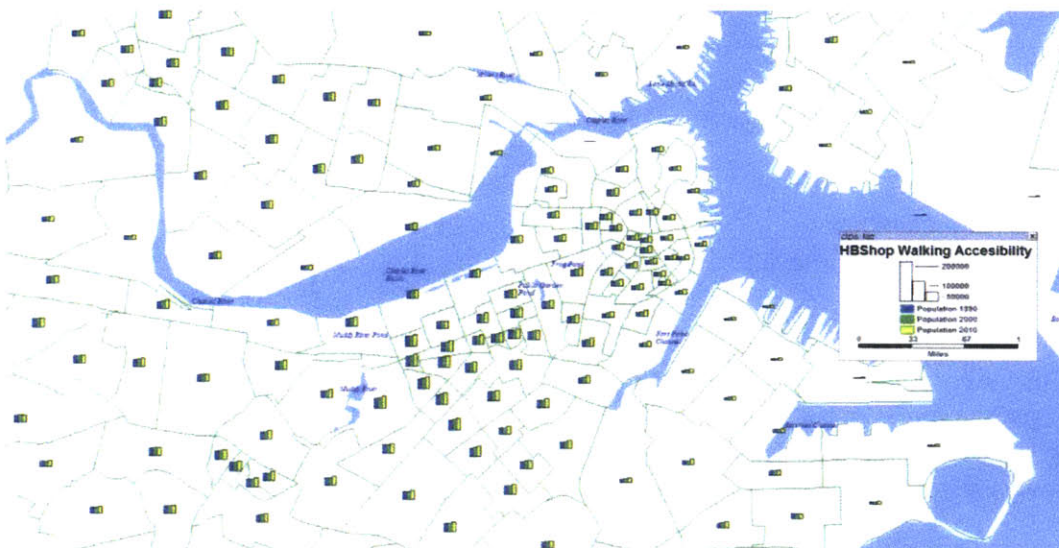


Figure 9.33. Auto Gravity Accessibility for HBSHOP Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	43,839	47,390	51,390
Financial District	36,715	40,205	47,587
LMC	68,905	70,719	79,054
Innovation District	25,658	27,558	32,016
Business Park Route 93	29,442	31,315	33,231
Average	41,250	43,893	48,944
Median	39,827	43,188	48,986
GBA Average	20,031	20,893	22,107
GBA Median	10,746	11,138	11,682

Table 9. 9 Summary of Walking HBSHOP Accessibility for main employment centers, statistics & Greater Boston averages

9.5 Home Based Other Accessibility

Among home based trips, home based other accessibility would appear not to have as great an importance on the overall notion of accessibility as HBW, HBS and HBShop when it comes to assessing the importance of accessibility of an employment center. However, one of the main aspects of cluster formation was that in fact it fostered a unique environment, which allowed for the collaboration of inter-related ventures. HBO trip accessibility might serve as another indicator of locations for this kind of unique opportunities. Therefore we examine HBO accessibility in a similar process.

The different modal skims allowed once again for a modal accessibility analysis of each block group destination based on the deterrence function of HBO trips and population levels for each analysis year. Figure 9.34 analyzes the automobile HBO destination accessibility at each block group; while figure 9.35 examines the changes in automobile HBO destination accessibility in year 1990, 2000 and 2010. The values for HBO trips that are auto accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.10.

As seen from these figures, the South End, Back Bay and Cambridge area appear to be most accessible for this trip purpose. Furthermore, the relative levels of auto HBO destination accessibility have remained fairly constant over the last years. A more regional view of the area (Appendix B, Figure B.5) demonstrates that as you move away from the city center the destination accessibility diminishes. Unlike other trips, some parts of the Seaport innovation district do provide a relatively high HBO accessibility.



Figure 9.34. Auto Gravity Accessibility for HBO Trips. Local View. Population 2010

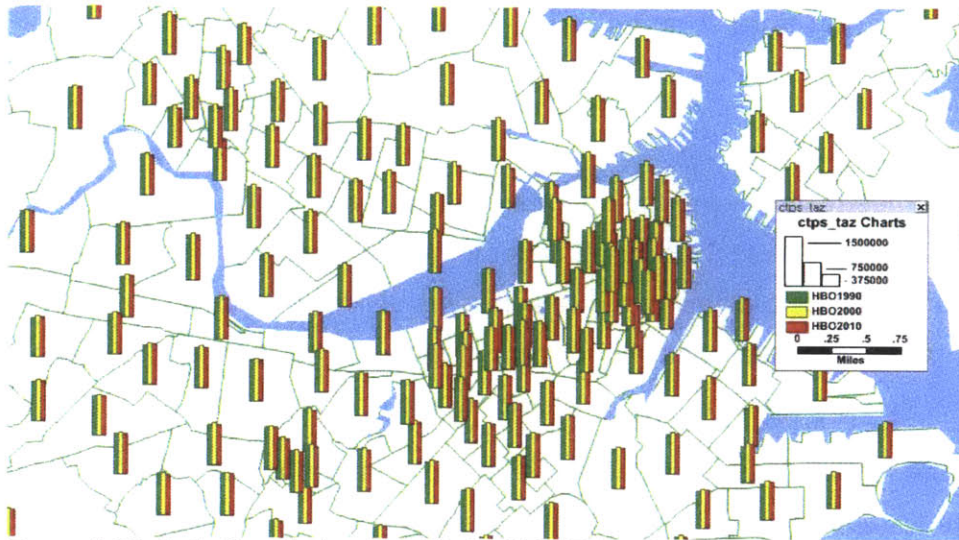


Figure 9.35. Auto Gravity Accessibility for HBO Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	1,300,478	1,304,008	1,219,855
Financial District	1,334,554	1,343,954	1,273,583
LMC	1,334,231	1,331,990	1,296,745
Innovation District	1,226,202	1,283,802	1,249,248
Business Park Route 93	1,310,288	1,328,154	1,257,039
Average	1,300,097	1,314,812	1,251,388
Median	1,305,383	1,316,081	1,253,144
GBA Average	782,110	803,577	783,194
GBA Median	725,642	755,585	734,863

Table 9. 10 Summary of Auto HBO Accessibility for main employment centers, statistics & Greater Boston averages

In a similar manner, we are able to analyze the transit patterns for HBO destination accessibility. The results from this figure present a very different picture than what we have seen in previous auto HBO accessibility figures. Figure 9.36 analyzes the transit HBO destination accessibility at each block group; while figure 9.37 examines the changes in transit HBO destination accessibility in year 1990, 2000 and 2010. These figures highlight the dominance of the transit network to the center of the city, the CBD and some parts of Cambridge (Kendall Square and other areas served by the Red Line). The small block group that is served by the Kendall Square stop of the Red Line is amongst the most accessible places for HBO trips in Boston. The values for HBO trips that are transit accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.11.

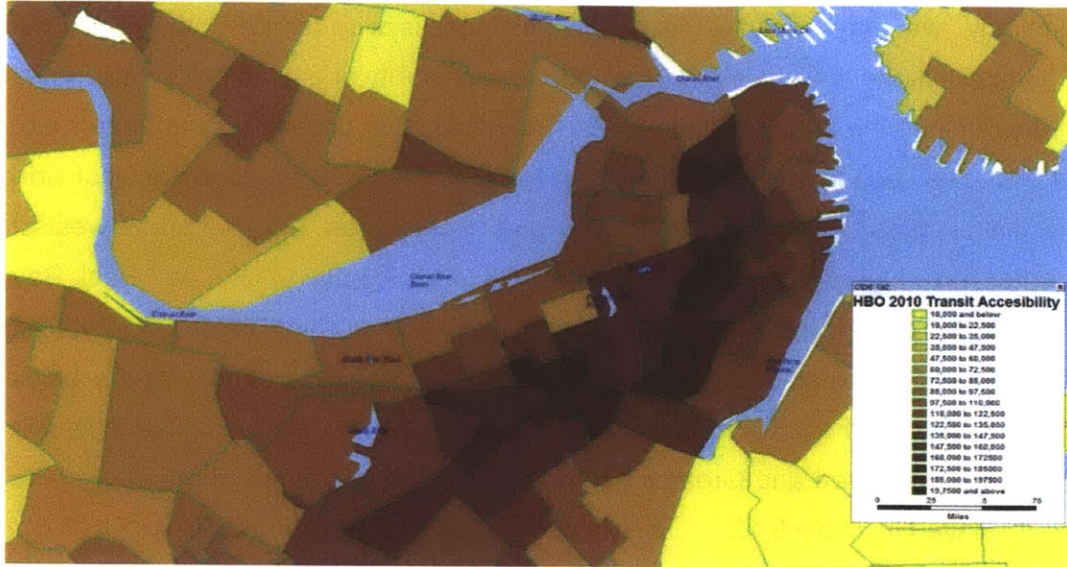


Figure 9.36 Transit Gravity Accessibility for HBO Trips. Local View. Population 2010



Figure 9.37. Transit Gravity Accessibility for HBO Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	85,045	89,558	96,739
Financial District	119,515	127,476	141,384
LMC	114,135	117,729	129,235
Innovation District	35,701	37,217	41,795
Business Park Route 93	26,906	27,796	29,529
Average	76,650	80,383	87,902
Median	81,820	86,041	92,735
GBA Average	22,027	22,508	24,668
GBA Median	6,453	6,155	6,464

Table 9. 11 Summary of Transit HBO Accessibility for main employment centers, statistics & Greater Boston averages

Similarly, we may analyze the destination accessibility for HBO walking trips. Figure 9.38 displays the walking HBO destination accessibility at each block group; while figure 9.39 examines the changes in walking HBO destination accessibility in year 1990, 2000 and 2010. As seen in this figure there is a better accessibility towards the west side of the city. This makes sense since HBO trips tend to be shorter, and the areas west of the city center have higher population. The Mass General Hospital (MGH) and Back Bay area in the center part of the city may be highlighted for their high HBO accessibility. However, Kendall Square also provides a comparable accessibility, mostly in the block groups that are west of the square. The values for HBO trips that are walking accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.12.



Figure 9.38. Walking Gravity Accessibility for HBO Trips Population 2010

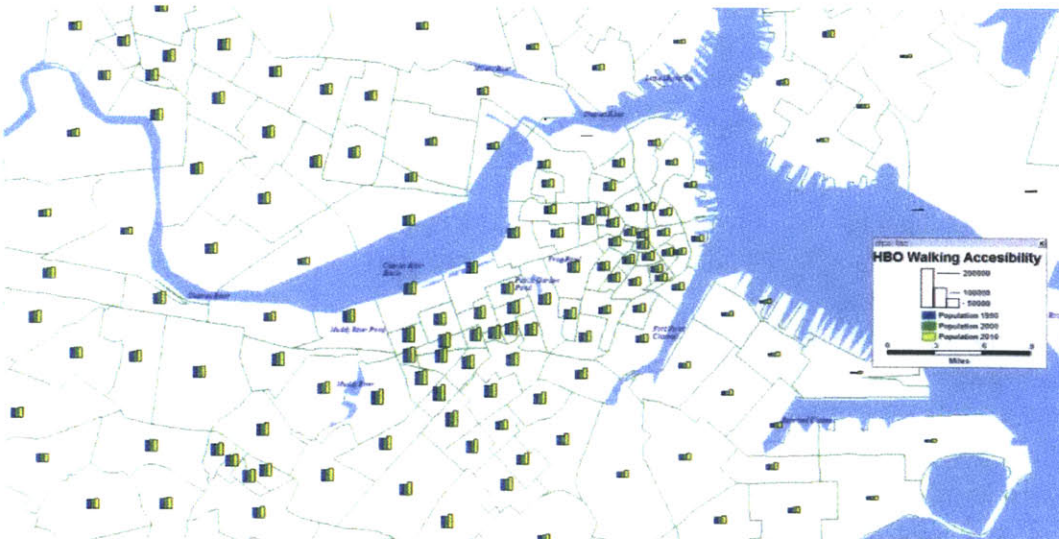


Figure 9.39. Auto Gravity Accessibility for HBO Trips. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	24,236	26,289	28,887
Financial District	21,141	23,539	28,690
LMC	43,661	44,858	50,477
Innovation District	14,036	15,109	17,659
Business Park Route 93	17,358	18,182	19,494
Average	23,977	25,637	28,947
Median	22,285	24,692	28,582
GBA Average	13,184	13,799	14,600
GBA Median	8,035	8,653	8,824

Table 9. 12 Summary of Walking HBO Accessibility for main employment centers, statistics & Greater Boston averages

9.6 Non-Home Based Trips Accessibility

Lastly, non-home based trips (NHBT) were analyzed to provide a complete understanding of accessibility for the Greater Boston area. As previously explored in Chapter 8, non-home based work trips and non-home based other trips have similar trip length distributions, which allows us to use the same deterrence function to replicate the probability pattern of trips based on trip length. As suggested by its name, non-home based trips originate in places other than an individual's home residence. Therefore, it is harder to predict the origins for these trips. For the purpose of this analysis jobs were used as the trip origin for non-home based trips since most of these trips tend to be linked to the individual's place of employment. Since non-home based trips tend to be shorter, utilizing jobs for non-home based trip origins will also serve as an indicator for interactions between workers during day time trips. As mentioned in Chapter 4, one of the main advantages of high employment density areas is the interaction among employees of the area. Therefore, the non-home based accessibility measure may suggest the degree of interaction of employees during the day. This interaction is indicative of the bump factor described in Chapter 3.2 as one of the main drivers of innovation.

Different modal skims allowed us once again to analyze different modal accessibility. Figure 9.40 displays the automobile accessibility for NHBT utilizing employment levels for 2010. As expected, the most accessible NHBT areas are in the center of the city, near the CBD and Back Bay, South End areas. Kendall Square presents high NHBT auto accessibility, mostly on the block groups closer to MIT. Figure 9.41 displays the changes in NHBT trips in years 1990, 2000 and 2010. Auto

accessibility has increased in the three study periods, unlike the previous results. Given that congestion levels have increased, the accessibility increases have been lead by the increase in job density (considered to be the captured opportunities for NHBT), rather than travel time improvements. The values for NHBT trips that are auto accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.13.

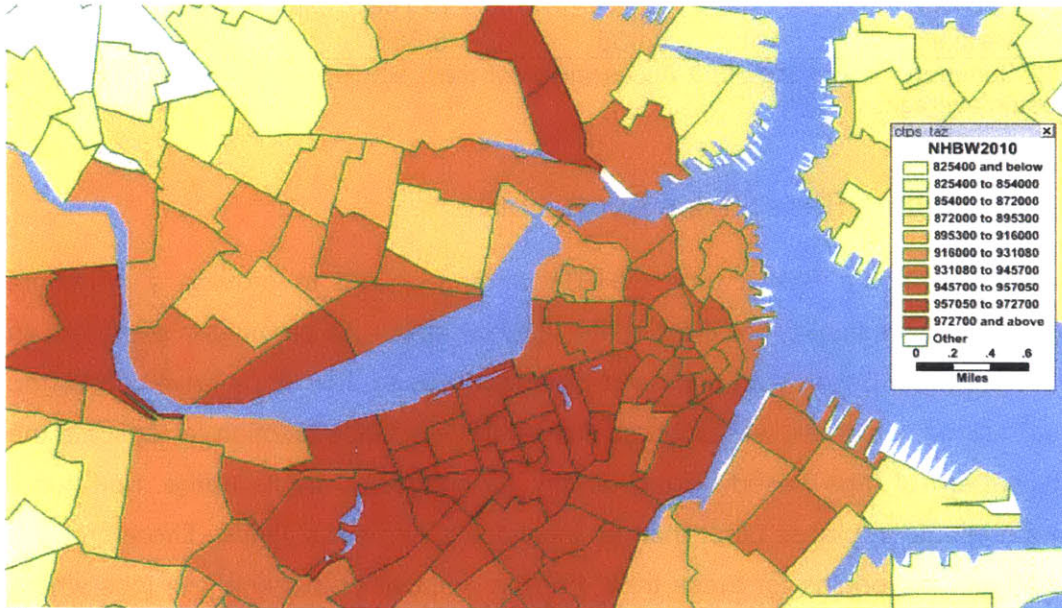


Figure 9.40. Auto Gravity Accessibility for NHBT. Local View. Employment 2010

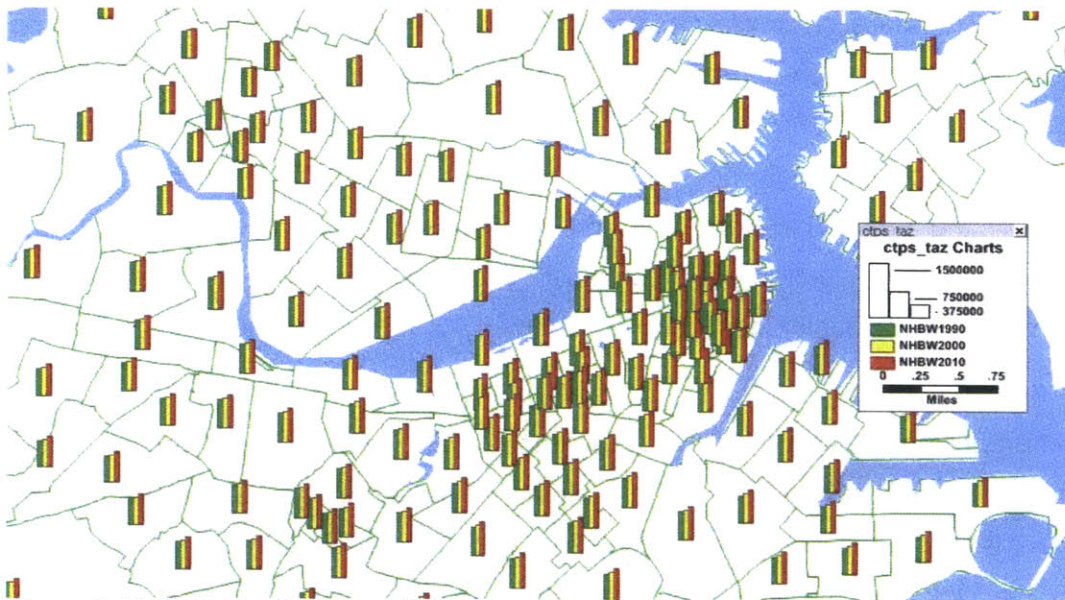


Figure 9.41. Auto Gravity Accessibility for NHBT. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	833,566	860,700	917,431
Financial District	839,421	869,180	946,132
LMC	844,918	868,637	965,381
Innovation District	779,405	828,418	916,888
Business Park Route 93	816,600	850,596	901,567
Average	824,134	855,891	927,667
Median	832,228	859,259	918,018
GBA Average	436,872	461,430	490,945
GBA Median	382,815	403,095	425,930

Table 9. 13 Summary of Auto NHBT Accessibility for main employment centers, statistics & Greater Boston averages

Utilizing the transit travel times, we are also able to analyze the transit NHBT accessibility. Figure 9.42 displays the values for NHBT transit accessibility for the study area. This picture once again highlights the dominance of the CBD in providing accessibility since it is the area of highest transit service and highest employment density. Kendall Square though provides comparable accessibility. Furthermore, a regional comparison of NHBT in the Greater Boston area (Appendix B, Figure B.8) demonstrates that among the other employment centers in Boston, Kendall Square offers the best NHBT transit accessibility. The nature of transit and the shared space it creates fosters the interaction among users. This interaction will increase the benefits that come from the exchange of ideas, a main factor in the benefits of agglomerations and clusters. Furthermore, Kendall Square's NHBT transit accessibility has greatly increased in the last 20 years, as figure 9.43 shows. The values for NHBT trips that are transit accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.14. These changes highlight the growth that Kendall has experienced and its importance as a major employment center for the Boston area.

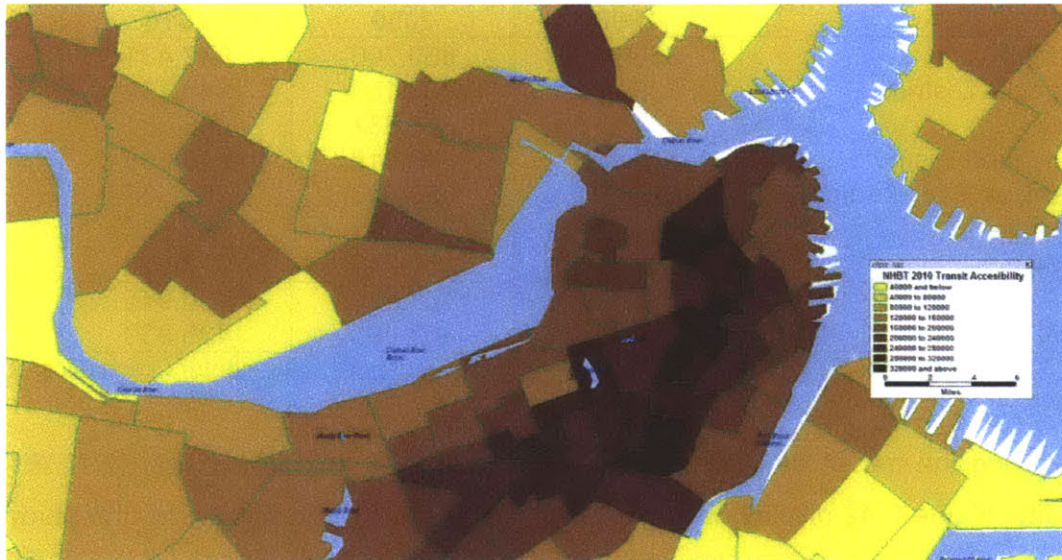


Figure 9. 42 Transit Gravity Accessibility for NHBT. Local View. Employment 2010

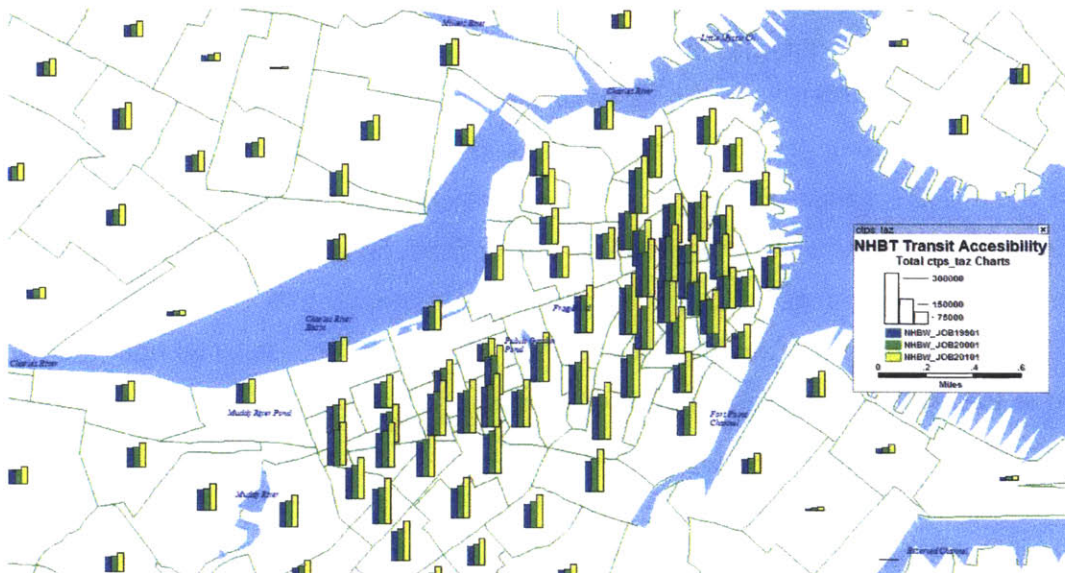


Figure 9.43. Transit Gravity Accessibility for NHBT. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	83,320	88,281	96,346
Financial District	119,453	127,828	140,592
LMC	113,104	117,198	128,333
Innovation District	36,080	38,127	41,555
Business Park Route 93	25,486	26,615	29,183
Average	75,707	79,865	87,413
Median	80,059	84,711	92,406
GBA Average	21,591	22,626	24,337
GBA Median	5,715	6,136	6,449

Table 9. 14 Summary of Transit NHBT Accessibility for main employment centers, statistics & Greater Boston averages

Using the same process we were able to calculate the levels of walking accessibility for NHBT. Given that NHBT might be the best representation of the employee interaction on a daily basis, walking would better display daily interactions since shorter walking trips from an employee's workplace would likely lead to relationships among workers of the area. Figure 9.44 displays the NHBT accessibility for walking trips. This picture highlights once again high employment density areas.

Most interactions, as expected, would take place in these locations that bring in a large number of people during daytime. Figure 9.45 highlights the changes in NHBT accessibility over the last two decades; confirming that Kendall Square has greatly increased in NHBT accessibility, most likely a product of the employment increases in the area. The values for NHBT trips that are walking accessible for every employment area and Greater Boston area statistics in each of the study time points are displayed in Table 9.15.

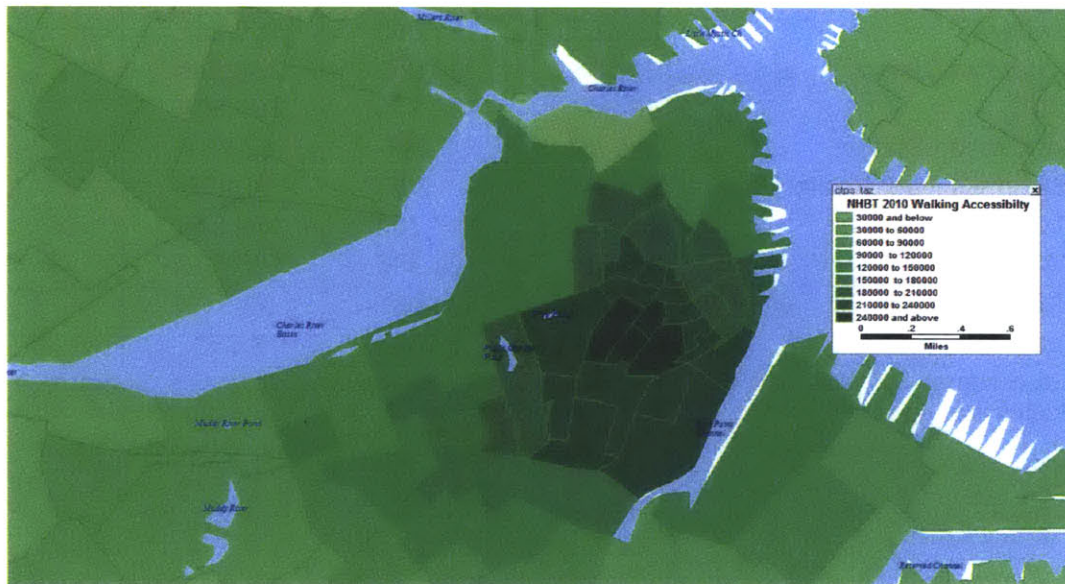


Figure 9.44. Walking Gravity Accessibility for NHBT. Local View. Employment 2010

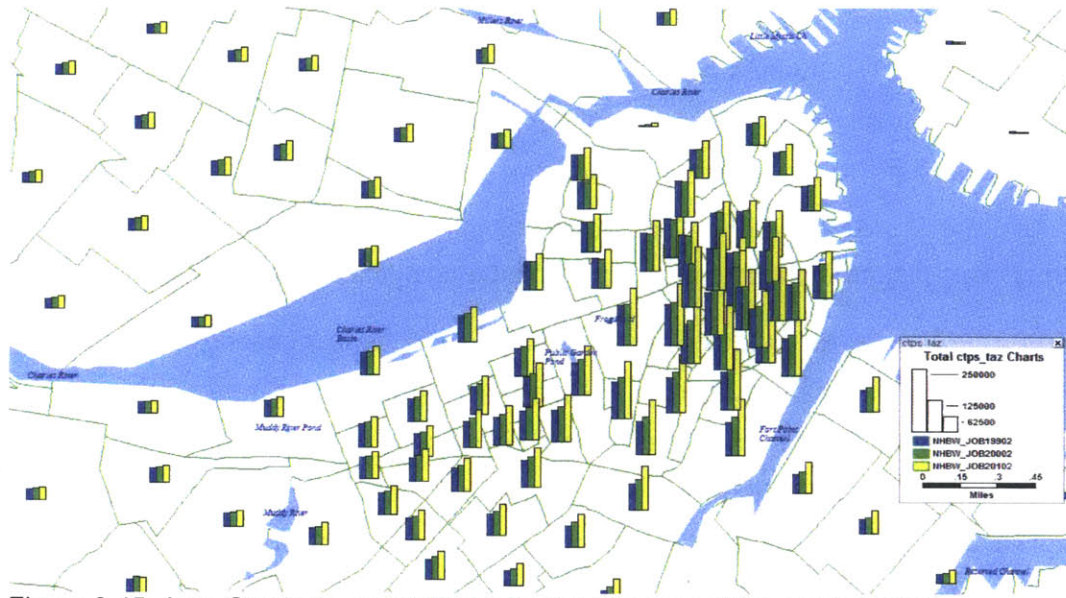


Figure 9.45. Auto Gravity Accessibility for NHBT. Changes 1990, 2000 & 2010

	1990	2000	2010
Kendall	124,485	131,090	169,257
Financial District	199,663	204,252	264,825
LMC	140,932	150,275	185,534
Innovation District	54,635	57,991	82,211
Business Park Route 93	39,997	41,938	51,272
Average	111,951	117,209	150,848
Median	118,239	124,397	160,623
GBA Average	24,097	25,442	32,713
GBA Median	2,736	2,936	2,830

Table 9. 15 Summary of Walking NHBT Accessibility for main employment centers, statistics & Greater Boston averages

Chapter 10 - Accessibility and Employment

As it was shown in the previous chapter, transit accessibility has on average improved in the Boston center over the last 20 years, while auto accessibility has decreased due to higher congestion levels in roads. During the same period, employment has increased, mainly in a number of areas in the city center. Accessibility is measured based on the number of people who are willing to make the trip to a given destination for a specific trip purpose.

According to Pushkarev and Zupan (1977) private (auto) transportation can only support a given number of trips per square mile, and dense employment areas could not be supported without a transit system. Furthermore Cluster theory highlights the importance of accessibility of highly qualified inputs, labor & services, to sustain employment growth. Therefore, given the previous research on accessibility and the increases in employment density in this area, we decided to explore the relationship between different modal specific accessibility measures and employment data.

10.1 Accessibility to Boston's main employment centers

As described in Chapter 4, there are certain areas in Boston that provide employment to a large number of people. These previously studied areas are:

- The Central Business District
- Kendall Square
- Innovation District / The Harbor
- Longwood Medical Center
- Business Park Route 93

In order to further understand the differences among these centers, we utilize the accessibility of each, as a destination. Also included in this analysis of employment centers in the Business Park off Route 93, in order to compare Kendall to the accessibility of different kinds of growing employment centers. This business park is part of a venture that office space in an area further removed from the city center.

The studied areas appear to have higher accessibility by automobile as destinations for all trip purposes, as is apparent in Figure 10.1. The lower levels of accessibility for trip purposes other than HBW is due to the fact that those trips are usually shorter, and thus capture smaller number of people who are willing to make the commute. Nevertheless, all employment centers appear to have the same level of auto accessibility as a destination for these trip purposes as

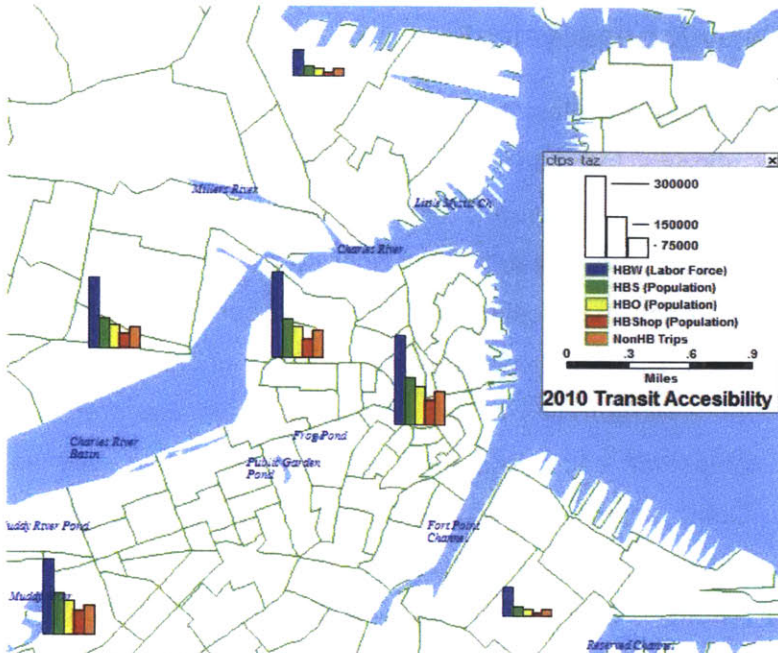


Figure 10.2. 2010 Transit Accessibility per trip type to main employment centers

Walking accessibility patterns are quite different than those previously shown, Longwood Medical center seems to be the area that is consistently most accessible as a destination for walking trips for all purposes, Kendall's walking accessibility for HBW trips is comparable to that provided in Longwood, although it is not as accessible for walk trips of other purposes. The Innovation district and the Route 93 Business Park once again are the least accessible destinations for walk trips of all purposes.

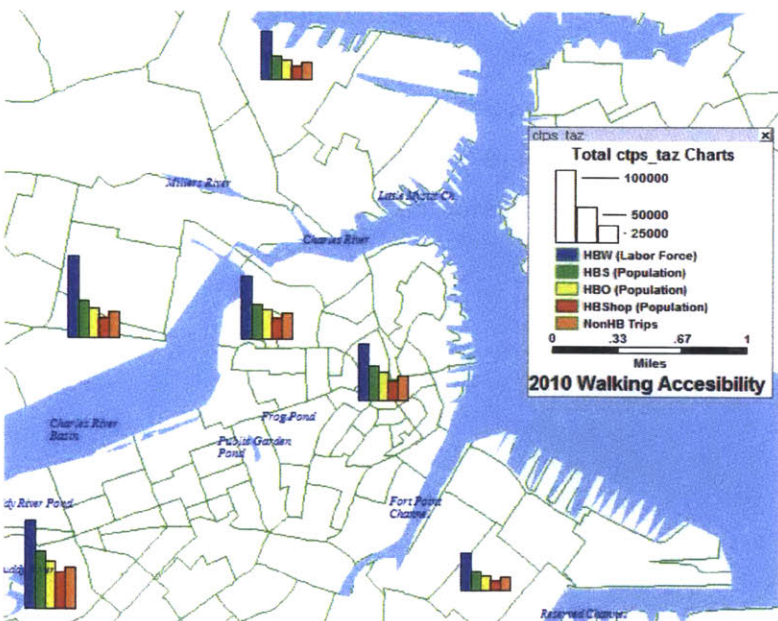


Figure 10.3. 2010 Walking Accessibility per trip type to main employment centers

10.2 Home Based Work Accessibility & Employment

Dense employment centers in the Greater Boston Area seem to be dependent on a large number of factors; one of which appears to be the accessibility of the center as a trip destination. Amongst the calculated accessibility measures, Home Based Work accessibility would appear to be the most important, given that it establishes how many people (who are currently in the labor force) are willing to reach that destination as a work center. In order to better understand the relationship among the different modal types of HBW accessibility and employment. IN order to have a deeper understanding of this relationship, we explored the correlation of absolute employment values for each TAZ and its accessibility, as well as employment density and accessibility. Doing so we created different graphics for each of the modal access modes, displayed in Figure 10.4 - Figure 10.10. After several comparisons we noticed that it was best to compare the results to density as this allows us to compare TAZs that have different areas.

Auto accessibility does not seem to have a clear relationship to either absolute values for employment or employment density. The scatter plot does not seem to identify a unique straight correlation between auto accessibility and employment density. Auto accessibility appears to be universal among different ranges of employment density. There seems to be a specific range, between 1.3 million and 1.4 million accessible people, which yields a vast range of high and low job densities. However, places that provides larger auto accessibility than that does not correlate to greater employment densities. This is a pattern that is repeated for every year in study. Once a block group provides auto accessibility to people in the specific range, it may yield higher employment densities, although not guaranteed. The Pushkarev and Zupan limit displayed in Figure 10.5 reveals that although there are places with high employment density and accessibility, they would not be reachable without the existence of complementary transit infrastructure.

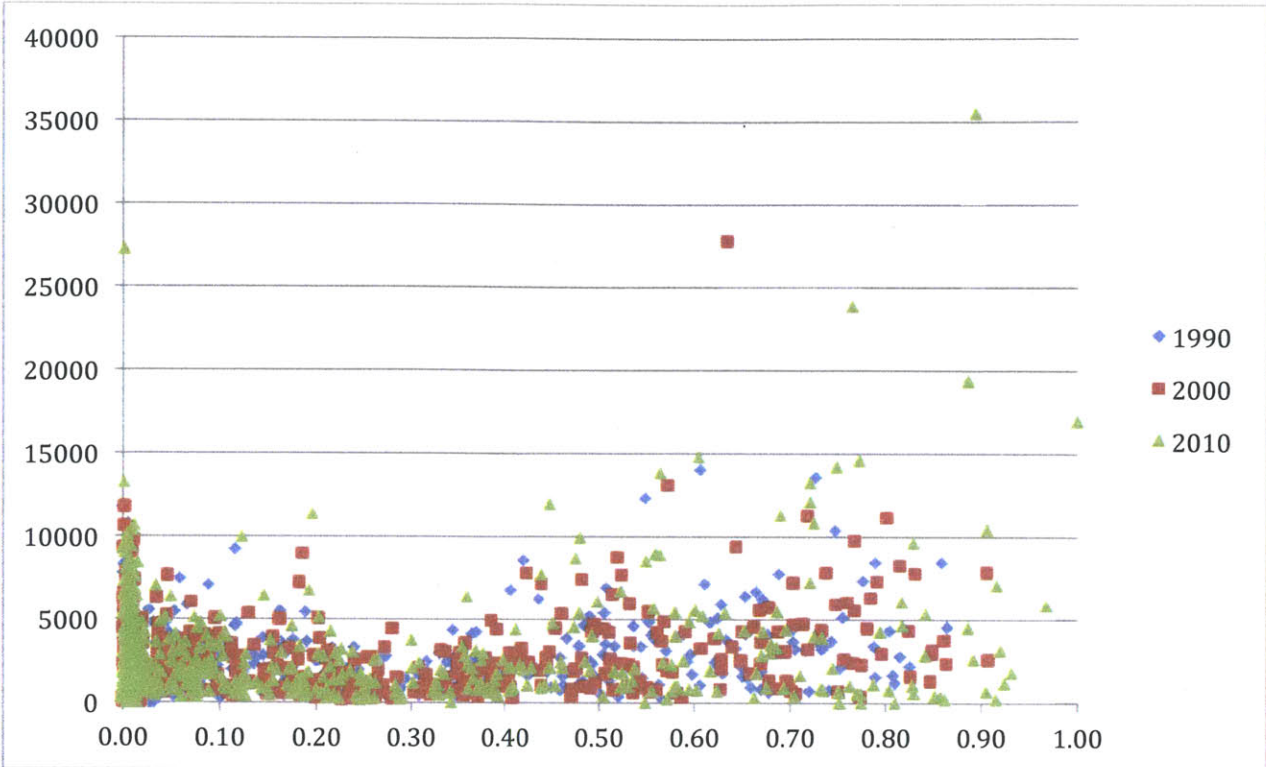


Figure 10.4. Yearly Transit Accessibility normalized with maximum accessibility value and plotted against Absolute TAZ Employment

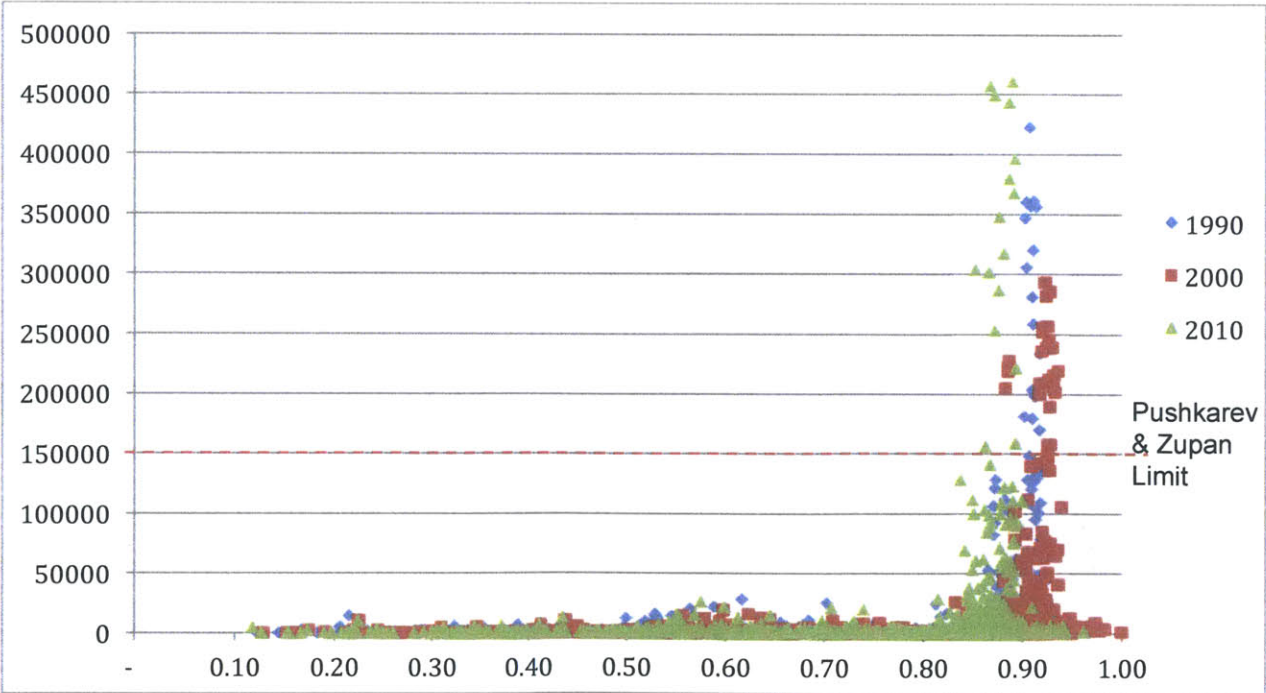


Figure 10.5. Yearly Auto Accessibility normalized with maximum accessibility value and plotted against Employment Density

Transit accessibility does appear to have a noticeable relationship with employment density. As displayed in Figure 10.8, there is a correlation between high transit accessibility and higher employment density. Furthermore, block groups that provide low transit accessibility, consistently yield the lowest employment densities.

While providing larger auto accessibility, or auto accessibility within the previously shown range allowed for higher densities, this was not a unique indicator of high employment density. This is not the case for transit accessibility, where high transit accessibility does correlate exclusively with high employment density. All the TAZs that allow for high transit accessibility display high employment density levels.

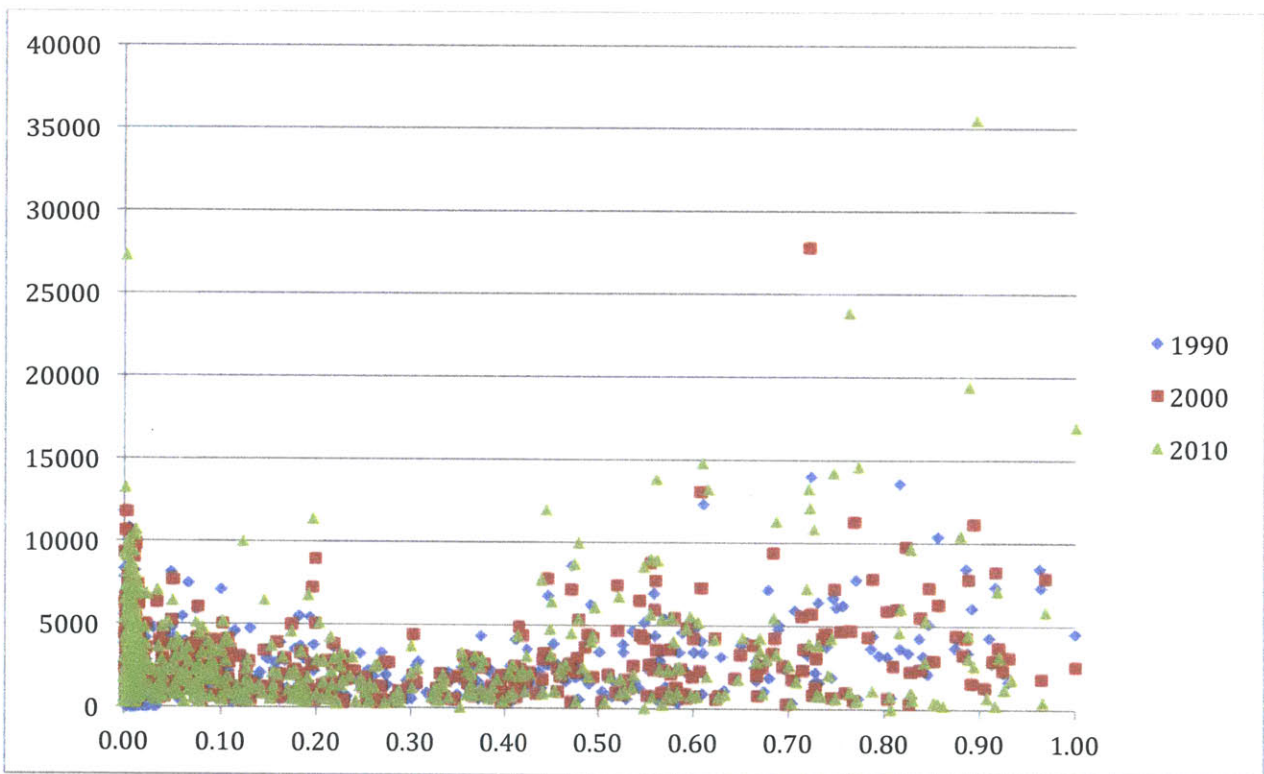


Figure 10.6. Yearly Transit Accessibility normalized with maximum accessibility value and plotted against Absolute TAZ Employment

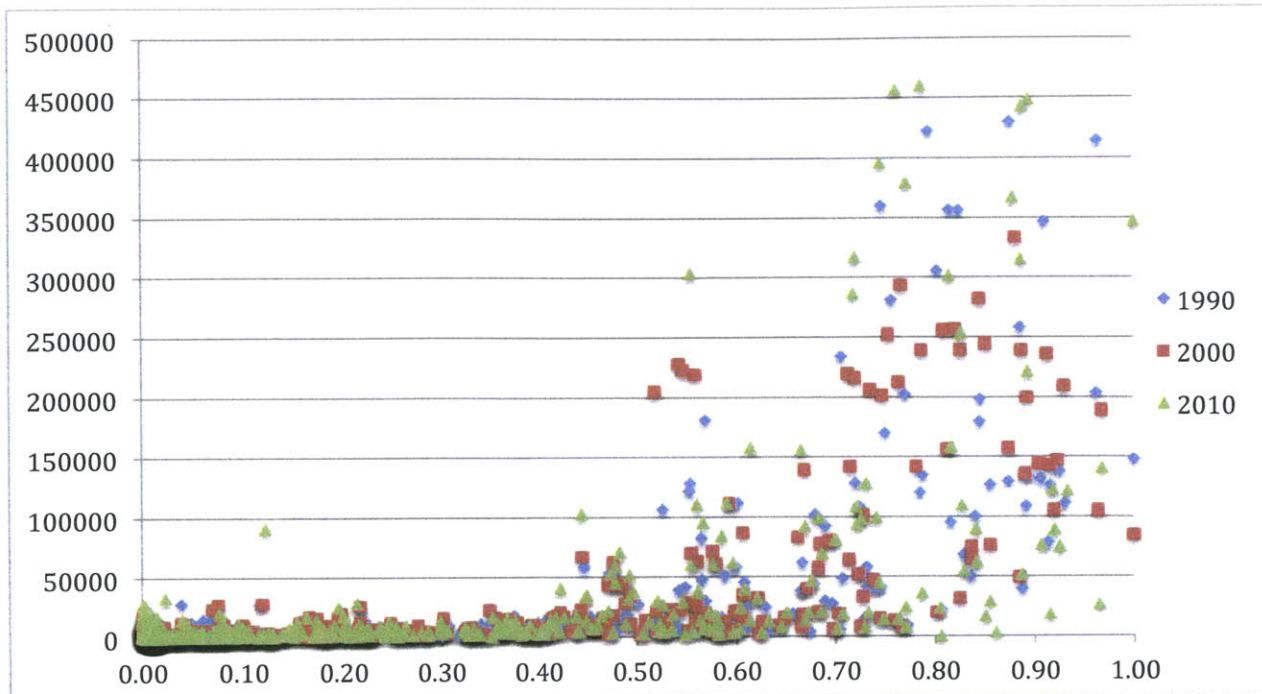


Figure 10.7. Yearly Transit Accessibility normalized with maximum accessibility value and plotted against Employment Density

Using this same process, we are also have plotted the relationship between walking accessibility and employment, as displayed in Figure 10.8 and Figure 10.9. The pattern in this graph is similar to the ones previously seen. The block groups that are accessible to the least number of people are consistently those with the lowest employment density. Once a block group is accessible to more than nearly 50,000 people by walking, there is a tendency to see larger values of employment density. While there is a correlation between employment densities and higher walking accessibility values, there is still a high scatter of densities displayed.

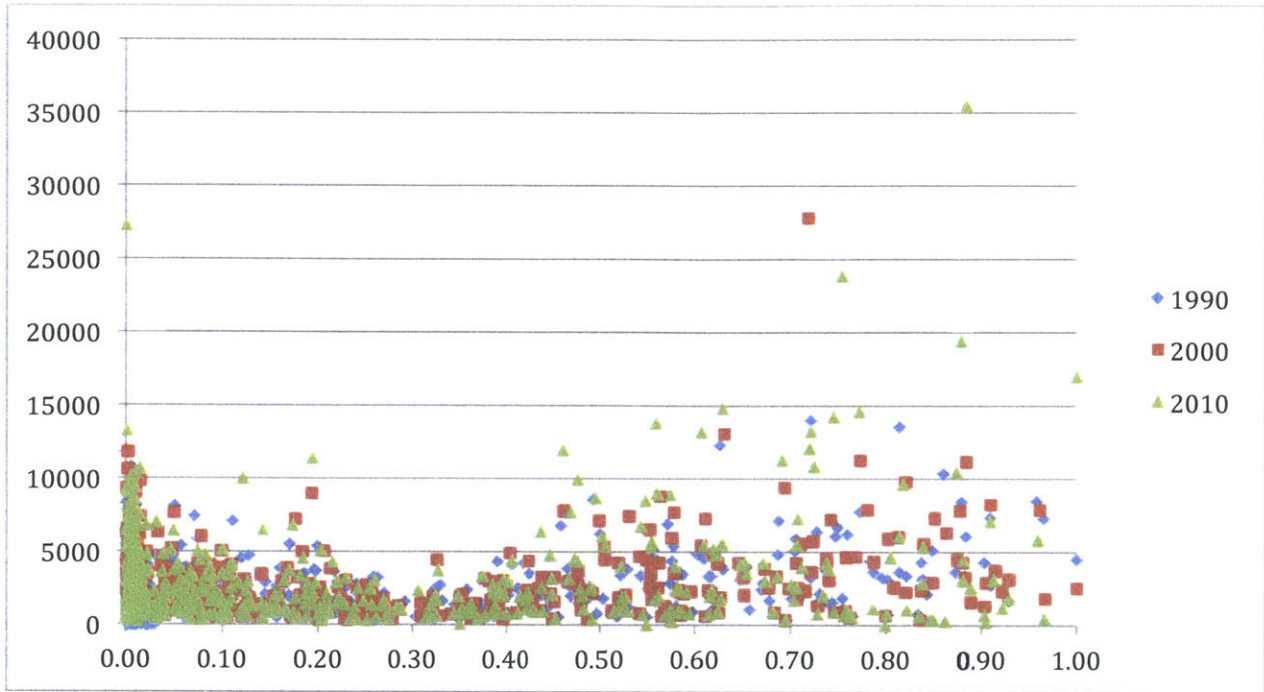


Figure 10.8. Yearly Walking Accessibility normalized with maximum accessibility value and plotted against Absolute TAZ Employment

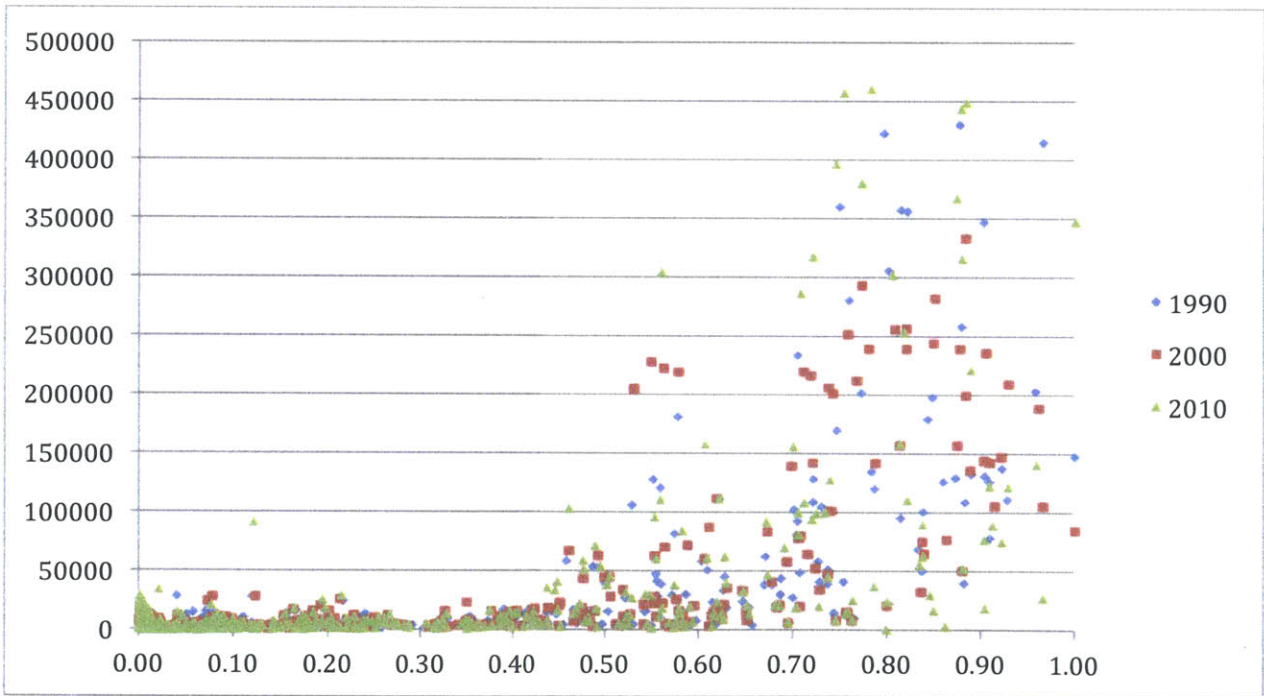


Figure 10.9. Yearly Walking Accessibility normalized with maximum accessibility value and plotted against Employment Density

10.3 Relationship between accessibility and employment

In order to further examine the relationship between the different kinds of accessibility and employment, we perform a series of linear regressions to reveal commuter preferences. By utilizing the block groups in the model area as data points, we can estimate the correlation between employment density in the Greater Boston area, and more specifically, the HBW accessibility of the labor force to each destination by the different modes.

The first regression performed utilized the values for employment density in each 986 TAZ for the three years periods: 1990, 2000 and 2010 and the auto, transit and walking accessibilities. Equation 10.1 displays the equation utilized for the first regression.

Equation 10.1. Regression Equation to estimate the correlation between employment density and auto, transit and walking HBW accessibility

$$\text{Employment Density} = \alpha \text{HBW}_{\text{Auto}} + \beta \text{HBW}_{\text{Transit}} + \gamma \text{HBW}_{\text{Walk}} + c$$

Where

$\text{HBW} = \text{HBW Accessibility based on Labor Force}$

$\alpha; \beta; \gamma; c = \text{constants}$

The regression was performed for each year analyzed, 1990, 2000 and 2010. From the previously analyzed results in Figure 10.5 and Figure 10.7, we may predict that the value for the coefficient for transit accessibility will be the largest, and that there will be a small relationship between auto accessibility and employment density. From Figure 10.9 it is difficult to predict the value for the coefficient of walking accessibility. The results for the values of $\alpha; \beta; \gamma; c$ are displayed in Table 10.1, while each t-statistics coefficients are displayed in Table 10.2.

		1990	2000	2010
α	Auto	0.004145	0.002607	0.00348
β	Transit	0.783061	0.737762	0.913937
γ	Walk	-0.92737	-0.78383	-1.02785
c	Constant	-131.836	709.4747	743.8124

Table 10.1. Values for the coefficients in the regression relationship between employment density and auto, transit and walking HBW accessibility

		1990	2000	2010
α	Auto	1.640	0.925	0.493
β	Transit	24.924	21.195	11.253
γ	Walk	-10.488	-7.965	-4.476
c	Constant	-0.034	0.157	0.067

Table 10.2. T-statistics values in the regression relationship between employment density and auto, transit and walking HBW accessibility

As seen from above table, the value for the coefficient of transit accessibility is consistently the largest. This indicates that employment density is most dependent on the transit accessibility of the labor force to the employment center. The coefficient for the value of auto accessibility is consistently close to zero.

As seen from Table 10.2, the t-stat value indicates that the employment density does not relate to the value of auto accessibility. This is consistent with the results previously seen in Figure 10.4 that showed little relationship between auto accessibility and employment density values.

The walking accessibility appears to consistently have a negative relationship with employment density. This might be due to the tendency of people to live farther away from where they work. As seen in previous chapters, places of high employment density, such as the central business district are usually not the places of high residential density. Nevertheless, it is important to note that although the value of the coefficient is negative in all three study periods, the value has become less negative throughout the years. This might be indicative of the growing tendency in recent years to live closer to the work place.

The larger coefficient value indicates the importance of other factors that are not represented in this very simplistic model. As previously stated, this model only takes into consideration simplifies the factors that affect employment density and thus must be utilized as a measure of relative rather than absolute importance.

Regression Statistics			
	1990	2000	2010
Multiple R	0.691	0.647	0.413
R Square	0.478	0.418	0.471
Adjusted R Square	0.476	0.416	0.468
Observations	986	986	986

Table 10.3. Regression statistics for the relationship between employment density and auto, transit and walk HBW accessibility

In order to further examine the relative dependency of transit and auto accessibility on employment density, we can also perform a regression that only utilizes the values of auto and transit HBW accessibility. This equation is presented in Equation 10.2

Equation 10.2. Regression Equation to estimate the correlation between employment density and auto and transit HBW accessibility

$$\Delta \text{Employment Density} = \alpha \Delta \text{HBW}_{\text{Auto}} + \beta \Delta \text{HBW}_{\text{Transit}} + c$$

Where

HBW = HBW Accessibility based on Labor Force

α ; β ; c = constants

Once again, the regression was performed for all three analyzed years. The results for the coefficient values of α , β , c and the regression statistics for this regression are displayed in Table 10.4 and Table 10.5

		1990	2000	2010
α	Auto	-0.00758	-0.00704	-0.0098
β	Transit	0.535731	0.525917	0.626286
c	Constant	7355.148	6951.805	9208.677

Table 10.4. Values for the coefficients in the regression relationship between employment density and auto and transit HBW accessibility

Regression Statistics			
	1990	2000	2010
Multiple R	0.648	0.617	0.3920
R Square	0.420	0.380	0.153
Adjusted R Square	0.418	0.379	0.152
Observations	986	986	986

Table 10.5. Regression statistics for the relationship between employment density and auto, transit and walk HBW accessibility

As previously seen when performing the more complex regression, employment density is more dependent on the block group's transit accessibility, rather than the auto accessibility. This finding is consistent for all the analyzed years.

Both the more complex regression that considers the HBW accessibility for auto, transit and walking modes, as well as the simpler equation that only focuses on HBW accessibility for auto and transit, serve as a tool to analyze the relative importance of different mode accessibility. Although the coefficients could be used as an indicator of the importance of accessibility on employment density, it is clearly an over-simplification of the many factors that actually have an influence. Nevertheless, the consistency of the results demonstrates that employment density is relatively more dependent on the destination's transit accessibility, than the auto and walking accessibility.

10.3 Relationship between changes in accessibility and employment

Given that our analysis included different study years, we can also perform a regression that looks at the changes in employment and the absolute values of modal HBW accessibilities, in order to further understand this relationship. Thus, we utilized Equation 10.3 in order to calculate the relative dependency of employment density to modal accessibility.

Equation 10.3. Regression Equation to estimate the correlation between changes in employment density and HBW accessibility

$$\Delta Employment = \alpha HBW_{Auto} + \beta HBW_{Transit} + \gamma HBW_{Walk} + c$$

Where

$HBW = HBW$ Accessibility based on Labor Force

$\alpha; \beta; \gamma; c = constants$

In order to more accurately capture this relationship, we divided the sample size into quartiles, based on the employment density of each destination. As suggested by Pushkarev and Zupan (1977) we would expect that the areas with higher employment density would have a stronger reliance on transit accessibility than auto. This would be different than what we would expect in low density areas where there will probably be a stronger reliance on auto accessibility. The results for this regression are displayed in Table 10.6 and Table 10.7.

	Q1	Q2	Q3	Q4
Auto	-0.0129	-0.0375	0.0003	0.0004
Transit	0.4965	0.1602	0.0019	0.0045
Walk	-0.9084	-0.8218	-0.0068	-0.0140
Intercept	472	751	-108	532

Table 10.6. Values for the coefficients in the regression relationship between changes in employment density and HBW accessibility, divided by density quartiles

Regression Statistics	Q1	Q2	Q3	Q4
Multiple R	0.095443	0.145355	0.076071	0.055418
R Square	0.091093	0.211279	0.057868	0.030712
Adjusted R Square	0.021638	0.142667	-0.01182	-0.0382
Observations	432	432	432	438

Table 10.7. Regression statistics for the relationship between changes in employment density and HBW accessibility, divided by density quartiles

Although the model does not seem to be as accurate as the previous regressions, the findings are consistent with those predicted and previously calculated. As seen from the values of the coefficients, changes in employment density are most positively affected by transit accessibility of a destination. Auto accessibility does not appear contribute to changes in

employment growth for high density areas. In areas of very low employment density, auto accessibility does contribute to increases in employment. As previously seen in results of the regression in Equation 10.1, walking accessibility also correlates negatively with changes in employment density. The results of this regression once again serve to understand the relative importance, rather than the absolute importance, of accessibility by different modes on employment density.

The results from the regressions performed, as well as the plots displayed in the previous section 10.2 consistently demonstrate that the areas that are accessible destinations for HBW trips via transit, offer higher employment density. Furthermore, the destination's employment density appears to be unaffected by the destination's auto accessibility. Although there seems to be a negative correlation between walking accessibility and employment density, this might be a product of the tendency to live in locations that are away from the work place.

10.4 Growth implications for Kendall Square

As Kendall Square continues to grow as an employment center, planners must consider the implications of the results outlined previously for its future growth. Kendall Square already houses major companies such as Google and Microsoft, who recently announced the addition of 800 jobs to their Kendall Square offices. Similarly Amazon has already expressed interest in opening an office in Kendall Square. This employment growth will bring about more commuters to the area.

The research presented above suggests that the transit network will absorb the majority of the increase in commuting jobs. If Kendall Square wants to continue increasing jobs, effectively increasing employment density in the area, transit capacity and accessibility to Kendall Square will also have to be increased. Alternatively walking and bicycling could play a major role if home to work distances are within an appropriate range.

Increases in transit accessibility may be achieved by changes in commuting times, or changes in the residences of people who are part of the labor force. Given that the MBTA Red Line is the main transit commuting route into Kendall Square, transit accessibility may be improved by increasing the capacity of this line by decreasing headways and thus increasing capacity. Red Line operations could be improved by changing signaling that would increase capacity (Tribone, 2013). It may also be advisable to provide new and better bus routes to serve

Kendall Square. To this same end, proposed projects such as the construction of the Urban Ring Transit Line and the Grand Junction would improve service to the area.

Transit accessibility might also be improved naturally by the growing culture to live closer to the city center. These shifts in residential areas would move in people closer to the square, placing them in the probable radius for a non-motorized HBW commute. Residential buildings are now being constructed in the Lechmere area, near Kendall Square, which might absorb the new demand. In order to increase the transit accessibility, the MBTA may also improve the bus routes service that connects Lechmere to Kendall Square

Kendall should be mindful of changes in residences or commuting patterns that will appear to increase accessibility and actually decrease employment density by moving it away from its current range. Increases in auto trips would likely cause more congestion and thus make commuter times longer and reducing accessibility. Local government and the Kendall Business Association might take advantage of this opportunity to deter auto commutes by reducing parking spaces or increasing parking costs in this area.

Chapter 11 – Conclusions

11.1 Summary

Transportation plays a key role in the formation of a city. Although benefits of transit usually focus on personal time and cost savings, there are a number of transportation and transit benefits that have yet to be quantified. The interdependency of transportation investment and land use development has yet to be fully understood and quantify the benefits of transit infrastructure. This research attempted to explore one of the aspects of this relationship.

Corporate theory suggests that in order to be successful in the long run, a company must find a niche and provide unique services, requiring innovation and infrastructure to play a mayor role. Given that succesful companies continually strive to be unique, accessibility to people, reseach innovation, and other firms of a high caliber becomes crucial. A location that is densely populated by these kinds of opportunities would be extremly attractive and lead to higher long term productivity.

Areas that are densly populated by companies of a similar industry, have proven to have higher productivity than those in low density areas (Graham 2007 Henderson 1986; Glaeser et al 1992). Cluster theory, first theorized by Harvard Professor Michael Porter (1998), suggests that since succesful companies thrive on uniqueness, productive locations must offer this same uniqueness. He stated that it is not only the agglomerations of the same business, but clusters of high density interrelated companies that results in more productive and in the long run more susccessful companies. Furthermore, Porter stressed the importance of the density of inputs as well as companies. In this context , the accesibility of high skilled labor becomes a key component for the development of a sustainable employment center.

Both theories seem to reiterate this idea that high-density areas create a more successful and productive environment. These high employment density areas must have the infrastructure to sustain the trips made by employees. In terms of auto accessibility it is important to highlight that Pushkarev and Zupan(1977) first discovered that after reaching a certain threshold of auto accessibility, high-density employment areas needed transit to remain accessible and that they can not continue to grow without

transit service. In other words, beyond a certain threshold automobile access alone would not sustain a high employment density area.

Looking specifically at the Greater Boston area, Boston's main employment center, the Central Business District, which houses mostly industries in Consulting and Banking. Professor Porter (2000) has previously used the Boston CBD to exemplify the characteristics of a cluster. There are other dense employment areas such as: Kendall, Longwood, Innovation District and Business Park in Route 93.

Kendall Square appears to be unique when compared the other business centers. Kendall stands in contrast to other dense areas for a number of reasons. First the high employment density in this area is comparable only to that of the CBD. However, Kendall Square employees work in a unique kind of industry, focusing on the cutting edge of technology and research, bio-tech and technology start-ups. Kendall Square is also right next to the Massachusetts Institute of Technology (MIT) that provides the information, technology and personnel capabilities for many of the employers in the area.

Secondly, as seen from the data of the 2000 CTPP, Kendall Square appears to be highly accessible and where commuter trips are the shortest. Furthermore, transit and automobile trips appeared to have on average the same length; while the median trip transit time was lower than the median auto trip. The modal share was similar only to that of the CBD, with a shifting tendency towards transit modes seen in the study period. Newer trends from employer surveys confirm the idea that employees are becoming more dependent on transit. This is apparently part of a shifting culture trend where workers tend to live closer to work or in transit accessible places. In this time period, the MBTA Red Line usage has increased becoming the main commuter line for Kendall Square.

The importance of accessibility was highlighted while studying the uniqueness of Kendall Square and explain the role of transportation infrastructure in the formation of this high employment density area. Previously, accessibility was utilized to measure the number the opportunities reachable from a given trip origin; however this research modified the previous accessibility model to measure the opportunities within the accessible radius of a given destination. Existing models to calculate accessibility include the isochrone model, gravity model approach, utility based and person based calculation. For the purpose of this thesis, the gravity model provided a more complex

understanding than the isochrone model, but could still be more efficiently calculated with the current available data than more sophisticated Ben-Akiva and Lerman models (1985).

The accessibility measure utilized trip times for every block group origin-destination pair. Skims were produced utilizing an academic four-step model for the Greater Boston area developed in Cube Voyager. This model calculated trip generation and attraction, trip distribution, modal split and traffic, public transportation and pedestrian assignment; and then iterated above steps in order to calculate travel times under congested conditions. Three models were made in order to replicate the socio-economic and infrastructure characteristics of the greater Boston area for 1990, 2000 and 2010. Most notable in the results of the different models was the increase in auto congestion levels. Even with the implementation of the Big Dig, increases in auto trips have increased travel times and decreased average speed for automobile trips.

In order to better represent a destination's accessibility, the gravity model utilizes a deterrence function that represents people's preference to make shorter trips. Utilizing the observed trips, we calculated a function that described the probability of an individual making a trip for a specific trip type depending on the trip's length. Utilizing the previous trip definitions, we calculated a deterrence function for Home Based Work (HBW) trips; Home Based School (HBS) trips; Home Based Shopping (HBSshop) trips; Home Based Other (HBO) trips; Non-Home Based Work (NHBW) trips; and Non-Home Based Other (NHBO) trips.

We then processed the measure for accessibility, which calculates the number of people who are willing to make a trip to a given destination for a specific trip type. Accessibility thus becomes a measure of the attractiveness of each destination. Origins for the trips were considered to be population, households or labor force for home based trips, and jobs for non-home based trips. For example, Home Based Work (HBW) accessibility counts the amount of people in the labor force who would be willing to make the trip from home to a specific destination for employment on a specific transportation mode (automobile, transit or walking). Utilizing data at the block group level, the skims produced by the academic Cube model, representing congested conditions and the deterrence functions calculated by observed trips, provide the accessibility for block groups for every time period and the trip types under consideration.

Kendall Square consistently results in high accessibility for different trip types and modes. While the CBD provides high accessibility for transit trips, since the main transit lines all connect to the CBD, this area does not succeed in providing good walking accessibility. Most notable in the auto accessibility for the city is that in 2010, due to the increases in congestion levels, the accessibility decreased. By automobile, the entire city is generally accessible, without taking into account parking considerations, while this is not the case for transit and walking. The Seaport Innovation District and Business Park Route 93 provide very poor transit and walking accessibility for all trip types.

Kendall Square appears to be amongst the most accessible destinations on average for transit trips. The MBTA Red Line transit stop in the Center of Kendall Square makes transit trips very accessible. However growing transit congestion is a threat to current capacity provided. Similarly, the residential buildings near Central Square, Lechmere and the MIT campus make Kendall Square highly accessible by walking.

Not only is Kendall Square highly accessible when observing different modes, it also consistently provides high accessibility for different trip types, which highlights the diversity of opportunities that are present in this area. HBW accessibility provides easy access for people working or looking to work in this area. The high rates of HBS accessibility demonstrate the importance of MIT, research and highly trained personnel to the area. HBSshop provides accessibility for business that search commercial ventures, while HBO may be used as an indicator of other unique trips that take place in this area.

Trips that do not originate in an individual's home, Non-Home Based Work (NHBW) and Non Home Based Other (NHBO) were calculated together, given their similar trip length distributions. Trip origins for this purpose were assumed to be places of employment, and thus non-home based trips (NHBT) may serve as a representation of daily employee interactions and the bump factor described in Chapter 3.2. NHBT accessibility for auto was found to be generally similar for most employment areas. Transit accessibility for this trip type highlighted Kendall Square and CBD as the most accessible. The accessibility of these trips serves as a proxy for interactions among employees, which fosters the collaboration and spread of innovative ideas.

Kendall Square's transit accessibility has improved for all modes in the past 20 years. The shifting tendency to live closer to the downtown area and near to the red line

has dramatically increased the transit and walking accessibility in Kendall, making it one of the most accessible areas in the Boston area. Furthermore, the accessibility provided to the labor force for HBW trips to Kendall Square is significantly higher, comparable to that in the Central Business District. Overall, Kendall Square appears to be the most accessible place on average when considering all trip purposes and modes.

The previous research on employment density and agglomeration suggested that transit accessibility plays a larger role in creating high job density areas, more than other modes. Furthermore, Kendall Square employers stated the importance of transit and the Red Line in the commuting patterns of their employees and the area in general. To explore this relationship in the Greater Boston area, we calculated accessibility measures to later estimate the relative importance of each mode's accessibility in supporting high employment density areas.

Creating scatter plots of accessibility measures and employment illustrated a number of patterns about their relationship. Transit accessibility seems to be directly correlated with high job density. Surprisingly, this was not the same for auto accessibility. There was a range of auto accessibility that presented higher employment density, but this was not a direct relationship; even in this range specified in chapter 10.2, locations showed both high and low employment densities. Low walking accessibility was correlated with low employment density, but there was a strong discernible relationship between high employment density and high walking accessibility.

The research also calculated a number of regressions in order to further explore the relationship between accessibility and employment density. These regressions attempted to explain the relative importance of different modal accessibilities and employment density. The regression results reiterated the previous findings: high employment density correlates with high transit density. Auto accessibility has a nearly negligible effect on employment density; although it does contribute to employment increases in low density areas. Walking accessibility on the other hand appeared to be negatively correlated with high employment density, but it might be due to the tendency to live far away from work, rather than within a walking radius. Furthermore, walking accessibility has become more important in recent years, suggesting that people might be moving closer to employment centers. Even when considering only transit and auto accessibility, transit was largely correlated with high employment density, and auto accessibility was negligible.

This research also explored accessibility changes and its correlation with employment density over the last twenty years. The finding from this regression reiterated previous findings. Changes in high-density correlate with changes in transit accessibility, while changes due to variations of auto accessibility were negligible.

Although the results of the regressions do not determine the absolute importance of automobile, transit or walking accessibility, they serve as a useful tool to determine the relative importance of different accessibility modes in supporting and creating high employment density areas. Accepting the 'lumpy' nature of transit accessibility and the universality of accessibility by auto, we focus on the synergy of transit accessibility leading to higher job density.

Looking forward for Kendall Square, it is important to remember the importance of transit accessibility to foster employment growth. As more jobs are located in the area, it will be important for the local government to improve transit accessibility since it is directly correlated to employment density. Similarly, it is important to stay in this specific range of opportunity of auto accessibility that allows for high employment density.

Kendall is unique in the Boston area due to its job types, employment density and accessibility. The increases in employment density and the formation of bio-tech and start-up clusters have been directly supported by the transit infrastructure in the Boston area. It is because of its transit accessibility that Kendall Square was able to support the high employment density increases that it has experienced and that make it one of the most attractive employment centers currently in the United States.

11.2 Research Limitations

This research has a number of limitations that should be noted. The benefits of agglomerations have been researched in terms of business and worker productivity. Cluster theory has not been explored as in depth as agglomeration impacts. The benefits of these high-density employment areas of interrelated companies appear to be more long term than those of simple agglomerations.

The largest limitation on this research nevertheless is data collection. As previously stated, the CTPP has yet to release complete dataset of its transportation survey, administered in 2010. Therefore, the data on the most recent commuting trips, and modal splits is not yet fully available. Furthermore, the 2010 employment data,

which was calculated for previous years from CTPP data, is still unavailable. In order to proceed with this research we utilized data sets for the city scale of Cambridge and Boston to calculate the increase in employment in every block group and utilized in this research to increase employment data from 2000 accordingly. Similarly, data from before the 1990 period was sparse and hard to decipher. For these reasons we decided to concentrate and study in the 1990 to 2010 period.

The process by which accessibility was calculated simplified many of the aspects of commuting patterns in order to perform this study. The model utilized a unique deterrence function for each trip type, which might misrepresent a portion of commuters. Furthermore, we considered everyone as a potential commuter. For example, when we considered HBW trips, the method by which we calculated accessibility considered everyone in the labor force as a potential employee, while in reality some people are better suited for a certain type of job giving its potential match between required job qualifications and employee skills. Nevertheless these simplifications were deemed necessary.

Lastly, as it has been noted previously, the regressions presented in Chapter 10, should be analyzed as a relative measure of accessibility importance, rather than as an absolute measure of the relationship between modal accessibility and density. Given our study area, we are limited to 986 Traffic Analysis Zones (TAZ) and the formulation of the regression as a series of accessibility measures was indeed an over-simplification of the factors that truly affect employment density, but the results yielded some noteworthy insights on the relative importance of modal access on employment density.

11.3 Areas of further research

This research brings to light new areas of study that could be further explored, such as:

- **Analyze the time period prior to 1990 to further understand the relationship of transit accessibility and employment density.** This research utilized data from 1990, 2000 and 2010; while data from prior years is not readily available, it would be beneficial to estimate this data on a similar scale to better understand the commuting pattern trends of Boston, and the importance that accessibility has played on creating high employment density areas. Repeating the regression

procedure with accessibility measures from prior years would yield a better representation of the relative importance of accessibility on employment density and growth.

- **Modify the transit system in the academic Cube model to years prior to the extension of the MBTA Red Line.** Including in this thesis where the effects of the Big Dig and Silver Line. Prior to this, the Red Line had been extended a number of times, (Andrew in 1918; Ashmont in 1928; Quincy Center 1971; Porter and Davis in 1984 and Alewife in 1985). This is the main transit mode for people travelling to Kendall Square. Therefore, utilizing a prior network to produce skims for those years to calculate accessibility may yield further insight into the actual importance of the MBTA's Red Line to the formation of Kendall as an employment center.
- **Further explore the importance of different kinds of accessibility (HBS, HBSshop, HBO, NHBW and NHBO) on employment density.** Given that the deterrence functions, skims, and accessibility indices for these measures have already been produced; one could easily generate numerous models (linear models, or more complex iterations) in order to determine if the accessibility of other trip types is also correlated to high employment density areas.
- **Compare different kinds of trip types accessibility to location densities to explore if mode accessibility patterns are replicated.** In the same manner, as we may relate HBW accessibility to a certain destination's employment density, we may explore the relationship between:
 - HBS accessibility and Educational Density;
 - HBSshop accessibility and Commercial Density;
 - HBO accessibility and related Density.
- **Repeating the accessibility and regression processes in another urban area** may be useful to examine if the tendency is specific to Boston cultural tendencies. This research focus in the Kendall Square area of Boston, however the same analysis method may be utilized in other urban areas in order to test the robustness of findings in other parts of the Country.
- **Examine the relationship between accessibility, GDP generation, employee income and productivity.** Using the previously explored relationship between

employment density and transit accessibility, one may further explore the advantages of dense employment areas on productivity and GDP. Since auto accessibility may only support a certain amount of trips, we may explore the extra yield provided by workers given the high-density areas are made possible by adding transit accessibility.

- **What is the role that MIT has played in the revitalization process of Kendall Square?** MIT has played a key role in the redevelopment process of Kendall Square. A further comparison of Kendall Square to the Longwood Medical Center, that provides similarly high values of accessibility might highlight the role that MIT and its students have played in the redevelopment of Kendall Square.
- **Explore the effects of accessibility, density and Kendall parking availability.**
- **Disaggregate employment and housing patterns**, describing the differences and effects of the graduate student and post doc population. Likewise, redefining choice and captive transit users can better explain employment and commuting patterns in the area.
- **Utilize the model to predict the extra transit accessibility needed to support increases of employment density.** Further exploration of the relationship between accessibility and employment density would allow for a more accurate prediction of the transit needs for employment density. This would allow growing employment centers to forecast the increases in transit access needed to support the employment in a given area.
- **Explore the effect of Transit Projects on both auto and transit accessibility.** Further exploration of the effects of proposed projects, such as the Urban Ring, the Blue Red Connector and the Grand Junction DMU on accessibility and the possible effects it will have on employment density in the area.

11.4 Closing Remarks

Employment increases in the Kendall Square area has fostered a unique research, innovation and technological high-density cluster. Kendall Square attracts companies due to the unique environment offered in its proximity. The Massachusetts Institute of Technology (MIT) brings in the latest technology and research, as well as

highly trained individuals; flexible office space provides adaptable locations for new companies; venture capital provides access to the capital needed to grow; while long-standing companies foster a sustainable business environment. Growth in recent years has brought an increase of commuters to the square that is supported by Kendall's Square transportation infrastructure.

Previous research suggests that high employment density areas, such as Boston's Central Business District and Kendall Square, rely on a transit system to serve commuting trips to the area. Transit accessibility therefore, becomes a catalyst to foster high density employment areas. Not only is Kendall Square unique in its industry and worker mix, this area offers high transit and walking accessibility, atop of the regular auto accessibility that is provided.

Employment changes in Kendall Square have greatly increased commuting trips to the area, which has been sustained by its transit infrastructure. This dependency is evident in the modal travel times for Kendall Commuters, as well as the changes observed in the modal splits that show a higher share of transit and walking trips.

In order to better understand the importance of different transportation infrastructure we calculated a gravity based destination accessibility for every mode and trip type. Utilizing socio-economic data for 1990, 2000 and 2010, and travel times derived from the four step travel model for the Greater Boston Area, we calculated each location's accessibility. Even as auto accessibility decreased in 2010, employment increased in some high-density areas. The relationship between accessibility and employment density over this time period indicated that high employment density areas are more dependent on transit infrastructure than any other mode.

Looking forward for Kendall Square these findings indicate that in order to foster future growth, transit service to the area must be improved. The findings of this thesis highlight the importance of transit accessibility to foster employment growth. As more jobs are located in the area, it will be important for the local government to improve transit accessibility since it is directly correlated to employment density.

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Appendix A - List of Acronyms

ACS	American Community Survey
BG	Block Group
CBD	Central Business District
CIC	Cambridge Innovation Center
CTPP	Census Transportation Planning Package
CTPS	Central Transportation Planning Staff
DMU	Diesel Multiple Units
GBA	Greater Boston Area
HBO	Home Based Other
HBS	Home Based School
HBSshop	Home Based Shopping
HBW	Home Based Work
LMC	Longwood Medical Center
MBTA	Massachusetts Bay Transportation Authority
NHBO	Non Home Based Other
NHBT	Non Home Based Trips
NHBW	Non Home Based Work
O-D	Origin-Destination
TAZ	Traffic Analysis Zone

Appendix B – Auto & Transit Regional Accessibility

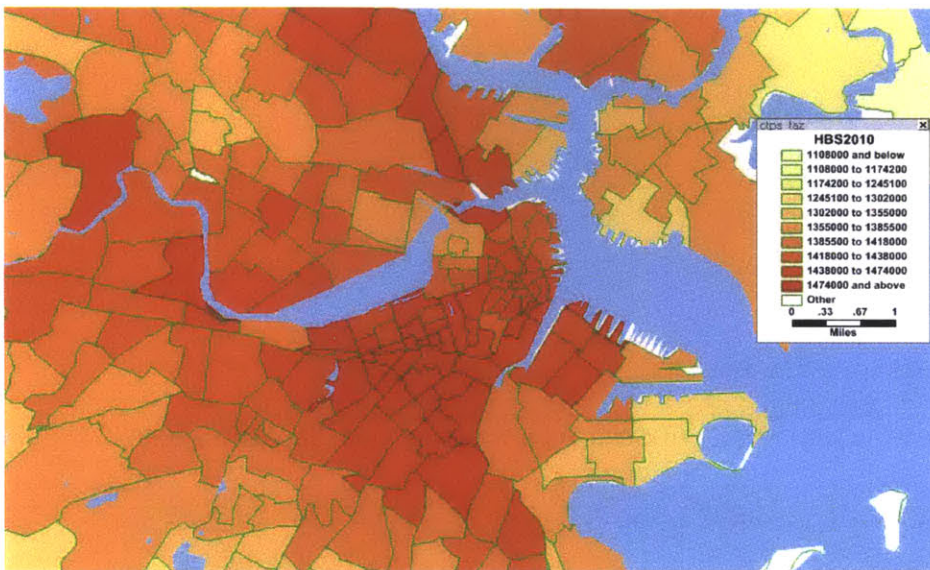


Figure B.1 Auto Gravity Accessibility for HBS Trips. Regional View. Population 2010

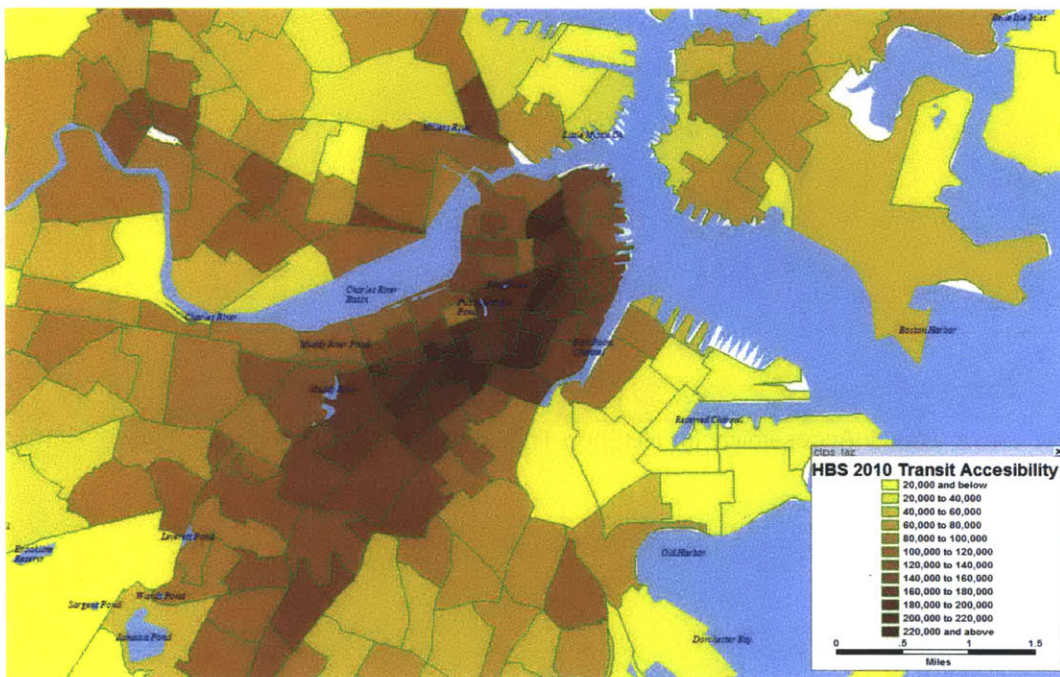


Figure B.2 Transit Gravity Accessibility for HBS Trips. Regional View. Population 2010

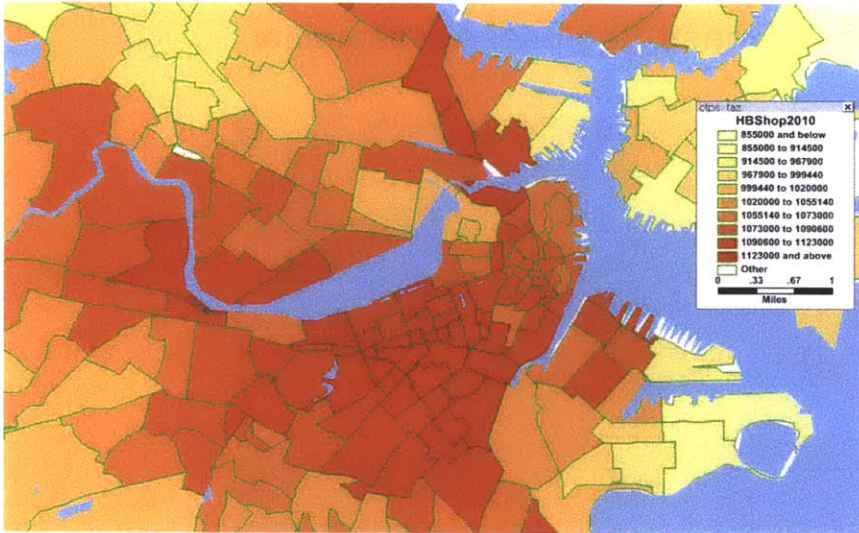


Figure B.3 Auto Gravity Accessibility for HBSHop Trips. Regional View. Population 2010



Figure B.4 Transit Gravity Accessibility for HBSHop Trips. Regional View. Population 2010

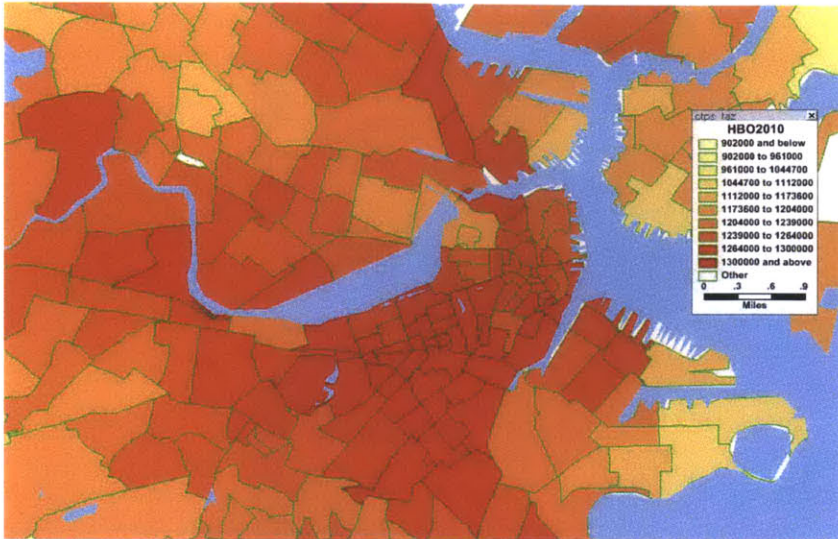


Figure B.5 Auto Gravity Accessibility for HBO Trips. Regional View. Population 2010

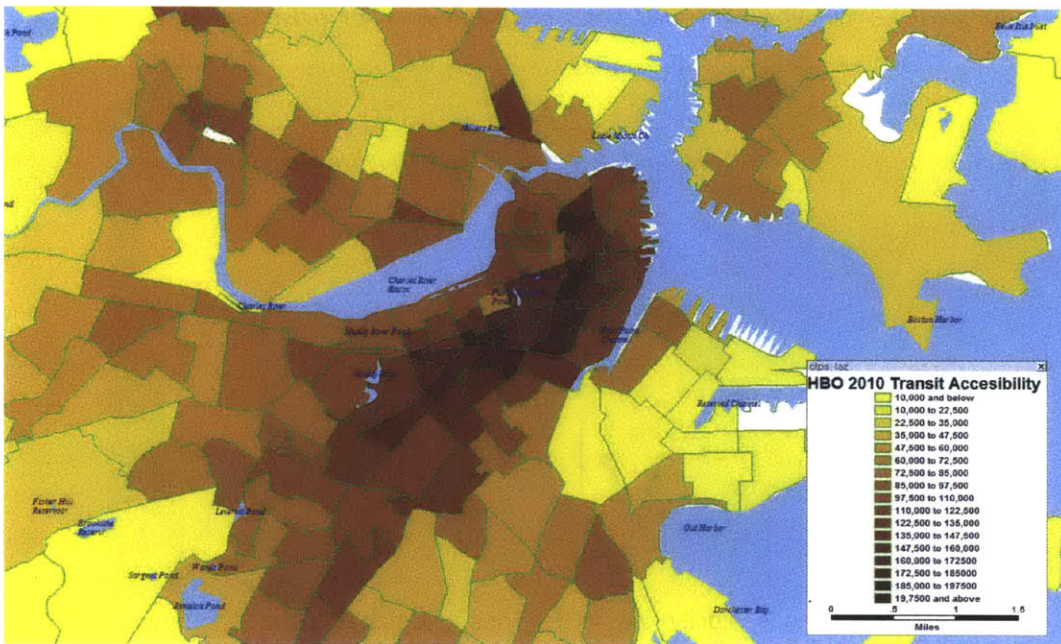


Figure B.6 Transit Gravity Accessibility for HBO Trips. Regional View. Population 2010

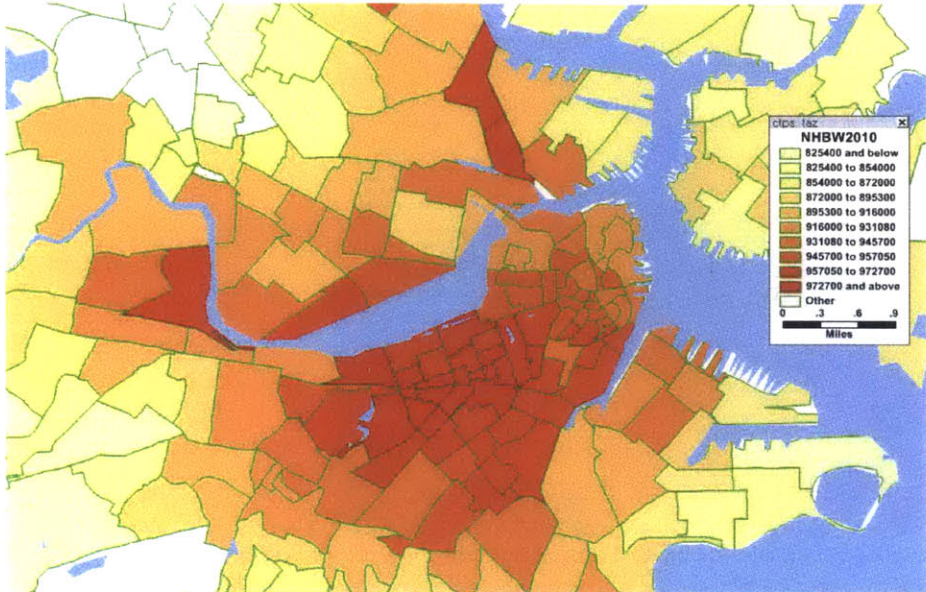


Figure B.7 Auto Gravity Accessibility for NHB Trips. Regional View. Employment 2010

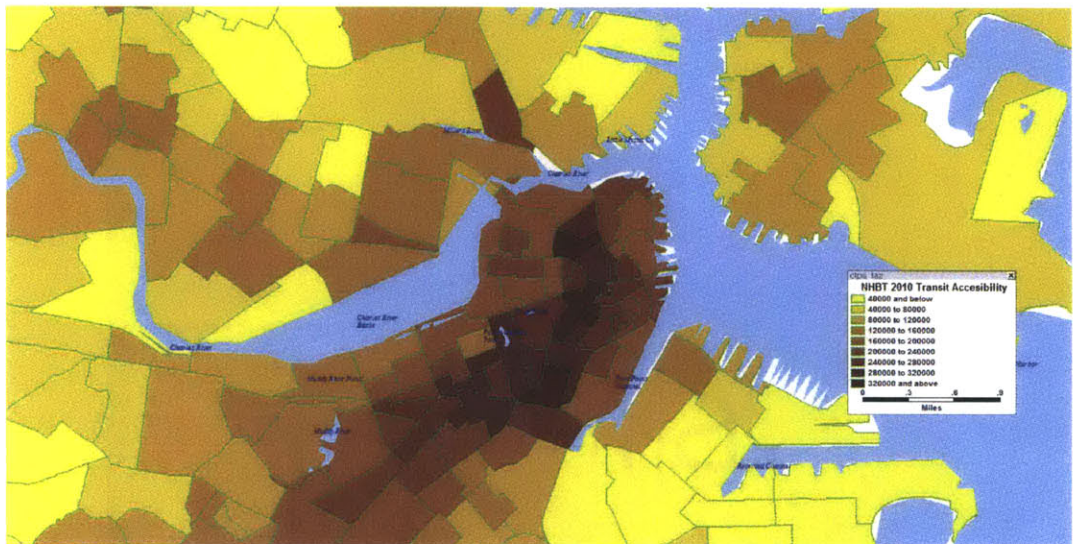


Figure B.8 Transit Gravity Accessibility for NHB Trips. Regional View. Employment 2010

Appendix C – Road Flow Changes with Big Dig Completion

This thesis was the first to include three different running models that replicated the cities socio-economic and infrastructure for the 1990, 2000 and 2010 time period. The aim of having three different models was to replicate fully the travel patterns in the Greater Boston Area prior to the Big Dig project. Socio-economic data was processed from the CTPP to match the models population, household, employment and vehicle requirements.

This four-step transportation model was used to calculate the congested AM travel times that were used for the accessibility calculations.

The following figures display the road flows for the AM Peak travel in the Greater Boston Areas. The thickness of the link displays the absolute volume, the color displays the volume capacity ratios; blue indicates a VC ratio below 1.1, brown a VC ratio between 1.1 to 1.5 and red a VC ratio above 1.5.

As seen from the figures below, the Big Dig infrastructure does not seem to mitigate congestion levels for the AM travel times. Given that the aim of this accessibility was to measure commuter accessibility, AM travel times would be the best indicator of travel to the work place. Congestion levels along the reconstructed Central Artery appear to increase from 1990 to 2000 and then again in 2010. Congestion is driven by trips to the workplace, affected more so by socio-economic data rather than auto infrastructure changes. This would seem to imply likewise that auto accessibility is driven by socio-economic changes, as much as from infrastructure improvements.

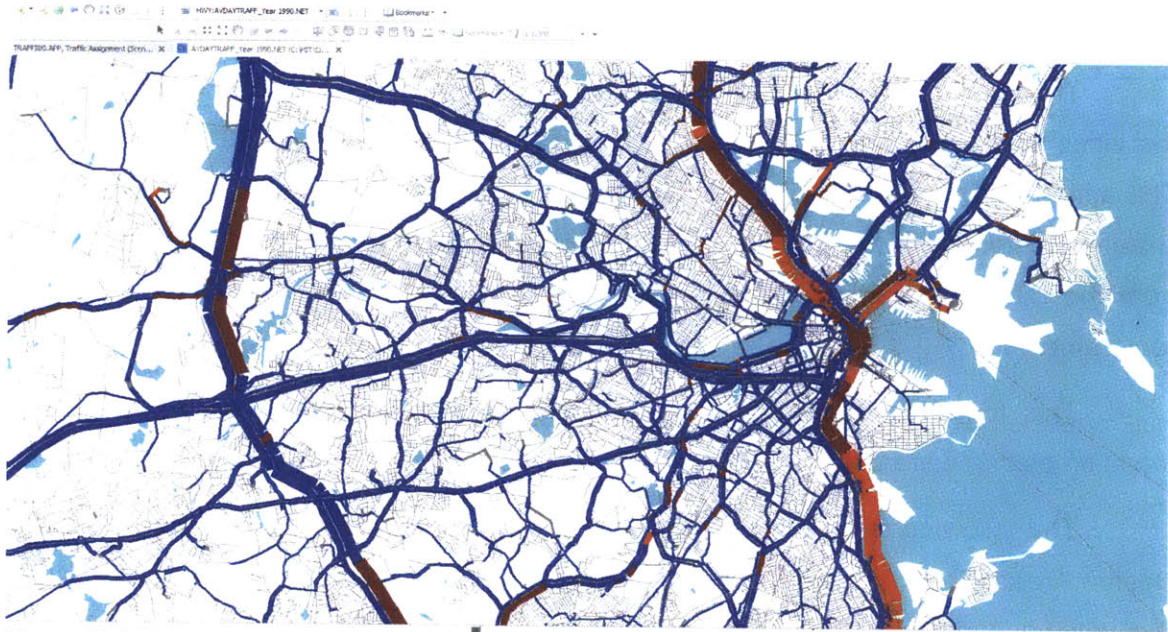


Figure C.1 Road Flows for 1990 prior to Big Dig. Regional View. Murga, 2013

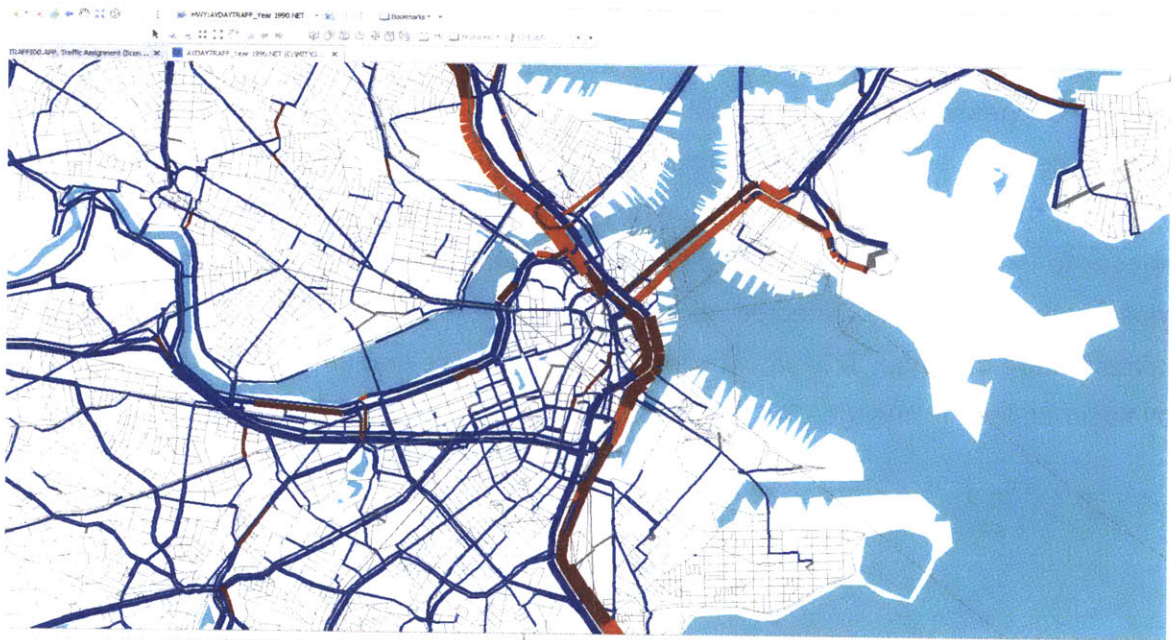


Figure C.2 Road Flows for 1990 prior to Big Dig. Local View. Murga, 2013

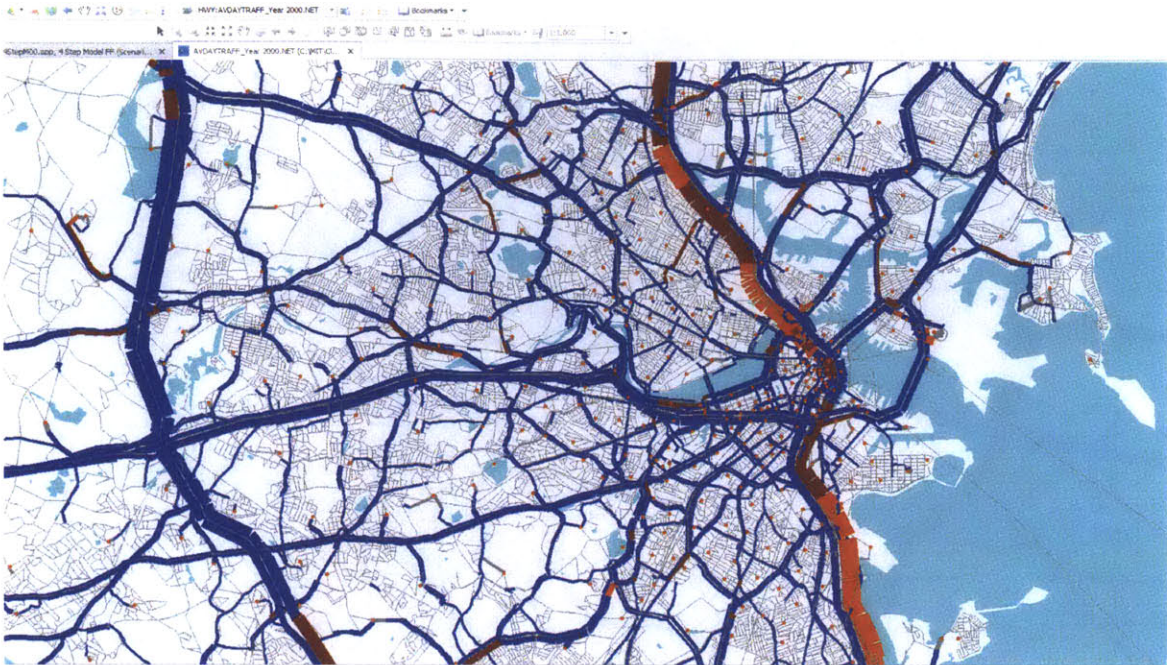


Figure C.3 Road Flows for 2000, after partial completion of the Big Dig. Regional View. Murgo, 2013



Figure C.4 Road Flows for 2000, after partial completion of the Big Dig. Local View. Murgo, 2013



Figure C.5 Road Flows for 2010 completed Big Dig. Regional View. Murga, 2013

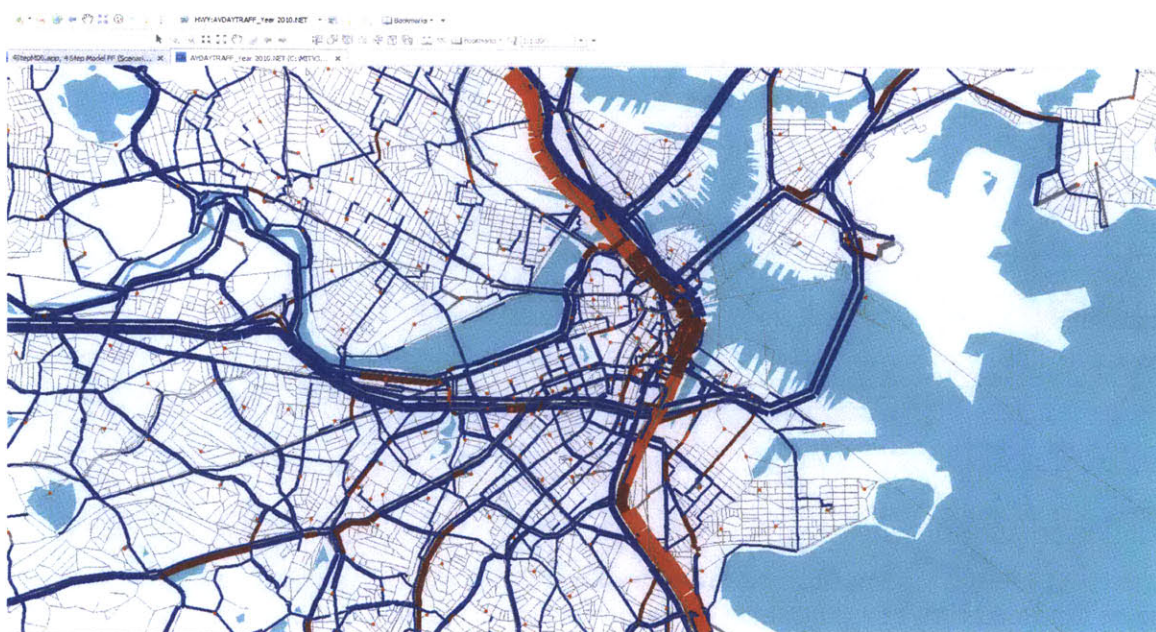


Figure C.6 Road Flows for 2010 completed Big Dig. Local View. Murga, 2013

		1990	2000	2010
HBW	Total Walk Trips	162,151	165,400	154,285
	Total linked Transit Trips	444,981	451,914	579,253
	Total Auto Trips	2,285,800	2,455,262	2,596,207
	Total Auto Pax Trips	249,162	241,418	252,162
	Total HBW Trips	3,142,094	3,313,994	3,581,907
HBS	Total Walk Trips	441,734	436,778	460,928
	Total linked Transit Trips	112,044	107,702	116,873
	Total Auto Trips	400,558	400,558	400,558
	Total Auto Pax Trips	345,408	355,232	372,912
	Total HBS Trips	1,299,744	1,300,270	1,351,271
HBShop	Total Walk Trips	996,494	776,604	707,088
	Total linked Transit Trips	41,610	44,642	65,419
	Total Auto Trips	979,717	903,737	1,031,822
	Total Auto Pax Trips	501,587	351,492	388,311
	Total HBShop Trips	2,519,408	2,076,475	2,192,640
HBO	Total Walk Trips	1,794,875	1,329,046	1,407,826
	Total linked Transit Trips	68,521	54,762	73,577
	Total Auto Trips	2,475,903	2,139,727	2,451,975
	Total Auto Pax Trips	523,448	402,653	442,827
	Total HBO Trips	4,862,747	3,926,188	4,376,205
NHBW	Total Walk Trips	646,107	456,175	472,439
	Total linked Transit Trips	93,309	68,242	81,351
	Total Auto Trips	2,011,176	1,763,386	1,996,144
	Total Auto Pax Trips	53,914	38,442	42,273
	Total NHBW Trips	2,804,506	2,326,245	2,592,207
NHBO	Total Walk Trips	1,138,001	878,000	923,181
	Total linked Transit Trips	37,359	38,766	50,265
	Total Auto Trips	1,729,954	1,442,874	1,653,419
	Total Auto Pax Trips	616,960	183,233	207,655
	Total NHBO Trips	3,522,274	2,542,873	2,834,520

Table C. 1 Daily trip rates for every trip type for 1990, 2000 and 2010 models